2019 Departmental Poster Competition

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Science Building

Book of abstracts

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High Resolution Muon Tomography using a Portable Prototype Muon Telescope

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We aim to develop a portable muon detector with an excellent spatial resolution that will be able to image archeological structures in detail. Muons are weakly interacting elementary particles that readily pass through objects and losing some of their energy in the process. Muon tomography is a technique that exploits this phenomenon to construct images of large objects of interest, such as volcanoes, buildings, or archaeological structures. The present prototype comprises a two-layered system of scintillator bars, optical system with Winston cones, silicon photomultipliers (SiPMs), readout electronics, and a network of Arduinos. The cosmic muons produce scintillation photons as they pass through the scintillator bars and the Winston cones transport these photons to the SiPMs where they are converted into electrical signals. These signals, in turn, are digitized and transmitted to a local computer. This entire system is mounted on a wheeled cart that spans an area of approximately 90 cm by 180 cm and can be rotated ± 90 degrees with respect to the vertical. We are presently able to reconstruct 2-dimensional images of large objects with an angular resolution of 50 milliradians. We are testing, debugging, and analyzing the data stream. We are also working on defining the parameters for the upgraded detector to vastly improve angular resolution.

2

A Rubric for Assessing Thinking Skills in Free-Response Exam Problems.

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We designed a rubric to assess free-response exam problems in order to compare thinking skills evidenced in exams in classes taught by different pedagogies. The rubric was designed based on Bloom's taxonomy. The rubric was then used to code exam problems. We analyzed exams from different sections of the algebra-based physics course taught the same semester by the same instructor with different pedagogies. One section was inquiry-based and the other was taught traditionally. We discuss the instrument, present results and present plans for future research. The inquiry-based students demonstrated all of the thinking skills coded more often than the traditional students.

3

Investigating state transition luminosities of Galactic black hole transients in the outburst decay

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We have performed a comprehensive spectral and timing analyses of Galactic black hole transients (GBHTs) during outburst decay in order to obtain the distribution of state transition luminosities. We have calculated transition luminosities of 11 BH sources in 19 different outbursts and for disc and power law emission separately. Our results show the tightest clustering in bolometric power law luminosity with a mean ELF of 1.99 ± 1.00 during the index transition (as the photon index starts to decrease towards the hard state). We obtained mean ELF of 1.58 ± 0.93 during the transition to the hard state and 3.16 ± 1.38 for disc-blackbody luminosity during the transition to the hard-intermediate state (HIMS). We discussed the reasons for clustering and possible explanations for sources that show a transition luminosity significantly below or above the general trends.

4

Approaching relativistic Quantum Theory via Probability Conservation

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The mathematical intractabilities of relativistic quantum theory are seldom traced back to outstanding conceptual problems in the foundations of quantum mechanics. This is surprising, since conceptual problems indicate a lack of proper understanding, thus impeding attempts to give a theory a firm mathematical foundation.

Indeed, several scholars have raised doubts whether one of the primary objects of quantum mechanics, the wave function, deserves its privileged status, trying instead to formulate the theory in terms of a probability density function and a velocity vector field. Taking probability conservation as a fundamental postulate, these two quantities will satisfy the continuity equation. Their time evolution is then determined by other dynamical equations and constraints. This perspective on relativistic quantum theory motivates an in-depth study of the general relativistic continuity equation, granting insights into aspects of a rigorous quantum theory on curved spacetimes -- even before introducing further dynamical equations and quantities.

This poster shows some of those results for the 1-body theory. Our work is part of the ongoing greater discussion pertaining to whether one can reconcile quantum phenomena with the axioms of Kolmogorovian probability theory.

