Friday (October 25)
Zelazo Center, Room 250

Registration ------------------------------------------ 8:30-8:55am
Welcoming Remarks ------------------------------------- 8:55-9am
(John Friedman)

Session 1a: General Relativity I -------------------- 9-10:30am
(Chair: John Friedman)

Coffee Break & Discussion -------------------------- 10:30-11am

Session 1b: General Relativity II ------------------- 11am-12:30pm
(Chair: David Garfinkle)

Lunch ----------------------------------------------- 12:30-2pm

Session 1c: General Relativity III ------------------ 2-3:50pm
(Chair: Robert Wald)

Coffee Break & Discussion -------------------------- 3:50-4:20pm

Session 1d: Equation of State ----------------------- 4:20-5:50pm
(Chair: David Kaplan)

End of the first day.

Saturday (October 26)
Zelazo Center, Room 250

Registration ------------------------------------------ 8:30-9am

Session 2a: Data Analysis ---------------------------- 9-10:30am
(Chair: Jolien Creighton)

Coffee Break & Discussion -------------------------- 10:30-11am

Session 2b: Data Analysis / GW-EM ------------------- 11am-12:30pm
(Chair: Patrick Brady)

Lunch ----------------------------------------------- 12:30-2pm

Session 2c: GW-EM / Numerical Relativity ---------- 2-3:30pm
(Chair: Patrick Brady)

Coffee Break & Discussion -------------------------- 3:30-4pm

Session 2d: Cosmology ------------------------------- 4-5:30pm
(Chair: Phil Chang)

End of the second day.

Social event (Black Rose Irish Pub/Cash-Bar)
Sunday (October 27)  
Engineering and Mathematical Sciences (EMS) Building, Room 190

Registration 8:30-9am

Session 3a: Astrophysics I 9-10:30am  
(Chair: Richard O'Shaughnessy)

Coffee Break & Discussion 10:30-11am

Session 3b: Astrophysics II 11am-12:30pm  
(Chair: Tom Paul)

Blue Apple Award!

End of the meeting.
Registration is open each morning

8:00-9:00

John Friedman  University of Wisconsin-Milwaukee  8:55
Welcoming Remarks

Session 1.a: General Relativity I
Chair: John Friedman

David Garfinkle  Oakland University  9:00
An electromagnetic analog of gravitational wave memory

Jim Wheeler  Utah State University  9:18
Weyl gravity as general relativity

Jeffrey Hazboun  Utah State University  9:36
Time and general relativity from conformal symmetry

George Hrabovsky  Madison Area Science and Technology  9:54
Using The New Tensor System in Mathematica for Relativity

Peter Zimmerman*  University of Guelph  10:12
Combining forces

Session 1.b: General Relativity II
Chair: David Garfinkle

John Friedman  University of Wisconsin-Milwaukee  11:00
Analytic post-Newtonian parameters from numerical EMRI computations

Robert Wald  University of Chicago  11:18
Turning Point Instabilities for Relativistic Stars and Black Holes

Joshua Schiffrin*  University of Chicago  11:36
Dynamic and Thermodynamic Stability of Relativistic, Perfect Fluid Stars

Kartik Prabhu*  University of Chicago  11:54
Gauge, energy and stability of black holes

Shawn Wilder*  Florida Atlantic University  12:12
Stability of Approximate Killing Fields and Black Hole Spin
Session 1.c: General Relativity III
Chair: Robert Wald

Stephen Green  University of Guelph  2:00
A Holographic Path to the Turbulent Side of Gravity

Ryan Westernacher-Schneider  Guelph-Waterloo-Perimeter Institute  2:18
Special Relativistic Inviscid Fluid Turbulence in 2+1

Jonathan Richardson*  University of Chicago  2:36
Probing Quantum Space-Time with the Fermilab Holometer

Yuri Bonder  Indiana University  2:54
Lorentz violation, spin and a newtonian gravitational field

Philippe Landry*  University of Guelph  3:12
Tides in Higher-Dimensional Newtonian Gravity

Jonah Miller*  University of Guelph  3:30
Transition Amplitudes in Causal Dynamical Triangulations

Session 1.d: Equation of State
Chair: David Kaplan

Leslie Wade*  University of Wisconsin-Milwaukee  4:20
On the feasibility of constraining the neutron star equation of state using advanced gravitational-wave detectors

Ben Lackey  Princeton University  4:38
What can we learn about the neutron-star equation of state from inspiralling binary neutron stars?

Johanna Olson*  University of Notre Dame  4:56
Quark Matter in Core-Collapse Supernovae

Alex Deibel*  Michigan State University  5:14
How unique is the crust of an accreting neutron star?

Sophia Han*  Washington University in St. Louis  5:32
Energy dissipation in hybrid stars

Session 2.a: Data Analysis
Chair: Jolien Creighton

Richard O'Shaughnessy  University of Wisconsin-Milwaukee  9:00
A single-spin precessing gravitational wave in closed form

Tyson Littenberg  Northwestern University  9:18
Improving the Odds (Ratio) for Gravitational Wave Detection

Ben Farr*  Northwestern University  9:36
A Hierarchical Approach to Compact Binary Parameter Estimation from Gravitational Waves

Madeline Wade*  University of Wisconsin-Milwaukee  9:54
Advanced LIGO’s ability to detect apparent violations of the cosmic censorship conjecture and the no-hair theorem through compact binary coalescence detections
Evan Ochsner  University of Wisconsin-Milwaukee  10:12
Parameter estimation of gravitational waves from nonprecessing BH-NS inspirals with higher harmonics: comparing MCMC posteriors to an effective Fisher matrix

Session 2.b: Data Analysis/GW-EM counterparts
Chair: Patrick Brady

Sydney Chamberlin*  University of Wisconsin-Milwaukee  11:00
Applications of the ExcessPower Data Analysis Pipeline in Gravitational Wave Detection Efforts

Hsin-Yu Chen*  University of Chicago  11:18
The Loudest LIGO Events

Alexander Urban*  University of Wisconsin-Milwaukee  11:36
Never Ignore a Coincidence: Enhancing LIGO sensitivity to compact binary mergers with GRB counterparts

