XIII MEXICAN SCHOOL ON GRAVITATION AND MATEMATICAL PHYSICS

November 8-11, 2021

Multi-Messenger Astronomy for Core Collapse Supernovae

http://www.divisiongravfismat.mx/xiii-escuela-de-la-dgfm

	Monday 8	Tuesday 9	Wednesday 10	Thursday 11
	WELCOME (8:45)			
09:00 10:00	***COURSE 1*** *Morales/Antelis*	***COURSE 3*** *Andresen*	***PLENARY 1*** *Mukherjee*	***COURSE 3*** *Andresen*
10:00 11:00	***COURSE 1*** *Morales/Antelis*	***COURSE 3*** *Andresen*	***PLENARY 2*** Quentin	***COURSE 3*** *Andresen*
11:00 11:30	***BREAK***			
11:30 12:30	***COURSE 2*** *Lunardini*	***COURSE 1*** *Morales/Antelis*	***PLENARY 3*** Szczepanczyk	***COURSE 2*** *Lunardini*
12:30 13:30	***COURSE 2*** *Lunardini*	***COURSE 1*** *Morales/Antelis*		***COURSE 2*** *Lunardini*
13:30 16:00	***BREAK***			
16:00 17:00		***PARALLEL SESIONS***	***PLENARY 4*** *Sand*	***PARALLEL SESIONS***
17:00 18:00				

	TUESDAY 9
16:00 16:25	**Hydrodynamic representation and Energy Balance for the Dirac and Weyl fermions in curved space-times** Omar Gallegos, Cinvestav, IPN
16:25 16:50	**3D Numerical Simulations of Structured Long GRB Jets** Gerardo Urrutia, Instituto de Ciencias Nucleares UNAM
16:50 17:15	**Frequency shift of light emitted from growing and shrinking black holes** Francisco S. Guzman, Universidad Michoacana de San Nicolas de Hidalgo
17:15 17:40	**Accretion of a Vlasov gas onto a black hole from a sphere of finite radius and the role of angular momentum** Carlos Eduardo Gabarrete Fajardo, Universidad Michoacana de San Nicolás de Hidalgo
17:40 18:05	**On the role of the magnetic field in the dynamics and the gravitational waves emission of a binary system of neutron stars** Mariana Lira Peralta, Instituto de Ciencias Nucleares, UNAM
18:05 18:30	**Parameter Estimation for GW from CCSNe** Alejandro Casallas Lagos, Universidad de Guadalajara

	THURSDAY 11
16:00 16:25	**Dissipative dynamics in the early universe** Rafael Hernández Jiménez, Universidad de Guadalajara
16:25 16:50	**Dynamics of a composite dark energy model with a tracker field and a cosmological constant** Luis Ureña-López, Universidad de Guanajuato
16:50 17:15	**The graviton Compton mass as Dark Energy** Tonatiuh Matos, Cinvestav, IPN
17:15 17:40	**Perturbaciones Gravitacionales en el Formalismo de Newman-Penrose: Aplicaciones a Agujeros de Gusano** Juan Carlos Del Águila Rodríguez, Centro de Investigación y de Estudios Avanzados del I.P.N.
17:40 18:05	**Sobre las parametrizaciones fenomenológicas de la distancia luminosa de las ondas gravitacionales** Pablo Andrés Lizardo Romo Universidad Autónoma de Zacatecas
18:05 18:30	**Waveform for rapidly rotating Core-Collapse Supernova** Laura Olivia Villegas Olvera Universidad de Guadalajara

COURSES

COURSE 1: *MACHINE LEARNING FOR GRAVITATIONAL WAVES SIGNALS DETECTION*

Manuel Morales/Javier M. Antelis
Tecnológico de Monterrey campus Guadalajara, México

Manuel David Morales is Ph.D. in theoretical physics from Universidad Michoacana de San Nicolas de Hidalgo. Currently, works as data scientist in the Jalisco State Government in Guadalajara, México. His research fields are gravitational wave astronomy, applied machine learning, data analysis, the relation between science and philosophy/theology, and he also has past experience in numerical relativity.