5

GRBs with afterglow plateaus during LIGO S6/O1/O2/O3 runs

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Several Gamma-ray Burst (GRB) afterglow light curves show a so-called "plateau" phase in the X-rays. Theoretical models predict that a long-lived central engine, such as a highly magnetized neutron star (magnetar), could power this plateau phase by injecting energy into the afterglow shock. Under the hypothesis that the newly-born magnetar is secularly unstable, its presence could be probed directly by searching for long-lived gravitational waves (GWs) during the plateau. In this work, we estimate the number of GRBs that could be potential targets for further long-duration GW signal searches. We considered all GRBs detected by the Swift Burst Alert Telescope (BAT) from April 2019 to October 1st, corresponding to advanced LIGO third observing run (O3). For completeness, we also extended our analysis to the past runs, advanced LIGO first and second observing runs (O1, O2) and initial LIGO 6th Science run (S6). Overall, we estimate that in O2, O1 and S6 each, $\approx$ 10% of Swift-triggered GRBs show an X-ray plateau with at least 1000 s of double coincidence time from the LIGO detectors. Our initial analysis for O3 is compatible with our results from the past runs.

6

Searching for Hidden Black Holes in APOGEE-2

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The Milky Way is believed to contain thousands of stellar mass black hole X-ray binaries, but only about 50 candidates are known. I discuss an examination of the APOGEE-2 data for X-ray sources in the Swift Galactic Bulge Survey region. The object HD 158902 stood out as warranting further investigation, because it showed a radial velocity discrepancy between archival data and APOGEE-2. I discuss my work in determining whether this is due to binary motions or other causes.

7

Optimizing the search for electromagnetic counterparts (EM) to Gravitational Wave (GW) events with the Liverpool Telescope (LT)

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Our understanding of gravitational wave (GW) events is greatly enhanced by identifying and studying their electromagnetic (EM) counterparts. For nearby GW events with a small localization uncertainty, an effective strategy is to search for new transient sources in previously catalogued galaxies, whose properties are consistent with the GW data. Even with a limited field of view, such as that of the Liverpool Telescope (LT), it is plausible to discover the EM counterparts using an efficient observational strategy. But because many galaxies must be observed and the EM counterparts are faint and fade rapidly, a reliable automatic procedure is crucial to schedule observations efficiently. To meet these challenges, we designed an algorithm in Python that uses a catalogue of nearby galaxies and the three-dimensional GW localization map to create a prioritized list of galaxies based on GW error-map probability, observability, and absolute magnitude. We tested our algorithm with past GW events and, within a few minutes, obtained consistent results with previous observations. For example, NGC 4993, host galaxy of GW170817, was in 3rd place in our observing schedule. Thus, this algorithm can swiftly assist in the formulation of effective follow-up plans which should increase the probability of localizing EM counterparts.

8

Isoflurane Increases Cell Membrane Fluidity Significantly at Clinical Concentrations

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There is an on-going debate whether anesthetic drugs, such as isoflurane, can cause meaningful structural changes in cell membranes at clinical concentrations. In this study, the effects of isoflurane on lipid membrane fluidity were investigated using fluorescence anisotropy and spectroscopy. In order to get a complete picture, four very different membrane systems (erythrocyte ghosts, a 5-lipid mixture that mimics brain endothelial cell membrane, POPC/Chol, and pure DPPC) were selected for the study. In all four systems, we found that fluorescence anisotropies of DPH-PC, nile-red, and TMA-DPH decrease significantly at the isoflurane concentrations of 1 mM and 5 mM. Furthermore, the excimer/monomer (E/M) ratio of dipyrene-PC jumps immediately after the addition of isoflurane. Our data indicates that isoflurane is quite effective to loosen up highly ordered lipid domains with saturated lipids. As a comparison of the effects on membranes, the decrease of nile-red fluorescence anisotropy in erythrocyte ghosts by 1 mM isoflurane is more than the corresponding decrease caused by 52.2 mM of ethanol, which is three times the legal limit of blood alcohol level. Our results paint a consistent picture that isoflurane at clinical concentrations causes significant and immediate increase of membrane fluidity in a wide range of membrane systems.

