## "An Analytic Approach to the Concept of Noise with Application to the Detection of Gravitational Waves"

**Daniel Bessis and Luca Perotti**
**Department of Physics**
**Texas Southern University, Houston Texas**

We propose a new method in the spectral analysis of noisy time-series data for damped oscillators. Our method makes use of Padé Approximations built on the time-series Z-transform. Extensive preliminary tests indicate that it can be effective in detecting signals when the signal to noise ratio is close to one and, with suitable adjustments, even well below that limit, which many believe cannot be passed without encountering overwhelming stability problems.

From the time series, we build an Hilbert space operator, a J-Matrix, where each bound state (inside the unit circle in the complex plane) is simply associated to one damped oscillator, the modulus being the exponential of the damping factor and the phase the pulsation; while the continuous spectrum of the J-Matrix, which lies on the unit circle itself, is shown to represent the noise.

Signal and noise are thus clearly separated in the complex plane.

Even if non-linear, the procedure of costructing such J-Matrix is surprisingly numerically stable, as the noise itself acts as a stabilizer.

Different classes of input noise, such as blank (white and uniform), Gaussian and pink, have been numerically analyzed by us. *Compelling evidence of a universal behavior in the final statistical distribution of the associated poles and zeros was found. In particular the poles and zeros tend, when the length of the time series goes to infinity, to the roots of unity in the complex plane which appear to be noise attractors*.

To clearly show the unique features of this approach, we have applied it to a number of examples. In particular we have taken advantage of the above properties of the Padé Approximations to develop a procedure for the search of Gravitational Wave Bursts in interferometric data series such as those of the LIGO and VIRGO projects. In this, we make use of undersampling, which is automatically taken into account when using Padé Approximations. We have succesfully applied our procedure to simulated data having a signal to noise ratio ten times smaller than the detection capability of current methods, thus highlighting the power of our system.

Our proposed research impacts diverse fields in basic and applied research including gravitational wave detection, Nuclear Magnetic Resonance Spectroscopy (NMRS) as applied to nuclear waste detection, brain/breast cancer detection, and oil exploration, and even the search for leaks in water distribution networks.

## "Reconstruction of coordinates of un-modeled burst sources with networks of gravitational wave detectors"

**Antony Searle for LIGO-Virgo**

Sky coordinate reconstruction is a necessary tool for the future of gravitational wave (GW) astronomy. It will give us fundamentally new information about GW sources and their population distribution. Prompt detection of GW signals and estimation of source coordinates enables coincident observations with other astronomical instruments, and therefore significantly increases the confidence of detection as well as providing complementary insights into the physics of events. We studied the position reconstruction capabilities of the LIGO-Virgo network for burst GW signals and present the results obtained with different reconstruction methods.

## Stacking Gravitational Waves from SGR Bursts

**P. Kalmus, Sz. Marka, B. Owen**

Soft gamma-ray repeaters (SGRs) have unique properties that make them intriguing GW targets. They are nearby, their burst emission mechanism may involve neutron star crust fractures and excitation of non-radial modes, and they burst repeatedly and sometimes spectacularly. Recently a LIGO search for transient GW from these sources placed upper limits on a set of almost 200 individual electromagnetic triggers. We present a new search method, which builds upon the method used in the individual SGR search by attempting to "stack" potential GW signals from multiple SGR bursts. We assume that the time difference between the peak in electromagnetic emission and the peak in potential gravitational wave emission in SGR bursts varies by no more than tens of milliseconds from burst to burst, and we time-align GW excess power time-frequency tilings containing individual burst triggers to their corresponding electromagnetic peaks. Using plausible simulated signals injected into two kinds of noise (white noise and simulated LIGO noise), we show that gains in GW energy sensitivity of N^{1/2} are possible, where N is the number of stacked SGR bursts. Estimated search sensitivities are also presented, for two stacking scenarios: the "fluence-weighted" scenario and the "flat" (unweighted) scenario.

**"Real-time searches for unmodeled gravitational waves burst in the next LIGO-Virgo joint science run"**
**Jameson Rollins, for the LIGO Scientific Collaboration and the Virgo Collaboration**

Coherent methods have been shown to be very effective in the analysis of unmodeled bursts in networks of gravitational wave detectors. During the next LIGO-Virgo science run (S6/VSR2), a true international network of detectors will be working at comparable sensitivity. Triple coincident data from three physically separated detectors will allow for the full power of coherent analysis methods to be brought to bear. During the S6/VSR2 science run, we will for the first time be using these coherent methods to analyze the data from all three LIGO and Virgo detectors in real-time. This real-time analysis will afford us exciting new possibilities, such as providing real-time detector glitch characterization for instrument commissioners, rapid analysis of events associated with interesting external triggers, and production of event candidates that can be passed off to other observatories for immediate follow-up. This talk will discuss the status of the various pipelines that will produce real-time burst event candidates during S6/VSR2.