Javier M. Antelis is researcher at the engineering and science school at Tecnológico de Monterrey, campus Guadalajara. He is a LIGO collaboration member. His research is focused on artificial intelligence, data science and gravitational waves detection from CCSN.

Abstract:
Application of machine learning (ML) for detection of gravitational waves (GW) is a new and promising field in GW astronomy. In this practical course, we will introduce some of these techniques through Python open source codes, using scikit-learn and TensorFlow libraries. In the first session of the course, we will present fundamentals of ML and application of several classical ML classifiers, using standard datasets of the ML community, and putting emphasis on exploratory data analysis and statistical evaluations of those algorithms, which are crucial steps in any end-to-end data science project. In the second session, we present a particular case of study of application of Deep Learning (DL), specifically Convolutional Neural Networks (CNN), to detect GW generated from Core-Collapse Supernovae (CCSNe) computer simulations that were injected in real noise data from LIGO interferometric detectors. In practice, this is a classical problem of binary classification to discriminate samples of noise only, and samples of noise+GW event. Strain data will be converted to images, to be inputted to the CNN. Besides, we will take two data approaches for the prediction: considering single-interferometer data, H1 and L1, and data from network of detectors, H1+L1.

COURSE 2: *PHENOMENOLOGY OF SUPERNOVA NEUTRINOS*

Cecilia Lunardini
Arizona State University, USA

Cecilia Lunardini was awarded her bachelor's degree from the University of Pavia (1998) and her doctorate in physics from the International School of Advanced Study (2001) in Trieste, Italy. She joined Arizona State University in 2007, where she is currently a full professor. Lunardini has accumulated an extensive list of peer-reviewed research publications, heavily focused in neutrino studies, with more than 4000 citations to date.

Abstract:
I give a pedagogical review of the physics of neutrinos from core collapse supernovae, including their production, propagation (including flavor oscillations), and detection. I will especially emphasize the physics potential of observing supernova neutrinos in the future, either as a burst from a nearby star or as a diffuse flux. Only fundamental physics knowledge is required to follow these lectures.

COURSE 3: ***STELLAR CORE COLLAPSE, FROM NUMERICAL SIMULATION TO GRAVITATIONAL WAVES***

Haakon Andresen
Stockholm University, Sweden

Haakon Andresen is Ph.D. in Theoretical astrophysics from The Max Planck Institute for Astrophysics, He was three years Postdoctoral Researcher at Albert Einstein Institute Max Planck Institute for Gravitational Physics in Berlin, Germany, actually is a Ph.D. in Stockholm University, Sweden. His research interests are mainly focused in Core-collapse Supernovae, gravitational wave astronomy, numerical hydrodynamics, signal analysis, General Relativity and Numerical Methods.

Abstract:

Will discuss the physics of the late-stage evolution of massive stars and the events leading up to the inevitable gravitational collapse of the stellar core. I will then give an overview of the events that occur within the next few seconds, which ultimately powers the supernova explosion. I will focus on the so-called neutrino heating mechanism, which is the canonical explosion scenario.

The explosion mechanism of core-collapse supernovae can only be studied by numerical simulations, but these simulations cannot include all the detailed physics governing the system. I will discuss where it is necessary to use approximations and which approximations are commonly used. Some simplifications drastically reduce the cost of the numerical simulations. These simplified simulations can be helpful to perform systematic studies, and I will show examples where this is the case.

In the second half of my lecture series, I will focus on the gravitational waves emitted by core-collapse supernovae. How do we extract the waves from the simulations, which analysis techniques are commonly used and are there any potential pitfalls? I will discuss all these questions and review the gravitational wave signals we expect from core-collapse supernovae. I will, towards the end, discuss open questions and challenges for the future.

PLENARIES

PLENARY 1

Gravitational wave tests of spacetime symmetries

Bailey Quentin
Embry Riddle Aeronautical University, USA

Quentin Bailey is Ph.D. in Physics with Minor Mathematics from Indiana University, currently is researcher at ERAU physics and astronomy department. His research includes fundamental theory of gravity, the general theory of relativity, theoretical and experimental aspects of testing Lorentz symmetry, the spacetime symmetry of Special Relativity.