Vasileios Paschalidis  University of Illinois at Urbana-Champaign  11:54
General relativistic simulations of binary black hole-neutron stars: Precursor electromagnetic signals

Roman Gold  University of Illinois at Urbana-Champaign  12:12
GRMHD simulations of disks accreting onto BH binaries: Effects of binary mass ratio

Session 2.c: GW-EM counterparts/Numerical Relativity
Chair: Patrick Brady

Koutarou Kyutoku  University of Wisconsin-Milwaukee  2:00
Anisotropic mass ejection from black hole-neutron star binaries: diversity of electromagnetic counterparts

Milton Ruiz  University of Illinois at Urbana-Champaign  2:18
Initial boundary value problem of the Z4c formulation of General Relativity

Dinshaw Balsara  University of Notre Dame  2:36
Multidimensional Riemann Solvers – Steps towards Relativistic MHD

Carlos Lousto  Rochester Institute of Technology  2:54
Where angular momentum goes in precessing black hole binaries

Alejandro Lopez*  University of Michigan  3:12
Gravity Waves from Bubble Collisions in Inflation in Advanced LIGO
Session 2.d: Cosmology
Chair: Phil Chang

Brett Bolen  Grand Valley State University
Effect of Global Expansion on Gravitational Lensing

Yurii Shylnov  IIT
Comparison of Supernovae Data Sets with f(R) Modified Gravity Models

Eda Gjergo*  IIT / ANL
Forecast of Cosmology Constraints for DES using photometric simulations of supernovae

Daniel Holz  University of Chicago
Measuring the Hubble constant with GWs

Richard Kriske  University of Minnesota
Time may be more complicated than current theory

Session 3.a: Astrophysics I
Chair: Richard O'Shaughnessy

Joe Antognini*  The Ohio State University
Mergers of Compact Objects in Hierarchical Triples

Doo Soo Yoon*  University of Wisconsin - Madison
The dynamics of jets in circum-binary environment of HMXBs

Thomas Maccarone  Texas Tech University
The Galactic Bulge Survey

Niharika Sravan*  Northwestern University
Importance of Tides for periastron Precession in Eccentric Neutron Star - White Dwarf Binaries

Megan DeCesar  University of Wisconsin-Milwaukee
Discovery of a Highly Eccentric Binary Millisecond Pulsar in a Gamma-Ray-Detected Globular Cluster

Session 3.b: Astrophysics II
Chair: Tom Paul

David Kaplan  University of Wisconsin-Milwaukee
A Metal-Rich Low-Gravity Companion to a Massive Millisecond Pulsar

Laleh Sadeghian  University of Wisconsin-Milwaukee
Dark matter distributions around massive black holes: A fully general relativistic approach

Laura Nuttall  University of Wisconsin-Milwaukee
First Search for Optical Counterparts to Gravitational-Wave Candidate Events

Astrid Lamberts  University of Wisconsin-Milwaukee
Gamma-ray binaries: hydrodynamics and high energy emission

Xavier Siemens  University of Wisconsin-Milwaukee
When will NANOGrav detect gravitational waves?

Blue Apple Award
Registration is open each morning

John Friedman  University of Wisconsin-Milwaukee  8:55
Welcoming Remarks

Session 1.a: General Relativity I
Chair: John Friedman

David Garfinkle  Oakland University  9:00
An electromagnetic analog of gravitational wave memory
We present an electromagnetic analog of gravitational wave memory. That is, we consider what change has occurred to a detector of electromagnetic radiation after the wave has passed. Rather than a distortion in the detector, as occurs in the gravitational wave case, we find a residual velocity (a "kick") to the charges in the detector. In analogy with the two types of gravitational wave memory ("ordinary" and "nonlinear") we find two types of electromagnetic kick.

Jim Wheeler  Utah State University  9:18
Weyl gravity as general relativity
We sketch two new results in conformal gravity. First, we show that a Palatini-type approach to fourth-order conformal gravity reduces it to scale-invariant general relativity. The variation of the full conformal connection provides and extra field equation which is precisely the integrability condition to reduce the system to vacuum Einstein. Our second result is a different conformal gauging of a Euclidean space which necessarily results in a Lorentzian phase space, with the presence of time consequence of conformal group structures.

Jeffrey Hazboun  Utah State University  9:36
Time and general relativity from conformal symmetry
We show that the Lorentz structure of spacetime and the Einstein equation may be derived as part of the solution within a conformal gauge theory of Euclidean space. Quotients of the conformal group of n-dim (pseudo-)Euclidean spaces by their Weyl subgroups are called biconformal spaces. These 2n-dim spaces naturally include both metric and symplectic form. We start from two known results. First, these spaces allow a scale-invariant action linear in the curvatures, making this theory distinct from the quadratic-curvature, Weyl gravity theory. The linear action leads to general relativity on the configuration submanifold. Second, flat solutions in the Euclidean case that are metric phase spaces are necessarily Lorentzian time arises as part of the solution in a Euclidean theory. We generalize, combining these results. We show that Lorentz symmetry and the Einstein equation follow from the Euclidean gauge theory with linear action when the biconformal space admits orthogonal metric configuration and momentum submanifolds, assuming only separability of the torsion field equation. The separable field equations lead generically to a signature (n-1,1) metric, with orthogonality of the conjugate submanifolds leading directly to the compatible Lorentzian connection on both. We find exact solutions in which the Weyl vector is hypersurface orthogonal to spatial slices of the configuration and momentum submanifolds. Relationships to shape dynamics and to models breaking Lorentz invariance will be discussed.

George Hrabovsky  Madison Area Science and Technology  9:54
Using The New Tensor System in Mathematica for Relativity
There is now built-in support for tensors in version 9 of Mathematica. So, How do you use this for doing calculations that are relevant to relativity? I will show you.