**"Gravitational-Wave Burst Searches Using LIGO-GEO S5 and Virgo VSR1 Data"**
**Peter Shawhan for the LIGO Scientific Collaboration and the Virgo Collaboration**

The data collected by the large gravitational-wave detectors in 2005-2007 has been searched for burst signals using multiple search methods. We will describe low-frequency and high-frequency burst searches, with an emphasis on the methods used to appropriately analyze different combinations of detectors and to combine the parts in order to establish limits on burst rates and amplitudes.

**"A PQ veto for burst and binary inspiral searches using data from Virgo's first scientific run"**
**M.-A. Bizouard for the LIGO Scientific Collaboration and Virgo Collaboration**

The use of vetoes generated from auxiliary channels suppresses most of the high amplitude noise triggers that impair gravitational wave (GW) burst and binary inspiral analyses. However, many of the remaining loud burst and inspiral Virgo triggers were observed with nearly equal significance in both the in-phase (P) and quadrature (Q) interferometer output channels, while we expect the Q-channel to be insensitive to a GW signal. We describe a veto based on the the ratio of the amplitude of the P and Q signals. From studying hardware signal injections, we demonstrate that the ratio of the amplitude of coincident P and Q triggers can be safely used to define a veto; we show its efficiency for the burst and binary inspiral analyses.

**" A gravitational wave burst search for binary black hole mergers in the Virgo C7 commissioning run data"**

**K. G. Arun for the Virgo collaboration.**

The final merger of a binary black hole produces an intense burst of gravitational radiation. Mergers of stellar mass black holes are among the most plausible sources for the ground-based gravitational wave detectors such as Virgo and LIGO. We report on our search for binary black hole mergers using a burst detection pipeline Exponential Gaussian Correlator (EGC). The search was carried out on the seventh commissioning run (C7) data of the Virgo detector. Numerical relativity waveforms, provided by the NASA Goddard group, have been used as a model of binary black hole mergers to estimate the efficiency of the search Upper limits on the distance reach are derived as a function of the total mass of the final black hole. A maximal distance reach of ~1.1Mpc for a 90% efficiency has been obtained, corresponding to a 80 solar mass binary black hole. We also compared the distance reach infered by the injection of numerical relativity waveforms as opposed to those from Sine Gaussian waveforms. Similar searches in future for advanced detectors would complement the template based searches for these sources.

**"Systematics of NR waveform accuracy and burst searches for binary black hole mergers"**

**Sebastian Fischetti, Laura Cadonati, Shourov Chatterji, Frank Herrmann, Satya Mohapatra, Deirdre Shoemaker**

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 joining forces and addressing the question of what is the most effective role for NR waveforms in the detection and characterization of binary black hole coalescences. We present the status of a study of detection systematics for binary black hole coalescences in the mass range where merger and ringdown constitute most of the in-band signal for ground based interferometers. Waveforms produced with the MayaKranc code are added to colored, gaussian noise and analyzed with the unmodeled burst search algorithm Qpipeline/Omega, which is used in LIGO-Virgo burst searches. Detection efficiency and parameter accuracy are systematically weighted against parameters such as spin and mass ratio as well as numerical details such as waveform accuracy, the number of included modes and extraction radius.

**Results of the Numerical INJection Analysis (NINJA) Project**

**Duncan Brown (on behalf of the NINJA project), Syracuse University**

Two important advances have occurred in recent years which have brought us closer to the goal of observing and interpreting gravitational waves from coalescing compact objects: the successful construction and operation of a world-wide network of ground-based gravitational-wave detectors and the impressive success of numerical relativity in successfully simulating the merger phase of Binary Black Hole (BBH) coalescence. The aim of the NINJA project is to study the sensitivity of gravitational-wave analysis pipelines to numerical simulations of waveforms and foster close collaboration between numerical relativists and data analysts. Over 75 numerical relativists and data analysis participated in the contribution of a simulated data set containing numerical waveforms, analysis of this data and interpreting the results of this analysis. We present the results of the NINJA project and the lessons learned for future collaborations of this kind.

### "Status of the First Search for Gravitational Waves from Compact Binary Coalescences with Joint LIGO-Virgo Data"

**Jessica Clayton for the LSC and Virgo**

The LIGO Scientific Collaboration (LSC) and Virgo Collaboration are currently pursuing the first joint search for gravitational waves from compact binary coalescences (CBC) using data collected during the LIGO S5 and Virgo VSR1 runs (May - October 2007). This search allows us to detect coincident signals with greater confidence, and for the first time allows us to locate sources in the sky using the coherent signal from three different observatory locations. The status of the search will be presented, along with how the LIGO CBC analysis pipeline was adapted to include Virgo. With the inclusion of another observatory, coincident triggers can now be found in many more double, triple and quadruple coincident-detector combinations and this adds complexity to the analysis. We examined the tuning process that allows us to effectively eliminate obvious background triggers from the computationally intensive portions of the analysis. The newly-implemented tuning procedure is based on the Neyman-Pearson criterion for maximizing the detection probability at a fixed false alarm rate. In addition, a modified chi-squared calculation is being performed that is much less computationally expensive because it operates with only a subset of the available templates.