Abstract:
In this talk I review aspects of testing principles of General Relativity using gravitational wave data. Also, I discuss 3+1 formulations of a test framework for GR that could be used to study models of CCSN. Additionally, ongoing work on multipole expansions shows that the test framework might contain novel signals from spherical collapse.

PLENARY 2

Data analysis techniques employed in the detection of gravitational waves from core collapse supernovae by a network of detectors

Soma Mukherjee
University of Texas Rio Grande Valley, USA

Dr. Soma Mukherjee obtained Ph. D in Physics from the University of Calcutta, and served as postdoctoral researcher at Caltech and Northwestern University (IL) and at Penn State. She was a scientist at the Max Planck Institute fur Gravitationsphysik before joining the University of Texas at Brownsville. She has co-authored over 200 peer-reviewed LIGO Scientific Collaboration (LSC) and other papers in high impact journals and presented many invited and plenary talks at international conferences. Her research has been well-funded through NSF and NASA. Dr. Mukherjee is a member of the LIGO Scientific Collaboration since its inception, and a co-author of the gravitational wave discovery paper in 2016. She is a co-recipient (with LSC) of the Breakthrough Prize in Fundamental Physics, Gruber Cosmology Prize and Princess of Asturias Award.

Abstract:
Core collapse supernovae (CCSN) are highly anticipated sources of gravitational waves (GW). The GW waveforms from these sources present special challenge because they are unmodeled and weak. Moreover, the rate of such events in our galaxy is only about 2 per century. With the upcoming fourth observation run (O4) by the network of detectors including the Laser Interferometric Gravitational Wave Observatories (LIGO) in the U.S., it is of utmost importance that efficient methods be developed in order to enhance the probability of detecting and characterizing such sources. Non-parametric search pipelines using a worldwide network of detectors have been employed to analyze the GW detector data to search for CCSN signals. CCSN GW signals are stochastic in nature and hence some noise sources present in GW data can mimic the CCSN signals. Thus, one needs to distinguish between the CCSN signals and noise. Machine Learning (ML) techniques have recently gained much attention in solving this problem. In this talk, I will give an overview of the GW detector network, CCSN explosion and different data analysis methods used in this search.

PLENARY 3

Detecting and reconstructing gravitational waves from the next Galactic core-collapse supernova

Marek Szczepanczyk
University of Florida, USA

Marek Szczepanczyk is Ph.D. in engineering physics from Embry Riddle Aeronautical University, currently He is a postdoctoral student at the University of Florida. He is LIGO collaboration member and his research is focused on gravitational waves from CCSN, binary black holes, and core-collapse supernovae.

Abstract:
Core-collapse supernovae (CCSNe) are one of the most spectacular phenomena known in the Universe. While we know that they are explosions of massive stars, the exact mechanism is not yet well understood. The detection of gravitational waves (GWs) will allow to directly probe the CCSN engine and help understand the explosion mechanism. I will explain how the stars explode and the GW signatures. Then, I will show a wide range of GW signatures derived from the multidimensional CCSN simulations. I will provide prospects of detecting GWs with the advanced GW detectors, indicating that the signals from neutrino-driven explosions and the explosions from the rapidly rotating progenitors could be detected up to an average distance of 10 kpc and 100 kpc, respectively. I will discuss the accuracy and the challenges of reconstructing the waveforms. Finally, I will talk about how well particular emission processes in CCSN can be reconstructed for a detected GW signal.

PLENARY 4

Early Optical Observations of Nearby Core Collapse Supernovae

David Sand
University of Arizona, USA

David Sand is associate professor at the department of Astronomy & Associate Astronomer, of the Steward Observatory at the university of Arizona. His research is focused on observational astronomer interested in time domain astronomy, and in particular understanding the progenitors and explosion mechanisms of supernovae.