Peter Zimmerman*  University of Guelph  10:12
Combining forces
We will present early results of our study considering the effects of coupling between gravitational and scalar field perturbations on the first-order self-force equations of motion of a point-like particle.
John Friedman  University of Wisconsin-Milwaukee  11:00

Analytic post-Newtonian parameters from numerical EMRI computations

We report a novel way to extract analytic high-order post-Newtonian (PN) parameters that govern quasi-circular binary systems. Coefficients in the PN expansion of the energy of a binary system can be found from corresponding coefficients in an extreme-mass-ratio inspiral computation of the change in the redshift factor of a circular orbit at fixed angular velocity. Remarkably, by computing this essentially gauge-invariant quantity to accuracy greater than one part in $10^{225}$ and by assuming that a subset of PN coefficients are rational numbers or products of pi and a rational, we obtain the exact analytic coefficients. We find the previously unexpected result that the post-Newtonian expansion has conservative terms at half-integral PN order beginning with a 5.5 PN term.

Robert Wald  University of Chicago  11:18

Turning Point Instabilities for Relativistic Stars and Black Holes

In the light of recent results relating dynamic and thermodynamic stability of relativistic stars and black holes, we re-examine the relationship between “turning points”—i.e., extrema of thermodynamic variables along a one-parameter family of solutions—and instabilities. We give a proof of a Sorkin’s general result for the presence of a thermodynamic instability on one side of a turning point that does not rely on heuristic arguments involving infinite dimensional manifold structure. We show that the turning point results imply the existence of a dynamic instability of black rings in 5 spacetime dimensions in the region where $c_J > 0$, in agreement with results of Figueras, Murata, and Reall.

Joshua Schiﬀrin*  The University of Chicago  11:36

Dynamic and Thermodynamic Stability of Relativistic, Perfect Fluid Stars

We give a comprehensive, uniﬁed analysis of the relationship between dynamic and thermodynamic stability for perfect ﬂuid stars in general relativity. Thermodynamic stability means being at a maximum of entropy with respect to all perturbations that leave the “fundamental conserved quantities” unchanged, including perturbations to states that may not be accessible to the star via perfect ﬂuid dynamics, i.e., states that would only be accessible if dissipation was included in the dynamics. Thus, one would expect thermodynamic stability to imply dynamic stability, but not the converse. Indeed, in the case of axisymmetric perturbations, we show that a necessary criterion for thermodynamic stability is the same as a necessary and sufﬁcient criterion for dynamic stability—namely, positivity of canonical energy on a particular subspace of Lagrangian perturbations.

Kartik Prabhu*  The University of Chicago  11:54

Gauge, energy and stability of black holes

Hollands and Wald showed that dynamic stability of a black hole is equivalent to the positivity of canonical energy on a space of linearised perturbations. The boundary/gauge conditions are naturally formulated on the space of initial data for the perturbations in terms of orthogonality to gauge transformations. Choosing the appropriate gauge condition, positivity of kinetic energy for perturbations can be proven. In certain special cases, the potential energy can also be shown to be positive implying stability in these cases.

Shawn Wilder*  Florida Atlantic University  12:12

Stability of Approximate Killing Fields and Black Hole Spin

In relativistic physics, a precise deﬁnition of a black hole’s angular momentum is possible only when its horizon possesses an axial symmetry. Unfortunately most black hole horizons have no such symmetry. However, it is possible to pose an eigenvalue problem that has solutions corresponding to any manifold’s approximate Killing ﬁelds. This allows one to generalize formulæ requiring symmetry to cases where no symmetry is present and thus deﬁne, for example, the spin of an arbitrary black hole. This talk will discuss work using perturbation theory of a horizon to quantify the stability of quantities generalized in this way. We will present precise conditions for the stability of solutions to the eigenvalue problem, and discuss potential applications to numerical relativity.
Session 1.c: General Relativity III
Chair: Robert Wald

Stephen Green  University of Guelph
*A Holographic Path to the Turbulent Side of Gravity*

We study the dynamics of a 2+1 dimensional relativistic viscous conformal fluid in Minkowski spacetime. Such fluid solutions arise as duals, under the "gravity/fluid correspondence", to 3+1 dimensional asymptotically anti-de Sitter (AAdS) black brane solutions to the Einstein equation. We examine stability properties of shear flows, which correspond to hydrodynamic quasinormal modes of the black brane. We find that, for sufficiently high Reynolds number, the solution undergoes an inverse turbulent cascade to long wavelength modes. We then map this fluid solution, via the gravity/fluid duality, into a bulk metric. This suggests a new and interesting feature of the behavior of perturbed AAdS black holes and black branes, which is not readily captured by a standard quasinormal mode analysis. Namely, for sufficiently large perturbed black objects (with long-lived quasinormal modes), nonlinear effects transfer energy from short to long wavelength modes via a turbulent cascade within the metric perturbation. As long wavelength modes have slower decay, this lengthens the overall lifetime of the perturbation. We also discuss various implications of this behavior, including expectations for higher dimensions, and the possibility of predicting turbulence in more general gravitational scenarios.

Ryan Westernacher-Schneider  Guelph-Waterloo-Perimeter Institute
Special Relativistic Inviscid Fluid Turbulence in 2+1

The chaotic behaviour which is characteristic of turbulence lends itself almost exclusively to statistical methods and dimensional arguments. Even so, the vast majority of analytic results rely heavily on the presence of statistical symmetries. I will discuss some such results in the case of non-relativistic turbulence, and motivate checking these results in the relativistic case via numerical simulations. In showing our progress, I will reveal the extent to which our preliminary results are unexpected.

Jonathan Richardson*  University of Chicago
Probing Quantum Space-Time with the Fermilab Holometer

I will discuss recent progress on the Fermilab Holometer, a novel experiment designed to probe Planck-scale unification physics. Arguments based on general principles of covariance and quantum mechanics suggest that a minimum length or time associated with Planck-scale unification may give rise to a new quantum position uncertainty detectable as correlated noise in neighboring interferometers. By cross-correlating two 40-meter power-recycled Michelson interferometers, the Holometer will be the first experiment sensitive to coherent transverse position fluctuations, expressed in spectral density units, smaller than a Planck time. A positive detection would open an experimental window into the quantum nature of space-time.