### "Probing seed black holes using the Einstein Telescope"

**Jonathan Gair**

It is generally accepted that galactic black holes were born from seeds formed at high redshift. These black holes have subsequently grown through mergers and accretion to form the massive black holes we observe in the Universe today. However, there are significant uncertainties in the properties of the seed black hole distribution. If these seed black holes were light (mass ~100 solar masses), the first generation of galaxy mergers would have generated gravitational waves in the 1-10Hz frequency range to which the proposed third generation ground based gravitational wave detector, the Einstein Telescope (ET), will be sensitive. ET will therefore provide us with a unique way to probe the seed black hole distribution and constrain models of galaxy evolution. We will present estimates of the number of events that the Einstein Telescope may see, under different assumptions about the initial seed mass distribution and accretion history. We will also discuss the accuracy with which a network of Einstein Telescopes could recover the system parameters, and what astrophysical information we could glean from such observations.

### "Investigation of the viability of a coincidence test based on a comparison of triggers from inspiral and ringdown searches"

**Lisa Goggin**

Matched filter-based searches for gravitational waves from compact binary coalescences in LIGO data have, to date, existed as independent searches for the inspiral and ringdown phases. Both searches filter the data with a bank of templates; the standardLSC inspiral search uses post-Newtonian templates and the ringdown search uses exponentially damped sinusoids. The triggers from multiple detectors are then subject to a coincidence requirement in time of arrival and waveform parameters in order to be considered detection candidates. In this study we investigate the possibility of combining information from both searches in order to perform a coincidence analysis between inspiral and ringdown triggers at a single detector level. As a first step toward achieving this, we add simulated compact binary coalescence waveforms into Gaussian noise coloured by the LIGO power spectrum and compare the parameters of triggers returned by both searches.

**“Tuning Coherent WaveBurst for Detection of Compact Binary Coalescence Signals”**
**C. Pankow, S. Klimenko, (full list TBD)**

Compact binary coalescence (CBC) is one of the most promising sources of gravitational waves. These sources are usually searched for with matched filters which require accurate calculation of the GW waveforms and generation of large template banks. We present a complementary search technique based on burst algorithms. Initially designed for detection of un-modeled bursts, which can span a very large set of waveform morphologies, the search algorithm presented here is constrained for targeted detection of the smaller subset of CBC signals. The constraint is based on the assumption of elliptical polarization. We expect that the algorithm will be sensitive to CBC signals in a wide range of masses, mass ratios, and spin parameters. In preparation for the analysis of data from the fifth LIGO-Virgo science run (S5), we performed preliminary studies of the algorithm on test data. We present the sensitivity of the search to different types of simulated waveforms. Also, we compare the performance of the constrained search and the coherent WaveBurst search used for the burst analysis of S5 data.

**“In Search of Optimal Statistic for Compact Binary Coalescence Analysis Pipeline”**
**Ruslan Vaulin for LSC**

It is well known that match-filtering is the optimal technique for detection of a know signal in the presence of Gaussian stationary noise. This technique is the foundation of the current hierarchical compact binary coalescence (CBC) algorithm for searching gravitational wave signal from compact binaries in LIGO and Virgo data. Unfortunately, non-Gaussian properties of real noise in these detectors strongly affect detection efficiency of statistical inference algorithm based on the statistic (signal-to-noise ratio), which was found to be optimal for ideal Gaussian stochastic processes.
To improve efficiency of the search a better estimate of the likelihood of the candidate signal to be a GW signal, that incorporates non-Gaussian artifacts of real noise, is needed. We present new likelihood estimating algorithms, new statistics, implemented in the context of CBC analysis pipeline. Using different set of parameters measured in the search, these algorithms attempt to directly estimate likelihood of the potential candidate signal by examining the fraction of population of simulated GW signals injected in the real data which were recovered with similar parameters verse the fraction of similar events found in the background. The latter is estimated by the standard time sliding technique. We evaluate detection efficiency of the new statistics by applying them to the results of the search in the data containing simulated GW signals. We compare their performance to that of several other statistics that has been already employed in CBC searches.

“ **Bayesian model selections and tests of general relativity”**
**Walter Del Pozzo**

Gravitational wave observations are one of the means by which the predictions of general relativity can be tested. Here we consider Bayesian model-selection as framework to test alternative theories of gravity. Using a Nested Sampling algorithm for the computation of the evidence of a model and the posterior odds ratio between two competing hypotheses, we provide a proof-of-concept example using observations of coalescing binaries with ground-based instruments.

**“Blandford's argument: The strongest continuous gravitational wave signal”**
**Benjamin Knispel**

For a uniform population of neutron stars whose spin-down is dominated by the emission of gravitational radiation, an old argument of Blandford states that the expected gravitational-wave amplitude of the nearest source is independent of the deformation and rotation frequency of the objects. Recent work has improved and extended this argument to set upper limits on the expected amplitude from neutron stars that also emit electromagnetic radiation.