Abstract:
Early observations of nearby core collapse supernovae are key to understanding their progenitor systems. Here I will outline the methods and technology used for detecting young supernovae, and future prospects. I will emphasize early observational signatures — such as pre-explosion outbursts, shock breakout cooling, flash spectroscopy, and early light curve modeling — which point to the final years of the progenitor star and its circumstellar medium prior to explosion.

SHORT TALKS
TUESDAY 9

Hydrodynamic representation and Energy Balance for the Dirac and Weyl fermions in curved space-times

Omar Gallegos
Cinvestav-IPN

Abstract:
Using a generalized Madelung transformation, we derive the hydrodynamic representation of the Dirac equation in arbitrary curved space-times coupled to an electromagnetic field. We obtain Dirac-Euler equations for fermions involving a continuity equation and a first integral of the Bernoulli equation. Using the comparison of the Dirac and Klein-Gordon equations we obtain the balance equation for fermion particles. We also use the correspondence between fermions and bosons to derive the hydrodynamic representation of the Weyl equation which is a chiral form of the Dirac equation.

3D Numerical Simulations of Structured Long GRB Jets

Gerardo Urrutia
Instituto de Ciencias Nucleares UNAM

Abstract:
Observations of GRB 170817A, the first unambiguous off-axis GRB, have been followed by numerous studies trying to understand the structure of GRB jets. It has been shown that, in short GRBs, the interaction with the environment resulting from the neutron star merger is responsible for shaping the jet structure. Nevertheless, the role of the initial jet structure at the launching point has not been studied in detail. In a previous study, we found that the initial structure of the jet plays indeed an important role in the jet dynamics and in determining the final structure of the jet when it propagates in a low-density environment characteristic of short GRBs. In this work, we explore the role played by the initial structure in jets propagating in a dense medium, characteristic of long GRBs produced during the collapse of massive stars. We perform 3D special relativistic, hydrodynamics simulations of top-hat and structured jets within a massive progenitor star. We consider jets dominated by kinetic and thermal energy. Additionally, we consider also jets propagating after a supernova (SN) explosion. We found that the initial structure of the jets is lost in pressure-dominated jets, while it is partially conserved in a kinetic-dominated jet. In addition, we found that the dynamics of the jet inside the progenitor star strongly depend on the presence of an associated SN, leading to faster acceleration and velocity in the jets.

Frequency shift of light emitted from growing and shrinking black holes

Francisco S. Guzman
Universidad Michoacana de San Nicolas de Hidalgo

Abstract:
In this paper we present a method to study the frequency shift of signals sent from near a Schwarzschild black hole that grows or shrinks through accretion. We construct the numerical solution of Einstein's equations sourced by a spherical shell of scalar field, with positive energy density to simulate the growth and with negative energy density to simulate the shrink of the black hole horizon. We launch a distribution of null rays at various time slices during the accretion and estimate their energy along their own trajectories. Spatially the bundles of photons are distributed according to the distribution of dust, whose dynamics obeys Euler equations in the test field limit during the evolution of the black hole. With these elements, we construct the frequency shift of photons during the accretion process of growth or contraction of the hole, which shows a variability that depends on the thickness of the scalar field shell or equivalently the time scale of the accretion.

Accretion of a Vlasov gas onto a black hole from a sphere of finite radius and the role of angular momentum

Carlos Eduardo Gabarrete Fajardo
Universidad Michoacana de San Nicolás de Hidalgo

Abstract:
The accretion of a spherically symmetric, collisionless kinetic gas cloud onto a Schwarzschild black hole is analyzed. Whereas previous studies have treated this problem by specifying boundary conditions at infinity, here the properties of the gas are given at a sphere of finite radius. The corresponding steady-state solutions are computed using four different models with an increasing level of sophistication, starting with the purely radial infall of Newtonian particles and culminating with a fully general relativistic calculation in which individual particles have angular momentum. The resulting mass accretion rates are analyzed and compared with previous models, including the standard Bondi model for a hydrodynamic flow. We apply our models to the supermassive black holes Sgr A* and M87*, and we discuss how their low luminosity could be partially explained by a kinetic description involving angular momentum. Furthermore, we get results consistent with previous model-dependent bounds for the accretion rate imposed by rotation measures of the polarized light coming from Sgr A* and with estimations of the accretion rate of M87* from the Event Horizon Telescope collaboration. Our methods and results could serve as a first approximation for more realistic black hole accretion models in various astrophysical scenarios in which the accreted material is expected to be nearly collisionless.