Yuri Bonder  Indiana University
Lorentz violation, spin and a newtonian gravitational field

The Standard Model Extension (SME) is a parametrization of possible modifications to conventional physics which violate (local) Lorentz invariance. A method allowing to calculate the hamiltonian for a Lorentz-violating spinor in a uniform newtonian gravitational field, within the SME framework, is presented. The result includes couplings of coefficients parameterizing Lorentz violation, spin and gravity, which were previously unknown. The nonrelativistic hamiltonian is computed and some of its phenomenological implications are discussed.

Philippe Landry*  University of Guelph
Tides in Higher-Dimensional Newtonian Gravity

Tidal deformations occur generically when a body is perturbed by an external, time-varying gravitational field. In Newtonian gravity, the tidal response can be described in terms of a spherical harmonic decomposition relating the body’s multipole moments to the moments of the tidal potential. The coupling between these two quantities is given by a set of dimensionless constants, known as the gravitational Love numbers, which depend on the equation of state. Motivated by theories of higher-dimensional gravity and string theory, the tidal deformation problem has been investigated beyond three spatial dimensions. In particular, Love numbers for higher-dimensional Schwarzschild black holes have been calculated via effective field theory. However, this talk will show that a simple comparison with the Love numbers of higher-dimensional Newtonian polytropes raises some important questions about the tidal response of these black holes.
Jonah Miller* University of Guelph 3:30

Transition Amplitudes in Causal Dynamical Triangulations

We study the causal dynamical triangulations of (2+1)-dimensional pure Einstein gravity with positive cosmological constant in the presence of past and future spacelike boundaries of fixed intrinsic geometries. We numerically simulate a variety of transition amplitudes from the past boundary to the future boundary and we compare these results to the Hartle-Hawking wavefunction.

Session 1.d: Equation of State
Chair: David Kaplan

Leslie Wade* University of Wisconsin-Milwaukee 4:20
On the feasibility of constraining the neutron star equation of state using advanced gravitational-wave detectors

It has been shown that advanced ground-based gravitational-wave detectors have the capability of measuring tidal influences in binary neutron star systems. In this work, we report on the statistical uncertainties in measuring tidal deformability by using a full Bayesian parameter estimation implementation found in LAL (LSC Algorithm Library). We show how simultaneous measurements of chirp mass and tidal deformability can be used to constrain the neutron star equation of state. We also present results from studies on the effect of systematic and statistical biases in these measurements.

Ben Lackey Princeton University 4:38
What can we learn about the neutron-star equation of state from inspiralling binary neutron stars?

Gravitational-wave observations of inspiralling binary neutron star systems can provide information about the neutron-star equation of state (EOS) through a tidally induced shift in the waveform phase. This shift depends on the tidal deformability Lambda of the neutron star which is a function of the stars mass and EOS. Previous work has shown that Lambda is marginally measurable by Advanced LIGO for a single event when including the entire inspiral waveform up to merger. In this work, we describe a method for stacking measurements of Lambda from multiple inspiral events to measure the EOS. Specifically, we use Markov Chain Monte Carlo simulations to estimate the parameters of a 4-parameter piecewise polytrope EOS that matches theoretical EOS models to a few percent. We find that when 10–50 observations are combined with the constraints from causality and recent high mass neutron-star measurements, the EOS above nuclear density can be measured to better than a factor of two. We also find that quantities that describe the neutron-star structure such as the radius and tidal deformability can be measured to $\sim 10\%$ over a wide range of masses.

Johanna Olson* University of Notre Dame 4:56
Quark Matter in Core-Collapse Supernovae

Recent studies have shown that a transition to a quark-gluon plasma during a core-collapse supernovae could provide a mechanism to revitalize a stalled accretion shock. An Equation of State (EoS) to describe the properties of matter in extremes of density and temperature allows us to incorporate these phases of matter in simulation. I will discuss the effects of a phase transition to quark-gluon matter in the new Notre Dame Livermore Equation of State (NDL EoS). The observation of a $1.97 \pm 0.04$ solar mass neutron star provides a stringent limit on the parameter space of a quark-gluon plasma phase in simulating supernovae collapse.

Alex Deibel* Michigan State University 5:14
How unique is the crust of an accreting neutron star?

The crust of an accreting neutron star is expected to have a composition that is different from cold-catalyzed matter. The non-equilibrium reactions induced by the accretion of matter gradually transform the ashes of hydrogen and helium burning to neutron-rich matter in the inner crust. These reactions heat and cool the crust, and if the composition is anisotropic, they may produce a mass quadrupole. An important question, then, is how much the composition can vary in the inner crust. We examine this question by using nuclear mass models to investigate the stability of nuclei that must co-exist with degenerate electron and neutron gases. We show that there are few stable nuclei deep in the inner crust and that the accreted inner crust does not contain equilibrium nuclei. We compare our results with a full reaction network that includes finite electron and neutron capture reaction rates and pycnonuclear reactions.
Sophia Han* Washington University in St. Louis 5:32

Energy dissipation in hybrid stars

We propose a novel mechanism for the saturation of unstable oscillation modes in multi-component compact stars, which is based on the periodic conversion between different phases due to overall density oscillations. The case of a hybrid star with a sharp interface between a quark matter core and a nuclear matter crust is studied in detail and we find that this mechanism can lead to low saturation amplitudes, and thereby it could present the dominant damping mechanism in hybrid stars. We study the dissipation due to hadron-quark burning in a hybrid star using a steady-state approximation and find that in this case the dissipation entirely vanishes in the subthermal regime, but becomes finite and very strong once the oscillation amplitude reaches a critical value. This strong dissipation saturates unstable r-modes just above the critical value and as a result leads to a simple analytic prediction for the saturation amplitude. We find that the r-mode saturation amplitude can be as low as $\alpha_{\text{sat}} \approx 10^{-4}$ for conditions present in typical observed pulsars.