We restate these arguments in a more general framework, and simulate the evolution of such a population of stars in the gravitational potential of our galaxy. The simulations allow us to test the assumptions of Blandford's argument on a realistic model of our galaxy. We show that the two key assumptions of the argument (two dimensionality of the spatial distribution and a steady-state frequency distribution) are in general not fulfilled. The effective scaling dimension of the spatial distribution of neutron stars is significantly larger than two, and for frequencies detectable by terrestrial instruments the frequency distribution is not in a steady state unless the ellipticity is unrealistically large. Thus, in the cases of most interest, the maximum expected gravitational-wave amplitude does have a strong dependence on the deformation and rotation frequency of the population. The results strengthen the previous upper limits on the expected gravitational-wave amplitude from neutron stars by a factor of 6 for realistic values of ellipticity.

**“A new search method for continuous gravitational waves exploiting global correlations“**
**Holger Pletsch (AEI Hannover, Germany)**

A new search method for continuous gravitational-wave detection is presented. Fully coherent searches over realistic ranges of parameter space and year-long observation times are computationally prohibitive. As more efficient approaches, multistage semi-coherent searches divide the data into segments, each of which are analyzed coherently. Then the results from all data segments are combined incoherently. Unlike previous methods, this work presents a technique which utilizes the global parameter-space correlations in the coherent detection statistic to identify candidate events in each segment for the subsequent incoherent combination. The approach is demonstrated by application to simulated data. Taking advantage of the global correlations yields lower computing costs and a drastic increase in sensitivity compared to the previous standard Hough-transform method.

**“How 'optimal' is the F-statistic? A Bayesian approach to detecting continuous gravitational waves”**
**Reinhard Prix**

We study the Bayesian formulation of the detection problem of continuous gravitational waves (GWs). The frequentist maximum-likelihood method, often referred to as "F-statistic", can be recovered within the Bayesian framework by marginalizing with a simple prior over the 4-dimensional amplitude parameter space of continuous GWs. However, this prior turns out to be very 'unphysical', when translated back into the properties of the emitting system. Marginalizing with a more physical prior, reflecting an isotropic probability distribution for the spin axis of the emitting system, we can obtain a new "detection statistic". Here we present Monte-Carlo simulation results comparing this Bayesian statistic to the F-statistic within the classical Neyman-Pearson framework.

**“Cleaning the peak maps using the Hough transform in the frequency-spin down plane”**
**F.Antonucci, P.Astone, S.D'Antonio, S.Frasca, C.Palomba**

In the hierarchical search for periodic sources of gravitational waves, the candidate selection, in the incoherent step, can be performed with Hough transform procedures. This implies the use of time-frequency peakmaps where the presence of spectral lines due to local disturbances is critical as it influences the sensitivity of the Hough search. The newly proposed frequency Hough procedure, which transforms the peak map plane into the source frequency and spin down plane, can be used to detect these noise lines, as they are seen as signals of zero spin down. Once detected, lines removal can be done by the inverse Hough transform, which identifies the points of the peak map associated to the detected signal and veto them. We will describe the procedure we have implemented and give examples of its characteristic.

**“The search for gravitational waves from known pulsars”**
**Matthew Pitkin for the LIGO Scientific Collaboration and Virgo Collaboration**

Millisecond and young pulsars provide an enticing target for gravitational wave searches. Our most sensitive searches for these objects require precise knowledge of their phase evolution and therefore rely greatly on up-to-date electromagnetic observations. Here I review the current search for gravitational waves from about 100 pulsars using data from LIGOs fifth science run and discuss how these have been enabled by close collaboration with pulsar astronomers. I will also discuss plans for the upcoming S6 run.

**“An All-sky, Broadband Search for Continuous-Wave Gravitation Radiation with LIGO using PowerFlux”**
**Vladimir Dergachev for the LSC**

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. We present an algorithm called PowerFlux, based on semi-coherent strain power sums, which accounts for Doppler and amplitude modulations, and for source spindown, over long time intervals. Current approaches to reconstruction of source parameters and analysis of data with a very large timebase will be discussed. We will present results from the application of the PowerFlux detection pipeline to a broadband search in the initial data of the S5 run.

**“Detecting gravitational waves from accreting neutron stars”**
**Badri Krishnan**

The gravitational waves emitted by neutron stars carry unique information about their structure and composition. Direct detection of these gravitational waves, however, is a formidable technical challenge. In a recent study we quantified the hurdles facing searches for gravitational waves from the known accreting neutron stars, given the level of uncertainty that exists regarding spin and orbital parameters. In this paper we reflect on our conclusions, and issue an open challenge to the theoretical community to consider how searches should be designed to yield

the most astrophysically interesting upper limits. With this in mind we examine some more optimistic emission scenarios involving spin-down, and show that there are technically feasible searches, particularly for the accreting millisecond pulsars, that might place meaningful constraints on torque mechanisms. We finish with a brief discussion of prospects for indirect detection.

### "How photon astronomy affects searches for continuous gravitational waves"

**Ben Owen**

Indirect upper limits on GW emission inferred from photon astronomy tell GW searches which objects are more interesting, and also set sensitivity milestones which GW searches need to beat to be considered GW astronomy. The sensitivity of GW searches improves as more information is incorporated from photon astronomy. How GW results are interpreted depends on previous indirect limits and the theory of astrophysical GW emission mechanisms. I describe the interplay between these issues for the four types of continuous GW search, and show how photon astronomers can help the growing field of GW astronomy right now and in the near future.

