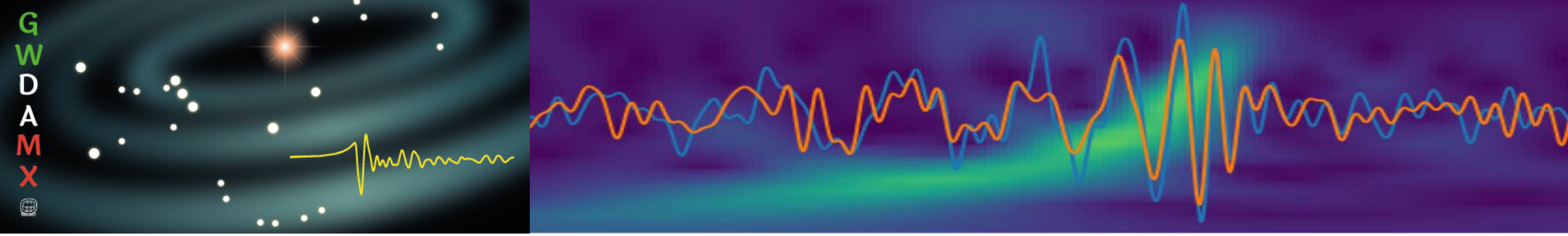

Mexican group in Astrophysical Sources of Gravitational Waves detection via Data Analysis

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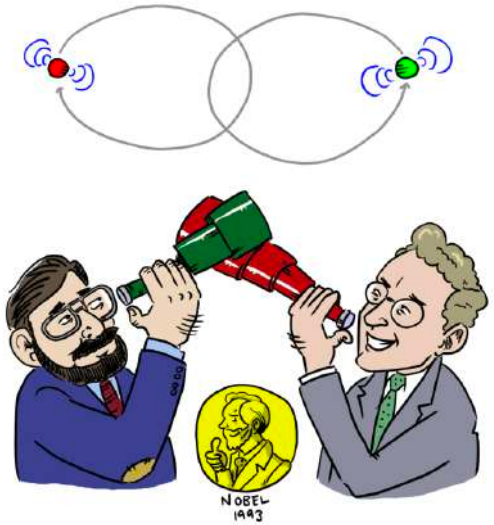
III LAS4RI for HECAP Symposium: Update of the Strategic Plan

August 27, 2024

Gravitational Waves

- **1915**: Einstein's General Relativity theory is published
- **1916**: Prediction of Gravitational Waves
- …
- **1993:** Taylor and Hustler win a **Nobel prize**
- ….
- **2015**: First direct observation of GWs by the ***Laser Interferometer Gravitational Wave Observatory (LIGO)*** win a **Nobel prize**



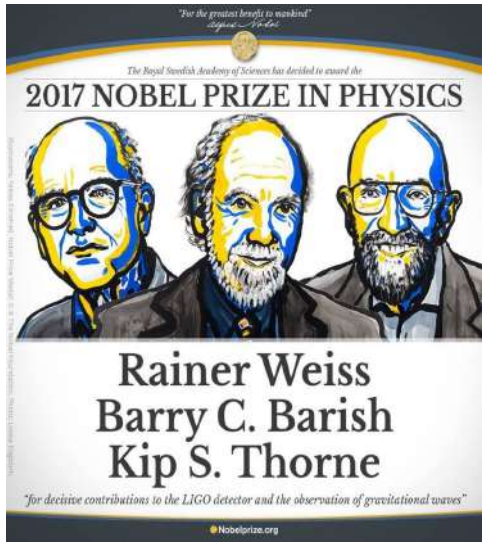
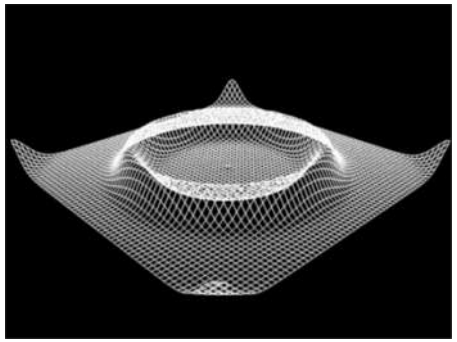
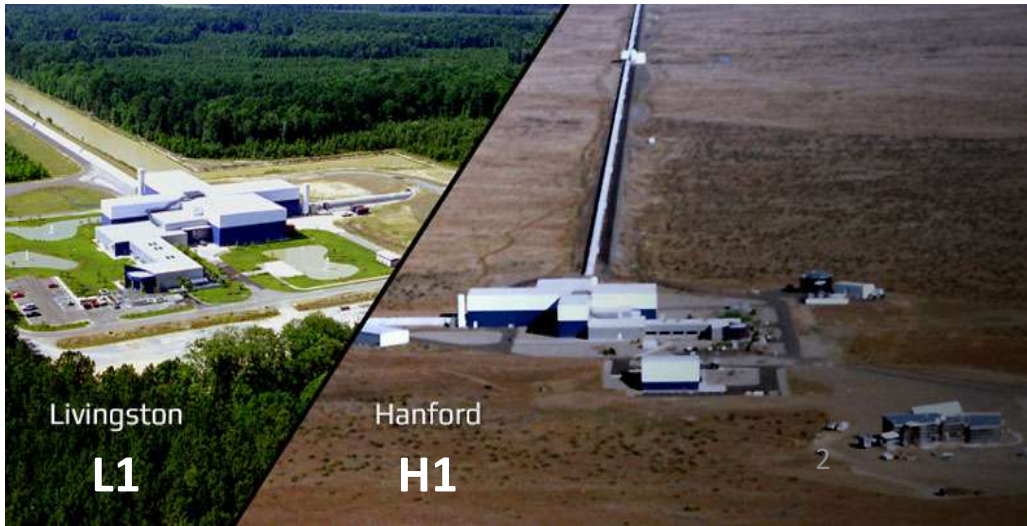