On the role of the magnetic field in the dynamics and the gravitational waves emission of a binary system of neutron stars

Mariana Lira Peralta
Instituto de Ciencias Nucleares, UNAM

Abstract:
Modelling as a dipole the magnetic interaction of a binary system of neutron stars, we are able to include the magnetic effects in the Newtonian and inspiral dynamics of the system using an equivalent one-body description. Furthermore, in the inspiral stage, we determine the role of the magnetic field in the waveforms generated by the system and obtain explicit formulas for the trajectories, time of collision, precession, luminosity and change of frequency, all this within the quadrupole approximation. For the magnitude of the magnetic field that is consider to exist in these binaries $\sim 10^{16} {\rm G}$ we are able to show that its effect on the observable quantities is of the order of the 2-PN correction, already close to the detection range of the gravitational waves observatories. We also compute the GW strains for some values of the magnetic field and use them to estimate the mass of the individual stars. Finally, we discuss cases in which the magnetic field could have a more significant influence."

Parameter Estimation for GW from CCSNe

Alejandro Casallas Lagos
Universidad de Guadalajara

Abstract:
In this work we present a methodology to estimate the g-mode slope using the cWB data analysis pipeline and spectrograms associated to detections of GW from CCSN. Extracting a set of pixels from a set of triggers reported by cWB in a simulation analysis, we implemented a methodology to obtain the g-mode slope.

THURSDAY 11

Dissipative dynamics in the early universe

Rafael Hernández Jiménez
Universidad de Guadalajara

Abstract:
Warm inflation presents an exceptional description of the early universe cosmology. It is a scenario of an inflationary dynamics in which the state of the universe during inflation is not the vacuum state, but rather an excited statistical thermal state. It introduces dissipation into the inflationary dynamics which can be well explained by first principles of a quantum multi-field theory. This approach has several attractive features. For instance, the additional friction may ease the required flatness of the inflaton potential. Besides, even if radiation is subdominant during inflation, may smoothly become the leading component if the ratio of dissipation $Q\gtrsim 1$ at the end of inflation ($\epsilon_{eff}\sim 1+Q$), with no need for a separate reheating period. It also may explain the nature of the classical inhomogeneities observed in the CMB, since for WI the fluctuations of the inflaton are thermally induced; hence there is no need to explain the troublesome quantum-to-classical transition problem of the standard inflation picture, cold inflation, due to the purely quantum origin of the density perturbations. Taking into account above encouraging warm inflation characteristics, in this thesis we will describe both warm inflation model building and the confrontation of theory with observation. We will examine two basic models: The {\it Warm Little Inflaton} scenario and the \emph{distributed mass} model.

Dynamics of a composite dark energy model with a tracker field and a cosmological constant

Luis Ureña-López
Universidad de Guanajuato

Abstract:
We study here phantom models of dark energy represented by a scalar field and with tracker properties. By means of a change of polar-like of variables, we study a general class of models classified in terms of a set of three free parameters. Upon comparison of the models with observations, and considering Bayesian evidence, our results suggest a preference for phantom-like dark energy and possibly a negative cosmological constant.