Session 2.a: Data Analysis
Chair: Jolien Creighton

Richard O'Shaughnessy University of Wisconsin-Milwaukee 9:00

A single-spin precessing gravitational wave in closed form

In coming years, gravitational wave detectors should find black hole-neutron star binaries, potentially coincident with astronomical phenomena like short GRBs. These binaries are expected to precess. Gravitational wave science requires a tractable model for precessing binaries, to disentangle precession physics from other phenomena like modified strong field gravity, tidal deformability, or Hubble flow; and to measure compact object masses, spins, and alignments. Moreover, current searches for gravitational waves from compact binaries use templates where the binary does not precess and are ill-suited for detection of generic precessing sources. In this paper we provide a closed-form representation of the single-spin precessing waveform in the frequency domain by reorganizing the signal as a sum over harmonics, each of which resembles a nonprecessing waveform. This form enables simple analytic calculations (e.g., a Fisher matrix) with easily-interpreted results.

Tyson Littenberg Northwestern University 9:18

Improving the Odds (Ratio) for Gravitational Wave Detection

With LIGO and Virgo completing major upgrades, the first directly detectable gravitational waves are literally on their way to Earth. These signals will land in noisy interferometers and we need robust data analysis procedures to distinguish between astrophysical signals and transient instrument artifacts ("glitches"). Bayesian model selection is well suited to solve this detection problem but the current analysis assumes the detector noise is stationary and Gaussian (it isn’t). In this talk I will demonstrate an approach to modeling the LIGO/Virgo data which provides robust Bayesian evidence despite non-Gaussian noise.

Ben Farr* Northwestern University 9:36

A Hierarchical Approach to Compact Binary Parameter Estimation from Gravitational Waves

The rapid localization of a gravitational wave source is crucial for successfully detecting electromagnetic counterparts. Techniques currently used for low-latency sky localization from ground-based detectors assume both objects to be non-spinning, potentially introducing large biases in sky position. Markov Chain Monte Carlo methods have proven capable of estimating the parameters of a generically spinning, circularized compact binary with high latency, and of rapid sky localization when operating in a lower-dimensional parameter space. We present a technique to connect the two domains, providing rough estimates of parameters on short time scales that then aid in producing more accurate estimates of sky location, masses, and spins at lower latencies than previously possible.

Madeline Wade* University of Wisconsin-Milwaukee 9:54

Advanced LIGO’s ability to detect apparent violations of the cosmic censorship conjecture and the no-hair theorem through compact binary coalescence detections

The cosmic censorship conjecture places a limit on the spin-to-mass-squared ratio for a Kerr black hole, and the no-hair theorem places a limit on the tidal Love number of a non-rotating black hole. Using the Fisher matrix formalism, we examine the theoretical measurability of the spin and tidal deformability of compact binary systems involving at least one putative black hole if gravitational waves were detected from the inspiral of such a system. Using parameter measurement errors and correlations obtained from the Fisher matrix, we determine the smallest detectable violation of bounds implied by the cosmic censorship conjecture and the no-hair theorem. We examine the effect of excluding unphysical areas of parameter space when determining the smallest detectable apparent violations, and we examine the effect of higher harmonics in the gravitational waveform.
In this work we investigate the prospects of measuring the parameters of black hole-neutron star binaries from their gravitational wave emissions detected via ground based interferometers, with an emphasis on the importance of higher harmonics. We find that including higher harmonics in our waveform model can improve the measurement of certain extrinsic parameters by breaking a degeneracy between them, but that they do not significantly impact the measurement of the masses and spins of the binary. Our study includes full Bayesian inference results computed via Markov chain Monte Carlo (MCMC) methods and simple analytic estimates from an effective Fisher matrix method. We argue that the effective Fisher matrix agrees well with the MCMC results and that it could be a cost-effective tool to predict parameter estimation performance for other regions of parameter space.

Session 2.b: Data Analysis/GW-EM counterparts
Chair: Patrick Brady

Sydney Chamberlin* University of Wisconsin-Milwaukee 11:00
App{}lications of the ExcessPower Data Analysis Pipeline in Gravitational Wave Detection Efforts
The ExcessPower data analysis pipeline has been proposed and implemented as a potential method to perform searches for generic transients (or "bursts") of gravitational waves using interferometric detector data. We present a study aiming to determine the efficiency of signal recoverability and detectability for astrophysically induced transients in interferometric data for the advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) using the ExcessPower pipeline. We also discuss another potential application of this pipeline, which involves the characterization of unwanted, non-astrophysically induced transients arising from the instruments themselves. These transients are detrimental to searches and several efforts are underway to mitigate them.

Hsin-Yu Chen* University of Chicago 11:18
The Loudest LIGO Events
While most Advanced LIGO-Virgo detections are expected to have signal-to-noise ratios (SNR) near the detection threshold, the loudest (highest SNR) events are likely to provide the most information about their sources. We derive the universal distribution of SNRs in a GW network, as well as the distribution of the loudest events. These distributions are independent of the detector network, sensitivity, and source distribution. We predict the loudest event for any number of detections, and discuss the improvement in parameter estimation of this single event.

Alexander Urban* University of Wisconsin-Milwaukee 11:36
Never Ignore a Coincidence: Enhancing LIGO sensitivity to compact binary mergers with GRB counterparts
"The first direct detection of gravitational waves is set to come later this decade with the Advanced LIGO and Virgo interferometers. Mergers of neutron star–neutron star (BNS) and neutron star–black hole (NSBH) binary systems are among the most promising and strongest known sources of gravitational waves. It is also considered likely that these merger events are responsible for short gamma-ray bursts (GRBs), although coincident observation of the electromagnetic and gravitational-wave (GW) signals is required to firmly establish the connection. We study the efficiency of coincident GRB-GW observations by simulating a population of BNS mergers that result in nearby gamma-ray bursts, assuming the electromagnetic signal would be detected by a space-borne observatory such as Swift or Fermi. We then frame our analysis in terms of recent results on sky localization of GW sources and electromagnetic followup of GWs."