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Muon Tomography Model for Monte Carlo Simulation of Prototype Muon Telescope

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Our main objective is to develop a portable muon detector with an excellent spatial resolution that will be able to image large structures in great detail. Muons are elementary particles that pass through matter, losing energy in the process. Muon tomography is a technique that exploits this phenomenon to construct images of large objects of interest, such as volcanoes, buildings, and pyramids. To better understand this technique and improvements for our approach, a Monte Carlo simulation of our experiment involving the detection of a nearby water tower and its contents was developed. The present Monte Carlo Simulation utilizes the GEANT4 software package combined with Cosmic-ray Shower Library (CRY) and ROOT for data analysis. CRY is being used to generate muons with an angular distribution and an energy spectrum corresponding to those of cosmic ray muons at sea level. This module is loaded on to GEANT4 and is used for simulating the geometry of our detector, tracking muons, and their interactions with the detector and water tower's material. To store this information, we created ntuple files containing the energy deposit and other properties of the muon particles interacting with each Layer of our detector. From these we can analyze the muon density detected for different configurations of our detector and construct 1D and 2D muon projections of the tower showing its contents. This analysis allows us to compare simulated results with experimental results and improve the current prototype.

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Detection of Hα emitters within the IPHAS field of view

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I present a list of likely Hα emitters among the sources in the INT Photometric Hα Survey of the Northern Galactic Plane (IPHAS) field of view.
Out of 7373236 objects, 17272 have been highlighted as emitters, in the Hα narrow band. For each of these objects, I calculated a significance parameter which provides a quantitative degree of confidence that the given source is a true emitter, with reference to an associated group of similar objects. In this way, future users can choose between applying a more conservative cut rather then opting for completeness, or vice versa.
In this study, I used a cross-matched catalog between Gaia DR2 and IPHAS DR2; this provided me with, besides the r, i and Hα IPHAS bands, also the Gaia Bp, Rp and M$_G$ colors, along with the distances between the sources and us. I could then build the Bp-Rp VS M$_G$ Color-Magnitude Diagram, which allowed me to identify which population each source most likely belongs to.

12

Microresonator-Based Frequency Comb Generation

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A frequency comb is a set of equidistant spectral lines and works as a ruler in the frequency domain due to the high precision of its frequency spacing. This technology has revolutionized many measurement metrologies such as dual-comb spectroscopy, distance measurement, light detection, ranging (Lidar), and optical atomic clocks. Recent advances made to microresonators have made comb generation from chip-scale devices possible. This is allowing the technology to become much more portable, which in turn gives it more real-world applications. This type of frequency comb generation requires a microresonator with certain characteristics, which are high quality factor (high-Q) and anomalous dispersion. The object of this experiment is to optimize geometric parameters of microresonators for these characteristics and to generate frequency combs. The resonances of multiple microresonators were tested by sending laser light through a fibercoupled photonic waveguide, and the results were fitted and analyzed to determine the quality factor and dispersion of each microresonator. We found a set of optimized microresonators that exhibit high-Q and anomalous dispersion, and generated frequency combs from these microresonators. Our research optimized the geometric parameters of microresonators that can efficiently produce frequency comb lines. Our optimized devices are portable and provide a precise frequency spacing, and therefore will have useful applications in many areas such as spectroscopy, bio/chemical sensing, Lidar, and time/frequency metrology.

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Compact Binaries in Globular Clusters

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Globular clusters
are very old groups of stars. Due to their age and the gravitational interactions dominating the dynamics of the clusters, they are home to a
significant fraction of compact binaries. The formation and evolution of these kinds of binaries is still not completely understood. Using MUSE and Hubble archival data we plan to characterize the compact binary
population in them. With MUSE in the cluster NGC 6397, we have been able so far to spectrocopically confirm two new CV candidates as well as retrieve higher quality spectra of the four previously identified CVs and of a candidate millisecond pulsar (MSP). With Hubble archival data we have been able to recover the period for the brightest CVs, as well as for the MSP candidate. The found 1.9 days period for the MSP, suggest that it is a new redback pulsar candidate. Altogether we have demonstrated how an IFU like MUSE, and archival data from Hubble
can be used to efficiently study the population of compact objects in globular cluster

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A Resonance Tuning of Localized Surface Phonon Polaritons on Hexagonal Boron Nitride

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Metasurfaces are sub-wavelength patterned layer which interact with light and alter optical responses. In particular, gradient optical metasurfaces have been used to control a wavefront of light in free space and in optical waveguides. However, a control of light on two-dimensional surface has been challenging because of the high optical power loss from metallic nanostructures. In recent years, we have chosen polar dielectrics as a metasurfaces platform because the polar dielectrics have a low optical power loss and a high coupling efficiency to the light from ionic crystals. We classified polar dielectrics into two groups (bulks and two-dimensional materials) depending on the evanescent field characters of surface waves of the light on polar dielectrics. In this work, we propose metasurfaces platform made of two-dimensional hexagonal boron nitride. We have searched for a localized surface phonon resonances by designing the device using full wave simulation with the fintie-difference time-domain method. We studied two different geometries; metal/dielectric multilayer boundary (1) underneath the polar dielectrics and (2) on the polar dielectrics.