The graviton Compton mass as Dark Energy

Tonatiuh Matos
Cinvestav-IPN

Abstract:
In Rev.Mex.Fis. 67(2021)040703 it was shown that by considering the quantum nature of the gravitational field mediator, it is possible to introduce the momentum energy of the graviton into the Einstein equations as an effective cosmological constant. The Compton Mass Dark Energy (CMaDE) model proposes that this momentum can be interpreted as dark energy, with a Compton wavelength given by the size of the observable universe R_H, implying that the dark energy varies depending on this size. The main result of this work is the existence of an effective cosmological constant $\Lambda=2\pi^2/\lambda^2$ that varies very slowly, being $\lambda=(c/H_0) R_H$ the graviton Compton wavelength. In the present talk we use that the dark energy density parameter is given by $\Omega_\Lambda=2\pi^2/3/R_H^2$, it only has the curvature Ω_k as a free constant and depends exclusively on the radiation density parameter Ω_r. Using $\Omega_{0r} = 9.54\times10^{- 5}$, the theoretical prediction for a flat universe of the dark energy density parameter is $\Omega_{0\Lambda} = 0.6922$. We perform a general study for a non-flat universe, using the Planck data and a modified version of the CLASS code we find an excellent concordance with the Cosmic Microwave Background and Mass Power Spectrum profiles, provided that the Hubble parameter today is $H_0 = 72.6$ km/s/Mpc for an universe with curvature $\Omega_{0k}=-0.003$. We conclude that the CMaDE model provides a natural explanation for the accelerated expansion and the coincidence problem of the universe.

Perturbaciones Gravitacionales en el Formalismo de Newman-Penrose: Aplicaciones a Agujeros de Gusano

Juan Carlos Del Águila Rodríguez
Centro de Investigación y de Estudios Avanzados del I.P.N.

Abstract:
En esta plática se tratará el problema de la estabilidad lineal ante perturbaciones gravitacionales en agujeros de gusano estacionarios y esféricamente simétricos. Para esto se hace uso del formalismo de Newman-Penrose, el cual es especialmente útil para expresar tanto radiación gravitacional en Relatividad General, así como el aspecto geométrico de esta teoría. Mediante este método se obtiene una "ecuación maestra" que describe el comportamiento de perturbaciones impares en la norma de Regge-Wheeler. Esta ecuación es posteriormente aplicada a una clase específica de agujeros de gusano de Morris-Thorne. El análisis de la ecuación que estos espacio-tiempos generan revela que no existen modos inestables de vibración provocados por el tipo de perturbaciones aquí estudiadas.

Sobre las parametrizaciones fenomenológicas de la distancia luminosa de las ondas gravitacionales

Pablo Andrés Lizardo Romo
Universidad Autónoma de Zacatecas

Abstract:
La propagación de ondas gravitacionales ofrece nuevas posibilidades de estudiar las teorías de la gravedad. Dentro de estas posibilidades se encuentra la distancia luminosa de ondas gravitacionales. Se ha propuesto estudiar esta propiedad mediante parametrizaciones fenomenológicas, las cuales en este trabajo, comparamos con predicciones reales de la gravedad tipo Einstein-scalar-Gauss-Bonnet, encontrando que la parametrización más simple hace mejores ajustes. También en este trabajo proponemos una nueva parametrización que cubre un mayor rango de modelos, en particular, dentro de los que consideran términos degenerados y de orden alto de los términos tenso-escalares. Esperamos que estos resultados sean relevantes para restringir futuros modelos de gravedad modificada basados en las propiedades de las sirenas estándar.

Waveform for rapidly rotating Core-Collapse Supernova

Laura Olivia Villegas Olvera
Universidad de Guadalajara

Abstract:
The core-collapse Supernovae (CCSN) are violent processes that occur at the end of the life of massive stars (with masses greater than $8M_\odot$). And these have a very important role in the evolution of the Universe. These types of events occur once every 30 years per galaxy. Because of this, the CCSNs are naturally stochastic, and the gravitational waves they produce are of short duration, making their detection a challenge. In a typical CCSN explosion, gravitational waves can be divided into three phases: The first stage, shortly after the core bounce. The second stage begins around 100ms when the convection driven by neutrinos and SASI develops an aspherical mass movement and gives rise to the strong emission of low-frequency gravitational waves. Accumulation begins in the neutron proto-star (PNS). In the latter phase, 50-100ms later, the collision begins to expand, and matter accumulates in the PNS. We apply to gravitational waves (GW) from the core-bounce phase of rapidly rotating core-collapse supernova a frequentist methodology to calculate analytically the error for a maximum likelihood estimate (MLE) of physical parameters. This technique can be used to quantify what is the best possible precision in estimating parameters for a core collapse supernova by rapidly rotating progenitor and from the core bounce.