Vasileios Paschalidis University of Illinois at Urbana-Champaign 11:54
General relativistic simulations of binary black hole-neutron stars: Precursor electromagnetic signals
"We present a new computational method for smoothly matching general relativistic ideal magnetohydrodynamics (MHD) to its force-free limit. The method is based on a flux-conservative formalism for MHD and its force-free limit, and a vector potential formulation for the induction equation to maintain the zero divergence constraint for the magnetic field. The force-free formulation evolves the magnetic field and the Poynting vector. Our force-free code passes a robust suite of tests, performed both in 1D flat spacetime and in 3D curved (black hole) spacetimes. Our matching technique successfully reproduces the aligned rotator force-free solution. As an application, we performed the first general relativistic, force-free simulations of neutron star (NS) magnetospheres in orbit about spinning and non-spinning black holes with BH:NS mass ratio 3:1. We find promising precursor EM emission: typical Poynting luminosities at, e.g., an orbital separation of 6.6 times the NS radius, are L ∼ 6 × 10^{42} erg/s for a 1.4 solar-mass NS endowed with a dipolar magnetic field with polar strength 10^{13} G. The Poynting flux peaks within a broad beam of ~ 40 degrees in the azimuthal direction and within ~ 60 degrees from the orbital plane, establishing a possible lighthouse effect."
GRMHD simulations of disks accreting onto BH binaries: Effects of binary mass ratio

We report on simulations in General Relativity of magnetized disks around black hole binaries. We vary the binary mass ratio from 1:1 to 1:10 and evolve the systems when they orbit near the binary-disk decoupling radius. We compare (surface) density profiles, accretion rates (relative to a single BH), variability, effective $\alpha$-stress levels and luminosities as functions of the mass ratio. We treat the disks in two limiting regimes: rapid cooling and no-cooling. The B-field lines clearly reveal jets emerging from both black hole horizons and merging into one common jet at large distances. The B-fields give rise to much stronger shock heating than the pure hydrodynamic flows, completely alter the disk structure, and boost accretion rates and luminosities. Accretion streams near the horizons are among the densest structures; in fact, the 1:10 no-cooling evolution results in a refilling of the cavity. The typical effective temperature in the bulk of the disk is $T_{\text{eff}} \sim 10^7 K (M/10^8 M_\odot)^{-1/4} (L/L_{\text{edd}})^{1/4}$, yielding thermal frequencies near $\nu_{bb} \sim 10^{15} / (1+z) H z (M/10^8 M_\odot)^{-1/4} (L/L_{\text{edd}})^{1/4}$. These systems are thus promising targets for many extragalactic optical surveys, such as LSST, WFIRST, and PanStarrs.

Session 2.c: GW-EM counterparts/Numerical Relativity
Chair: Patrick Brady

Koutarou Kyutoku  University of Wisconsin-Milwaukee  2:00
Anisotropic mass ejection from black hole-neutron star binaries: diversity of electromagnetic counterparts
Coalescences of black hole-neutron star binaries are one of the most promising gravitational-wave sources. In recent years, electromagnetic counterparts has been getting a lot more attention and many theoretical emission models are proposed. Most of the models require mass ejection from the binary merger, and numerical relativity is the most reliable method to predict properties of ejecta such as the mass and velocity. In this talk, I will present results of recent numerical-relativity simulations performed focusing on dynamical mass ejection from binary mergers, and discuss possible electromagnetic radiation focusing on features derived from anisotropy of the ejecta.

Milton Ruiz  University of Illinois at Urbana-Champaign  2:18
Initial boundary value problem of the Z4c formulation of General Relativity
We consider the initial boundary value problem for the $Z_4c$ formulation of general relativity coupled to a parametrized family of coordinate conditions that includes both the moving puncture and harmonic gauges. We present high-order-derivative boundary conditions for the gauge, constraint violating and gravitational wave degrees of freedom of the formulation. Using Kreiss-Agranovich-Metivier theory we demonstrate, in the frozen coefficient approximation, that eighth and higher derivative order boundary conditions, make the initial boundary value problem boundary stable. For a choice of the gauge condition that renders the system strongly hyperbolic of constant multiplicity, well-posedness of the initial boundary value problem follows in this approximation. Taking into account the theory of pseudo-differential operators, it is expected that the nonlinear problem is also well-posed locally in time.

Dinshaw Balsara  University of Notre Dame  2:36
Multidimensional Riemann Solvers – Steps towards Relativistic MHD
The Riemann problem plays a very important role in numerical methods. A very recent innovation in numerical MHD comes from the invention of multidimensional Riemann solvers. They permit a space-time view of the Riemann problem and resolve many of the difficulties that plague numerical MHD codes. For classical MHD, this innovation has been consolidated through our recent work. For relativistic MHD, we are making an effort to achieve the same goal.
We compare future supernovae data sets with models of quintessence and modified gravity as alternatives to vacuum energy. We present various factors which impact the FoM analysis such as purity of the sample and number of supernovae. The Dark Energy Task Force defined a Figure of Merit (FoM) which is a standard tool to determine confidence intervals for cosmological parameters. Many of the new supernovae data will be photometric, thus we are faced with contamination from other supernovae types like core collapse. Improved statistics must be accompanied by an improvement in systematic uncertainties. Many of the new supernovae data will be photometric.

In the next ten years the number of Type Ia supernovae observed will increase ten-fold. In order to be useful for cosmology, the improved statistics must be accompanied by an improvement in systematic uncertainties. Many of the new supernovae data will be photometric, thus we are faced with contamination from other supernovae types, like core collapse. We examine the impact of core collapse contamination on supernova cosmology. The Dark Energy Task Force defined a Figure of Merit (FoM) which allows us to propose and test models for the merger remnant’s mass and spin. For instance, we verify that the hangup effect is the dominant effect and largely explains the observed total energy and angular momentum radiated by these precessing systems. We also verify that the total angular momentum, which significantly decreases in magnitude during the inspiral, varies in direction by less than $\sim 5^\circ$. The maximum variation in the direction of $\vec{J}$ occurs when the spins are nearly antialigned with the orbital angular momentum. Based on our results, we conjecture that transitional precession, which would lead to large variations in the direction of $\vec{J}$, is not possible for similar-mass binaries and would require a mass ratio $m_1/m_2 \sim< 1/4$.