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Fitting and analysis of radio afterglow light curves from GW sources

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Gravitational Wave observations have given us yet another way to understand the cosmos. Gravitational wave events are often accompanied by emission from across the electromagnetic (EM) spectrum. EM follow up observations help in pushing the boundaries of our understanding of gravitational physics, nucleosynthesis and cosmology. GW170817 is the first detection of gravitational waves and light from the merger of two neutron stars. Radio observations, in particular, and analysis of the broad-band afterglow of GW170817 in general, led to verification of the predictions of various jet models. These models are parametrized by a large number of correlated parameters. Fitting them requires a robust tool like affine invariant Markov Chain Monte Carlo (MCMC) simulations, that can be used to obtain the best fit parameters and the errors associated with them. This poster presents preliminary testing of a dedicated MCMC code, and some ongoing work to model the expected very-late-time radio emission of GW170817 arising from the interaction between the neutron-rich ejecta and the surrounding interstellar medium.

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Search for VBF production of heavy resonance decaying to Z(nunu)W/Z(qqbar) final state

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A search for heavy resonances decaying to a pair of vectors bosons is presented which utilizes events in which a hadronically decaying Z or W boson is identified using jet substructure techniques and large missing transverse momentum is found. Data analyzed were recorded by the Compact Muon Solenoid experiment at the CERN Large Hadron Collider in 2016, 2017, and 2018, and correspond to 137 fb^-1. The events are categorized as having arisen from Vector Boson Fusion process or not, and are characterized by their transverse mass distribution. The standard model backgrounds are estimated based on observed yields in control regions. No excess of events above the expected SM background are observed and limits are placed on the production cross section of Radion (spin-0), Wprime (spin-1) and Bulk graviton (spin-2) particles.

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Broadband near-zero dispersion with multiple mode couplings

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We present a thin silicon nitride waveguide array that achieves a broadband near-zero dispersion profile at near-infrared (1350 – 1800 nm). Multiple mode couplings are introduced at four different wavelengths by coupling different orders of modes. A super continuum is also generated solving the nonlinear Schrodinger equation using the designed complementary metal-oxide-semiconductor technology compatible thin array of Silicon nitride waveguides.

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Using Gravitational Waves to Resolve the GRB Central-Engine Mystery

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Gamma-ray Bursts (GRBs) are flashes of gamma-rays thought to originate from rare forms of massive star collapse (long GRBs), or from mergers of compact binaries (short GRBs) containing at least one neutron star (NS). The nature of the post-explosion / post-merger remnant (NS versus black hole, BH) remains highly debated. In ~50% of both long and short GRBs, the temporal evolution of the X-ray afterglow that follows the flash of gamma-rays is observed to ``plateau'' on timescales of 100-10000 s since explosion, possibly signaling the presence of energy injection from a long-lived, highly magnetized NS (magnetar). The Cross-Correlation Algorithm (CoCoA) proposed by [R. Coyne et. al., (2016)] aims to optimize searches for intermediate-duration (100-10000s) gravitational waves (GWs) from GRB remnants. In this work, we test CoCoA on real data collected with ground-based GW detectors. We further develop the detection statistics on which CoCoA is based to allow for multi-waveform searches spanning a physically-motivated parameter space, so as to account for uncertainties in the physical properties of GRB remnants.