### " Rapid sky localization of bursts to Bayesian confidence regions"

**Antony Searle**

Fast and accurate localization of gravitational wave bursts and compact binary coalescences is an important part of an ambitious 2009-2010 science run of the LSC-Virgo network of interferometers. We present a well-tested Bayesian analysis that produces probability "sky maps", whose confidence regions can be used within minutes of an event to direct electromagnetic observations of an afterglow, or which may be used to swiftly check consistency with an optical discovery. We discuss characteristics of the probability sky maps, precision, waveform dependence and the impact of calibration uncertainties.

### " Gamma-Ray Burst afterglow plateaus and Gravitational Waves"

**Alessandra Corsi (1) and Peter Meszaros (2)**
(1) University of Rome ''Sapienza'' (2) Penn State University

The existence of a shallow decay phase in the early X-ray afterglows of gamma-ray bursts is a common feature, which may be connected to the formation of a highly magnetized millisecond pulsar pumping energy into the fireball on timescales longer than the prompt emission. In this scenario, the nascent neutron star could undergo a secular bar-mode instability, leading to gravitational wave losses which can affect the star's spin-down. If this is the case, nearby gamma-ray bursts with isotropic energies of the order of 1e50 ergs would produce a detectable gravitational wave signal emitted in association with an observed X-ray light-curve plateau, over relatively long timescales of minutes to about an hour. The peak amplitude of the GW signal would be delayed with respect to the gamma-ray burst trigger, thus offering gravitational wave interferometers such as the advanced Virgo and LIGO the challenging possibility of catching its signature on the fly.

**"Gravitational Waves and Multimessenger Astrophysics"**
**Szabolcs Marka for the LSC and Virgo collaborations**

Gamma-ray, X-ray, optical, radio and neutrino observations of cataclysmic cosmic events with plausible gravitational wave emission can be used in combination with searches for gravitational waves. Information on the progenitor, such as trigger time, direction and expected frequency range, shall enhance our ability to identify gravitational wave signatures with amplitude close to the noise floor of the detector. Even in the absence of detection, the association of the astrophysical trigger with a known source distance allows to set upper limits on the energy emitted in gravitational waves. Results from multimessenger based gravitational wave searches will be summarized along with proposed multimessenger searches. A quantitative outlook on the future will be provided.

## "Automated multidimensional glitch classification analysis and complete near-real time glitch identification for the sixth science run of LIGO"

**Soma Mukherjee for the LSC. UTB**

Multidimensional glitch classification pipeline has been in operation since the inception of LIGO's fifth science run and has analyzed the entire glitch database generated by the Kleinewelle algorithm for both gravitational wave (gw) as well as the auxiliary and environmental channels. The analysis brings out complete information about the list of glitches thus classified and relates them to their possible origin. An enhanced version of the pipeline will be in operation during the sixth science run of LIGO starting in 2009. Analysis will be done in near-real time, the lag being determined by the rate of on-line kleine Welle trigger generation and accessibility of the glitch data in the database. This enhanced pipeline will give instantaneous and readily interpretable information on how the glitch data cloud fragments into statistically significant classes and also track the origin of glitches belonging to significant classes, leading to complete glitch identification and hence data quality flags. An online tool based on this pipeline (called MARTINI) has also been designed and tested, waiting to be implemented at one of the sites for use by the wider collaboration. Given a trigger GPS time of interest and a time window, MARTINI will scan the entire detector state in the given time interval in terms of the number of triggers, significance volume and daily statistics. A complete visualization of the gw channel glitches and all relevant auxiliary channel glitches will also be presented. This analysis proves essential in near-real time glitch identification and source tracking as well as in offline data quality flag generation and vetting. The enhanced pipeline's capability will be shown using triggers from the LIGO fifth science run Kleinewelle database.

**"Robust estimation of the parameters of a disturbed non-stationary Gaussian process"**
**P.Astone, S.Frasca**

A typical problem in the detection of the gravitational waves in the data of gravitational antennas is the non-stationarity of the gaussian noise (and so the varying sensitivity) and the presence of big impulsive disturbances. In such conditions the estimation of the standard deviation of the gaussiann process done with a classical estimator applyed after a "rough" cleaning of the big pulses often gives poor results. We propose a method based on a matched filter applyed to an AR histogram of the absolute value of the data.

**"Low latency automatic glitch classification using the tracksearch analysis pipeline"**

**Cristina Valeria Torres[1], Soma Mukherjee[2]**

The LIGO collaboration will begin its sixth science run, S6, 2009. We are planning a number of near real-time analysis efforts. In order to maximize the astrophysical information that the various analyses can extract, we must rigorously characterize the detector as quickly as possible. LIGO experimentalists will study and monitor detector noise and instrumental properties during the run, flagging data that fail to meet a minimally acceptable data quality. We introduce a new algorithmic approach intended for use in this near real-time monitoring. This approach involves combining a wide parameter space, which tracksearch uses to identify noise artifacts, with standard multivariate classification techniques (ref: Mukherjee, CQG, 2007). We show with a small sample of S5 data that when using these algorithms together, we were able to construct group catalogs of similar noise artifacts for a single LIGO detector, our goal in S6 is to do this for both detectors simultaneously. These catalogs can be used to identify groups of troublesome noise artifacts and track their propertie. Easy identification and tracking of these groups at near real-time for S6, should be helpful in correcting problems before too much potentially good running time is lost. We intend to develop this tool as an on-line control room facility to encourage direct use by the instrumentalists and operators.