**Alejandro Lopez**  University of Michigan

**Gravity Waves from Bubble Collisions in Inflation in Advanced LIGO**

Inflation models ending in a first order phase transition produce gravitational waves (GW) via bubble collisions of the true vacuum phase. We demonstrate that these bubble collisions can leave an observable signature in Advanced LIGO, an upcoming ground-based GW experiment. These GW are dependent on two parameters of the inflationary model: $\varepsilon$ represents the energy difference between the false vacuum and the true vacuum of the inflation potential, and $\chi$ measures how fast the phase transition ends ($\chi \sim$ the number of e-folds during the actual phase transition). Advanced LIGO will be able to test the validity of single-phase transition models within the parameter space $10^7$ GeV $< \varepsilon^{1/4} < 10^{10}$ GeV and $0.19 < \chi < 1$. If inflation occurred through a first order phase transition, then Advanced LIGO could be the first to discover GW from inflation.

**Session 2.d: Cosmology**  
**Chair: Phil Chang**

**Brett Bolen**  Grand Valley State University

**Effect of Global Expansion on Gravitational Lensing**

Traditionally it had been thought that the cosmological constant played no role in gravitational lensing, but recently it has been shown that the cosmological constant effectively changes the impact parameter and thus does have an effect on lensing. In this paper, we will examine the effects of a $Λ$FRW cosmology on null geodesics via numerical integration of the geodesics of the McVittie metric.

**Yurii Shynov**  IIT

**Comparison of Supernovae Data Sets with $f(R)$ Modified Gravity Models**

Multiple probes in modern observational cosmology point to an accelerated expansion of the Universe, which has revived the famous Einstein $Λ$ - cosmological term. This poses the challenge of explaining its value, extremely small, but non-zero. One way to approach the problem is to modify general relativity by taking into account quantum corrections. Calculations of n-loop Feynman graphs yields terms of $R^n$ type in the low energy effective action. Therefore the $f(R)$ Modified Gravity Models are worth considering as possible modification of cosmology. We discuss a popular model of $f(R)$ Modified Gravity and its effects on the expansion rate of the Universe as measured with Type Ia Supernova data sets.

**Eda Gjergo**  IIT / ANL

**Forecast of Cosmology Constraints for DES using photometric simulations of supernovae**

In the next ten years the number of Type Ia supernovae observed will increase ten-fold. In order to be useful for cosmology, the improved statistics must be accompanied by an improvement in systematic uncertainties. Many of the new supernovae data will be photometric, thus we are faced with contamination from other supernovae types, like core collapse. We examine the impact of core collapse contamination on supernova cosmology. The Dark Energy Task Force defined a Figure of Merit (FoM) efficiency algorithm based the Fisher-information matrix, which is a standard tool to determine confidence intervals for cosmological parameters. We present various factors which impact the FoM analysis, such as purity of the sample and number of supernovae. We compare future supernovae data sets with models of quintessence and modified gravity as alternatives to vacuum energy.
Daniel Holz University of Chicago

Measuring the Hubble constant with GWs

By combining GW and electromagnetic observations of compact binary coalescence it is possible to put points on the luminosity distance-redshift relation. Ground-based GW observations of these standard sirens thus have the potential to provide an accurate, comparatively clean, measurement of the low-redshift Hubble flow. We show that 15 observable GW and EM events should allow the Hubble constant to be measured with 5% precision using a network of detectors that includes advanced LIGO and Virgo. Measuring 30 beamed GW-SGRB events would constrain the Hubble constant to better than 1%.

Richard Kriske University of Minnesota

Time may be more complicated than current theory

Time itself may require some new thought. Moving forward in time one sees Non-Laplacian Statistics as is found in QED, QCD, etc. It is not clear that this applies looking backward. All of the evidence we have about backward time indicates that events are "stacked", in such a way as to produce the common sensation of a path in time, a memory of what happened on Monday, then Tuesday etc. for many years, centuries and perhaps to the "Big-Bang". It may be the case for massless particles that reverse time is easier to travel to than forward time. Reverse time may have a direct path, as is seen when one looks toward the Horizon of the Universe, whereas forward time is undetermined.

Session 3.a: Astrophysics I
Chair: Richard O'Shaughnessy

Joe Antognini* The Ohio State University

Mergers of Compact Objects in Hierarchical Triples

The Kozai-Lidov mechanism is a dynamical phenomenon in hierarchical triple systems in which the inner binary is driven to high eccentricities under the perturbative influence of the tertiary. Because gravitational radiation has a strong dependence on orbital eccentricity, the Kozai-Lidov mechanism can accelerate the merger of compact objects in hierarchical triple systems. The Kozai-Lidov mechanism has typically been explored in the double-orbit-averaged approximation in which changes to the orbital parameters are assumed to be slow relative to the orbital timescales. We test this approximation using direct three-body integration including post-Newtonian terms up to order 3.5 to account for relativistic effects. We find that when the inner binary is driven to high eccentricity the eccentricity of the inner binary oscillates on the timescale of the outer orbit, an effect which is inconsistent with the double-orbit-averaged approximation. We compare the dynamical evolution of a suite of hierarchical triple systems in the double-orbit-averaged approximation to the direct three-body integration and find that these rapid eccentricity oscillations (REOs) can lead to a substantially reduced merger time, often by one to two orders of magnitude. Indeed, REOs double the fraction of systems which merge within one to two eccentric Kozai-Lidov timescales from 20% to 40%. We lastly find that the inner binary in most systems remains highly eccentric ($e > 0.1$) immediately prior to merger and that $\sim 10\%$ of systems retain eccentricities of $e > 0.9$.

Doo Soo Yoon* University of Wisconsin - Madison

The dynamics of jets in circum-binary environment of HMXBs

The jet of a microquasar interacts with the interstellar medium, generating characteristic signatures that may unveil important properties of the compact object. For High Mass X-ray Binaries (HMXBs), the presence of the OB type companion star should be taken into account in studying the interaction of the jets with the ambient medium. The strong wind from the companion star dominates in the circum-binary environment, forcing the jet to be bent with characteristic inclination angle which depends on parameters of the jet and the stellar wind. We perform 3 dimensional hydrodynamic simulation in order to illuminate the relationship between the angle and the jet power, opening angle, and wind power. In the small jet bending approximation, we derive an analytic solution for the bending angle, which can be used to constrain observational parameters in HMXBs.