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Study of the Effect of the VO2 Layer Coated on Metallic Surfaces for Smart Window Applications

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Optical coatings are key components in modern optoelectronic devices such as solar cells, optical filters and smart windows. One of the materials which have recently found some applications as a uniform or patterned layer in optical devices is vanadium dioxide (VO2). The electrical and the optical properties of VO2 change remarkably when it undergoes a reversible phase transformation from an insulating and a metallic phase near 68 0C. This phase transformation is accompanied with a crystalline structural change from monoclinic to tetragonal which results in the collapse of its 0.7 eV bandgap and provides a unique opportunity for designing photonic devices with tunable optical properties which can be employed in electro-optical switches and as a passive radiative cooling coating for energy efficient vehicles and buildings. In all these applications, the effect of the VO2 coating layer thickness on the absorption spectrum is of great significance which has been not explored in detail. In this work, we have numerically and experimentally investigated the absorption of a single thin layer VO2 over different metallic films over a wide range of wavelengths at normal and oblique incident angles. We have found that in the insulating phase, the air/VO2/metal structure can be considered as an asymmetric Fabry-Perot resonant cavity which its resonant absorption wavelength depends on both the VO2 layer thickness and the type of the metallic layer. In the metallic phase, there is always a narrow wavelength region with zero reflection which does not depend on the type of the metallic layer.

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Hydrodynamic Analog for Radioactivity

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It has been shown that a drop of fluid can be made to bounce on a vertically oscillating bath of fluid. These droplets, known as “walkers”, couple to the waves they generate and propagate forward with a constant velocity. When a variation of depth in the fluid bath is introduced it creates a difference in potential; droplets crossing the barrier must do so on a transmitted exponentially decaying wave. We have created a system which spontaneously generates walker droplets to simulate particles leaving a potential well. Previous studies of walker droplets have used forcing amplitudes just below the Faraday instability threshold to study the drop’s trajectory about the fluid bath. In this system we use a forcing amplitude well above the threshold in order to generate walker droplets autonomously. The droplets then tunnel across a potential barrier to a damped region where the fluid is below the instability threshold. The formation of these droplets and their resulting kinetic energy is related to the amplitude and frequency of the driving oscillation. We studied the corral barrier’s geometry and the driving frequency to understand the energy and formation of the droplets. The system could provide an analog to radioactivity in which particles spontaneously tunnel across a potential barrier, showing promise for future analysis.

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Search for R-modes from Known Pulsar

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Continuous gravitational waves are weak in signal but it can beat the spin down limits if observed for a longer time span. R-modes are the current quadruple oscillation of fluid in neutron star, which emits gravitational waves in 4/3 times the spin frequency in Newtonian case. Crab And Vela pulsar have the best spin down limit in amplitude strain and beats the LIGO noise curve. We present here the first search of R-mode gravitational waves from known pulsar from a LIGO O1 & O2 run using the F-statistic method.

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Search for resonance in inclusive and b-tagged dijet mass spectra in proton-proton collision at $\sqrt{\square}=\square\square$ TeV

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Btag requirement is developed to increase the sensitivity to final states with jets coming from the hadronization of b-quarks. This algorithm is based on the reconstruction of tracks with large impact parameter and the identification of displaced secondary vertices. In this analysis, we use the >=1btag category with tight WP(Working Point) to search for bstar and 1btag category with medium WP to search for

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Methods to Search for New Physics in Proton-Proton Collisions at the LHC - Same Sign Dimuon Final State for Lepton Number Violation Process.

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The Standard Model (SM) of particle physics is a very successful model to explain matters and interactions of matters in the universe with quarks, leptons, vector bosons and the Higgs particle. On the other hand, SM is incomplete. For example, the model does not explain the existence of dark matter and gravitation in the universe. After the discovery of the Higgs particle in 2012, searches for dark matter, graviton and other new physics beyond the SM continued at the Large Hadron Collider (LHC). A search for new physics in proton-proton collisions at the LHC same sign dimuon final state for lepton number violation process is presented with the data collected by the CMS experiment for proton-proton collision at 13 TeV with 35.9/fb . Methods used in search for lepton number violation in proton-proton collisions at the LHC have been focused, which produce two same sign muons in the final state. The measurements of cross sections for the signal region in data and estimated backgrounds from Monte Carlo (MC) simulation for the same sign dimuon channels are consistent. No excess signal is observed in those channels.