1 LIGO Livingston Observatory/Louisiana State University
2 The University of Texas at Brownsville

**"It's (almost) all signal processing"**

**Warren Johnson, Louisiana State University**

I present a unified mathematical framework for discussing the analysis of gravitational wave data, and show how most of the methods that LIGO groups have used are known or disguised versions of textbook techniques of signal processing. Since there are an infinite number of variations of those techniques, optimization is still a work in progress. There is at least one technique invented by LIGO groups (multidimensional test statistics) that is not covered in the textbooks, shows promise in handling non-gaussian noise, and optimization is not straightforward.

**"Searching for spinning supermassive black hole binaries using agenetic algorithm"**

**Antoine Petiteau, Shang Yu, Stanislav Babak**

Coalescing Super Massive Black Hole binaries are the strongest gravitational wave source for the future LISA mission. We use a genetic algorithm to analyze data from the third round of the mock LISA data challenge. These data consist of gaussian stationary instrumental noise, a galactic background and four to six signals from inspiralling spinning BHs in quasi-circular orbits. We present a particular implementation of the genetic algorithm which uses properties of the signal and the response function. We discuss the results of a preliminary search for a single signal in instrumental noise.

**" Non-Gaussianity of LISA's Confusion Background"**
**Curt Cutler (Jet Propulsion Lab, California Institute of Technology)**

Abstract: Among the most interesting gravitational-wave sources for LISA will be mergers of supermassive black holes and inspirals of compact stellar-mass objects into supermassive black holes. While some such events will "stick up" out of the noise, the great majority will be buried in noise, and therefore will have to be dug out of the noise using matched filtering. Now, over much of the LISA band, the noise will be dominated by confusion noise from unresolved sources--especially unresolved Galactic white dwarf binaries--rather than instrumental noise. Previous analyses of confusion noise sources have generally approximated these noise sources as Gaussian, based on the Central Limit Theorem and the large number N of unresolved sources. However the Central Limit Theorem generally guarantees Gaussianity only out to ~(log N)^{1/2} sigma, and so says little about the high-sigma tails of the distribution. This raises the question of how often matched filtering might lead to false alarms, even when one sets the signal-to-noise detection threshold fairly high (~10). Physically, the question is: how often will some set of white-dwarf binary signals together mimic some supermassive black-hole merger signal or inspiral signal? We report on recent results by Racine & Cutler that answer this question using two techniques from statistics: the Edgeworth expansion and large-deviations theory.

**"Search for isotropic stochastic GW background using noise-supressed TDI variables in LISA"**
**Emma Robinson**

Stochastic backgrounds of both astrophysical and cosmological origin will be important GW signals in the LISA observation band. The isotropic component of this background is not accessible to the standard cross-correlation search, so a different approach must be taken. We present an analysis method by to the search for isotropic stochastic GW backgrounds in LISA, using noise-suppressed TDI variables.

**"The Status of Space-based Gravitational-Wave Detectors"**
**Curt Cutler (Jet Propulsion Lab, California Institute of Technology)**

Abstract: I will briefly review the current status and plans for LISA, LISA Pathfinder, and DECIGO. I will also briefly describe the preparatory work that has been going on for LISA data analysis, especially the Mock LISA Data Challenges and the work of the LISA Parameter Estimation Taskforce.

**"The status, achievements, and prospects of the Mock LISA Data Challenges"**

**Michele Vallisneri, Jet Propulsion Laboratory**

For the last three years, many gravitational-wave analysts around the world have supported the Mock LISA Data Challenges (MLDCs), a program to demonstrate and encourage the development of LISA data-analysis capabilities, tools and techniques. In this talk, I review the milestones achieved in the first three MLDCs; I describe the current, ongoing MLDC 3; and I discuss how future challenge problems may broaden in scope from the technical analysis of LISA data to the investigation of LISA's science objectives. GWDAW participants are warmly invited to join in this discussion.

**“Numerical trial of cleaning of gravitational wave foreground from neutron star binaries in DECIGO”**

**Mitsuru Tokuda, Nobuyuki Kanda**

***Graduate School of Science, Osaka City University,***

DECIGO (Decihertz Interferometer Gravitational Wave Observatory)[1] is a space base gravitational wave detector project which focused on frequency band around 0.1Hz, same as BBO.
In this frequency band, there probably are gravitational wave foreground from large number of neutron star binaries. The number of neutron star binaries might up to104∼6 coalescences per year within a few Gpc. To see the background gravitational wave from the inflation of the early universe, we must subtract these large number of gravitational waves from neutron star binaries. However, due to its large number, identification of waves are very hard. For long duration of observation, the accuracy of the waveform parameters (i.e. mass, arrival time, phase of waves, amplitude modulation due to detector antenna pattern, etc.) are also serious problem to propagate errors of subtracted gravitational waves. We studied this ’cleaning’ problem. Our ideas are

- identification in time-frequency domain at the coalescence of the binary,
- current data cleaning by using following three years data,

and

- to confirm them using numerical simulation with an appropriate parameter error estimation.