Thomas Maccarone Texas Tech University

The Galactic Bulge Survey

I will discuss the Chandra Galactic Bulge Survey. This is a survey of 12 square degrees of sky just off the Galactic Plane, near the Galactic Center. Its goals are to collect statistically meaningful samples of accreting black holes, neutron stars and white dwarfs in order to (1) get a better understanding of the mass distributions of black holes and neutron stars and (2) get a better understanding of binary stellar evolution and how it affects the number counts of these classes of source. At the present time, about 1600 X-ray sources have been detected, with optical counterparts having been found for the bulk of them, and optical spectroscopic identifications for a substantial fraction.
Importance of Tides for periastron Precession in Eccentric Neutron Star - White Dwarf Binaries

Although not nearly as numerous as binaries with two white dwarfs, eccentric neutron star-white dwarf (NS-WD) binaries are important gravitational wave sources for the next generation of space-based detectors sensitive to low frequency waves. Here we investigate periastron precession in these sources as a result of general relativistic, tidal, and rotational effects; such precession is expected to be detectable for at least some of the detected binaries of this type. Understanding the importance of the different physical mechanisms at play is important for the correct determination of the system properties. Currently, two eccentric NS-WD binaries are known in the galactic field, PSR J1141-6545 and PSR B2303+46, both of which have orbits too wide to be relevant in their current state to gravitational-wave observations. However, population synthesis studies predict the existence of a significant Galactic population of such systems with a wide range of orbital periods and eccentricities, such that as a population they are relevant to future space-based detectors. We find that the contribution from tides should not be neglected when analyzing periastron precession signatures in gravitational-wave signals: and not accounting for tides can produce errors as high as 8500% in the WD mass inferred. We also find that the effect of tides is stronger for hotter, younger WDs: 0.5 (13.8) Gyr old systems having WD masses between 0.60 and 1.03 (0.72) solar masses and eccentricities approximately less than 0.16 (0.05) suffer an error of at least 10%. We derive a function that relates the WD radius and apsidal precession constant to the WD mass, allowing for the inclusion of tidal effects when using periastron precession as a mass measurement tool.

Discovery of a Highly Eccentric Binary Millisecond Pulsar in a Gamma-Ray-Detected Globular Cluster

I report on the Green Bank Telescope discovery of a highly eccentric binary millisecond pulsar (MSP) in NGC 6652, the first MSP to be detected in this globular cluster. The pulsar search was guided by the Fermi Large Area Telescope, which detected NGC 6652 at GeV energies, identifying the cluster as a likely host of a population of gamma-ray-emitting MSPs. Initial timing of the MSP yielded an eccentricity of 0.95 and a minimum companion mass of 0.73 solar masses, assuming a neutron star mass of 1.4 solar masses. These results strongly indicate that the pulsar has undergone one or more companion exchanges in the dense stellar environment of the cluster, and that the current companion is a compact object, likely a massive white dwarf or a neutron star. Further timing of this system will result in a measurement of the post-Keplerian rate of periastron advance and therefore a direct measurement of the total system mass, allowing additional constraints to be placed on both the pulsar and companion masses.

A Metal-Rich Low-Gravity Companion to a Massive Millisecond Pulsar

We discovered the eclipsing millisecond pulsar J1816+4510 in a radio survey toward an unidentified Fermi source. Since then we have identified its companion in optical/ultraviolet data, and its multi-wavelength properties place it apart from all other sources: we see strong absorption from hydrogen, helium, and metals, but while significantly larger than a white dwarf it is much smaller than a B star. The companion could be evolving into a helium white dwarf, although the mass loss required for the radio eclipses is surprising, and the (a priori) likelihood of finding an object in this phase is rather small. Independently, though, PSR J1816 appears to be a unique transition object, with implications for studies of white dwarf evolution, relativistic winds, and neutron star masses.

Dark matter distributions around massive black holes: A fully general relativistic approach

The cold dark matter at the center of a galaxy will be redistributed by the presence of a massive black hole. The redistribution may be determined by beginning with a model distribution function for the dark matter, and growing the black hole adiabatically, holding the adiabatic invariants of the motion constant. Unlike previous approaches, which adopted Newtonian theory together with ad hoc correction factors to mimic general relativistic effects, we carry out the calculation fully relativistically, using the exact Schwarzschild geometry of the black hole. We consider a range of initial distribution functions, including cuspy profiles, and find that the density spike very close to the black hole is significantly higher than that found previously by Newtonian analyses. The potential implications for detection of signals from galactic center dark matter will be discussed.
First Search for Optical Counterparts to Gravitational-Wave Candidate Events

Electromagnetic observations of gravitational-wave sources would bring unique insights into a source which are not available from either channel alone. During two observing periods between 2009-2010, gravitational wave data from the two LIGO and Virgo detectors were analysed within minutes to identify candidate events. The sky position of these events were determined and the most likely coordinates sent to astronomer partners for follow-up observations, in the hope of detecting any associated electromagnetic transients. Images were obtained for eight such gravitational-wave candidate events using eight different optical telescope systems. I will discuss the methods used to point these telescopes, the techniques used to analyse the images taken as well as the results from this first search.

Gamma-ray binaries: hydrodynamics and high energy emission

The very high energy gamma-ray radiation from gamma-ray binaries is thought to arise from the interaction between a relativistic pulsar wind and the stellar wind of its massive companion. Multiwavelength observations display phase-locked variability in all wavebands and suggest that at least two distinct populations of high-energy particles are present. I present hydrodynamical simulations of such systems, using a recently developed relativistic extension to the RAMSES code. I explain how the relativistic nature of the pulsar wind affects the colliding wind structure. I show how these simulations have been coupled to a radiative code in order to model the emission properties of gamma-ray binaries.

When will NANOGrav detect gravitational waves?

TBD

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