We studied them with numerically simulated DECIGO signal with detector noise and incident gravitational waves. We will display them and demonstrate a ’partial’ cleaning of gravitational wave foreground from neutron star binaries.

[1] N.Seto, S.Kawamura, T.Nakamura, Phys. Rev. Lett. 87 221103 (2001)

**“Cleaning the Virgo sampled data for the search of periodic source of gravitational waves”**

**P.Astone on behalf of the Virgo collaboration**

The cleaning procedure we use to produce the data we analyze for the search of periodic sources, is composed by different steps and different veto procedures which are applied to both time and frequency domain data. We have recently improved the procedure, by adding a final time domain cleaning step used on the small sub-bands selected for coherent procedures. We will here describe the whole cleaning chain, by giving details of the characteristics of each veto step.

**“Correlation analysis of data from gravitational collapse neutrino and gravitational wave detectors”**
**Kate Scholberg, Laura Cadonati, Eugenio Coccia, Walter Fulgione, Ray Frey, Erik Katsavounidis, Isabel Leonor, Francesco Vissani, Giulia Pagliaroli**

Core-collapse supernovae are potential sources of gravitational waves with well-established neutrino and optical signatures that are expected to rise shortly after and hours, respectively, of the gravitational wave signal. This sequence of events constitute a cornerstone of the detection process in gravitational wave physics. Significant uncertainties exist in the gravitational wave emission associated with such events. On the other hand, neutrino emission is well understood and is expected to be robustly measured by the global network of neutrino detectors and out to O(100kpc). In this poster we examine the improvements in the gravitational wave and neutrino sensitivity by performing a targeted search involving lower threshold gravitational wave and neutrino events available from the global network of gravitational wave and neutrino detectors. We also discuss the potential of coordinated observations and analyses in the regime of advanced instruments and the role the combined network of gravitational wave and neutrino detectors may play on the next nearby supernova.

**“Bayesian reconstruction of supernova gravitational wave burst signals”**
**C. Roever, M.-A. Bizouard, N. Christensen, H. Dimmelmeier, I. S. Heng, R. Meyer**

Presented is the description of a technique that we propose to use to extract information on a core collapse supernova from the observation of the associated gravitational wave burst signal from the collapse, bounce and ring-down phase. We use libraries of supernova waveforms, computed for different combinations of physical parameters like progenitor mass, spin and the nuclear equation of state. Frome these we create a sparse set of orthogonal basis vectors using principal component analysis (PCA). Bayesian inference techniques are then used to reconstruct the supernova produced gravitational wave signal that was detected by an interferometric detector; posterior probability distribution functions are derived for the amplitudes of the PCA eigenvectors, and the pulse arrival time. We discuss how we propose to use the signal reconstruction scheme to help establish detection confidence, localise the source, and extract information on the physical parameters associated with the supernova.

**“Analysis Method and Science Reach Options for Joint Searches between a Gravitational-wave Detector Network and High-Energy Neutrino Detectors”**
**Shin'ichiro Ando, Kotake Kei, John Dwyer, Yoichi Aso, Chad Finley,Zsuzsa Marka, Imre Bartos, Irene Di Palma, Bruny Baret, Matteo Barsuglia,Eric Chassande-Mottin, Veronique Van Elewyck, Antoine Kouchner, Szabolcs Marka, Thierry Pradier, Antony Searle, Jameson Rollins, Christian D. Ott**

Cataclysmic cosmic events can be plausible sources of both gravitational waves (GW) and high-energy neutrinos (HEN). Requiring the consistency between GW and HEN detection channels shall enable new searches as one has significant additional information about the common source. Beyond the benefit of a potential discovery, coincident detection of GW and HEN arriving from the same astronomical source might allow us to answer important scientific questions, which would be out of reach for a single channel detector. A network of gravitational wave detectors such as LIGO and Virgo can determine the direction/time of gravitational wave bursts while the IceCube and ANTARES neutrino detector can also provide accurate directional information for high energy neutrino events. By combining timing and/or directional information of events from these totally independent detectors, we can search for cosmic events that may arrive from common astrophysical sources. Analysis method options and Monte Carlo simulations will be discussed to demonstrate the expected performance of feasible searches. A survey of cosmic source candidates will be presented to describe the possible science reach of the data analysis initiative.

**"Optimal Strategies for Detecting Stochastic Backgrounds of Gravitational Waves from Pulsar Timing Data"**
**Larry Price, University of Wisconsin - Milwaukee**

A low frequency stochastic background of gravitational waves may be detected by pulsar timing experiments in the next five to ten years. The focus of this presentation will be the optimal statistic for the detection of a stochastic background of gravitational waves and how to apply it to pulsar timing data. This discussion presents an example of applying the expertise gained from the analysis of interferometer data to other searches for gravitational waves.

**"Prospects for Gravitational Wave detection with forthcoming Pulsar Timing Arrays"**
**Alberto Sesana**

In the next decade the detection of gravitational waves (GW) will (hopefully) be a reality, opening completely new window on the Universe. The primary actors on this upcoming stage are expected to be massive black hole (MBH) binaries (MBHBs). Utilizing detailed MBHB population models (based on our current best understanding of galaxy formation and evolution trough mergers and on our knowledge of the relations between MBHs and their hosts), I describe prospects of detecting GWs with forthcoming pulsar timing arrays (PTAs). A strong GW background, detectable at a level of 10-100ns timing precision, is a robust predictions of all the models. Single bright sources may also be resolvable, providing unique information about MBHB dynamics, and the physics of the processes driving their final coalescence.

**"Directional Searches for Stochastic Gravitational-wave Background with LIGO"**
**Eric Thrane**
**With:**
**Stefan Ballmer, Sukanta Bose, Vuk Mandic,**
**Sanjit Mitra, Joseph Romano, Dipongkar Talukder**

We present an algorithm for estimating the angular distribution of power in an anisotropic stochastic gravitational-wave background (SGWB) using laser interferometers. Using the maximum likelihood formalism, the SGWB can be decomposed into spherical harmonics, which provide a useful basis for deconvolving a SGWB signal from the synthesized response function (or beam matrix.) In particular, this choice of basis allows us to regularize data with a singular-value decomposition (SVD) scheme that removes modes to which the detector network is insensitive and which are associated with large errors. By considering networks of three or more detectors, we show how data from multiple detectors can be combined to emulate some of the attractive properties of SVD. We present the results of simulations conducted to assess the performance of the SVD scheme and we show that the decomposition of data into spherical harmonics recovers previous results in two limiting cases: the isotropic search and the radiometer search.

**"Wavelets entropy based decomposition filter and crosscorrelation of gravitational waves data"**

**R. Terenzi and R. Sturani**

In gravitational data analysis cross-correlation methods are used in order to search both for gravitational wave bursts and for narrower band signals. In published works the cross-correlation is performed on the detectors data passed through a whitened filter, in order to deconvolve the signal with the spectral sensitivity of different detectors. Here we present an improved process: a whitened filter followed by hard threshold wavelets filter, using entropy criterium decomposition. We will show, via software simulations over thrue gravitational detectors data, that such process will improve the cross-correlation coefficient with respect to the white filter process alone.

**“Coherent network analysis: new constraints in coherent WaveBurst”**

**Sergey Klimenko (+ list of authors)**

Coherent burst methods have been successfully used in the analysis of data collected by the world wide network of gravitational wave (GW) detectors. They provide not only a confident detection of GW signals and strong rejection of the burst artifacts produced by non-stationary detector noise, but also robust reconstruction of the GW waveforms and source parameters. The performance of the coherent methods strongly depends on assumptions used in the burst searches. These assumptions can be both model independent or model dependent, and they are used as constraints in the analysis. We present the improved coherent WaveBurst algorithm designed for the all-sky burst searches. Based on the constraint likelihood method, it employs new constraints which significantly improve the detection and reconstruction of burst signals. The constraints eliminate unphysical solutions produced by the variation of the likelihood ratio functional and allow inclusion of source models into the analysis. We describe the constraints, and discuss the performance and possible applications of the algorithm

**“Pulsar timing near supermassive black holes: Schwarzshild holes and eclipsing orbits”**

**Teviet Creighton**
**Center for Gravitational Wave Astronomy, University of Texas at Brownsville**
**For Yan Wang, Fredrick Jenet, and Richard Price**

If a pulsar orbits a supermassive black hole, the timing of pulses that pass close to the hole will show a variety of strong field effects. We analyze the case of Schwartzschild black holes using a straightforward formalism with two "universal functions" describing photon path bending and travel time in strong fields. In this first analysis we also consider only pulsar beams within the orbital plane. We find that multiple sets of pulses arrive at the detector from different trajectories around the hole, bearing distinctive amplitude and phase relationships. The phenomena and formalism should also apply to systems with more general orientations.

**"Searching for spinning SMBHs in the 3rd Mock LISA Data Challenge"**
**Edward K. Porter, Neil J. Cornish, Scott A. Hughes, Ryan N. Lang & Samaya Nissanke.**

In previous rounds of the Mock LISA Data Challenge we applied a Metropolis-Hastings method which was extremely successful in the detection of sources and the extraction of parameters in the case of Schwarzschild black holes. In this presentation we discuss the current status of an updated Metropolis-Hastings search for Kerr black hole binaries in the 3rd round of the challenge.

**"Status of Nano-Hertz gravitational wave detection using pulsar timing"**

**Rick Jenet**

This talk will give an overview of gravitational wave detection using pulsar timing techniques as well as discuss the status of the collaborations involved in this effort.