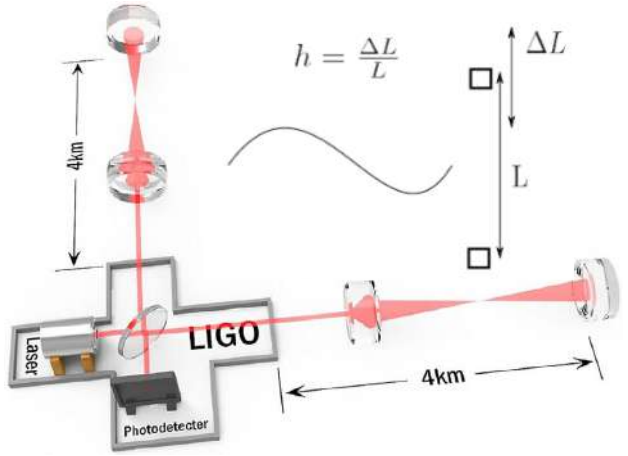
Image: phys.org





Gravitational Wave detectors

- GW passing through two objects change distance between them
- GW detectors: interferometers (the longer, the more sensitive)
- Preferably far away from human activities



- L-shaped Interferometer
- Michelson-Fabry-Pérot
- Sensitivity about:

$$h = \frac{\Delta L}{L} \approx 1/10^{22}$$

- Isolated from disturbances
- Mirrors are suspended
- Laser beam operates in vacuum

The dynamic Universe

Quadrupolar formula for GW production:

$$\mathbf{h}_{ij}^{TT}(t,\mathbf{x}) = \frac{1}{D}\ddot{Q}_{ij}(t - D/c, \mathbf{x})$$

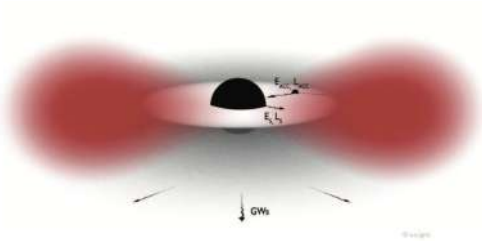
To produce GW we need **aspherical** mass-energy movement.

Compact Binaries:

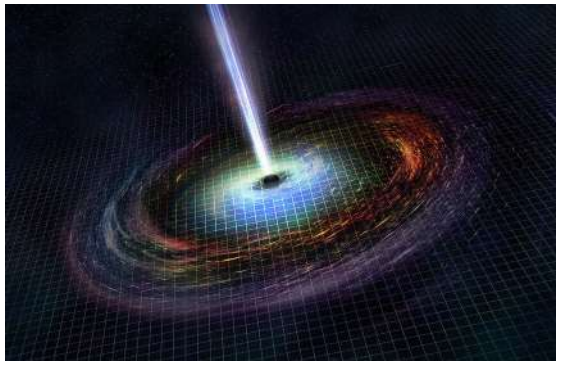
- BBH with circular/elliptical orbits
- Black hole – neutron star
- Binary neutron stars
- Intermediate-mass black hole
- Primordial black holes

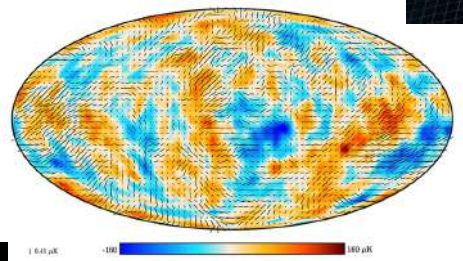
Other:

- Core-collapse supernovae
- Gamma ray burst
- Cosmic strings
- Boson cloud
- Background polarizations, etc.

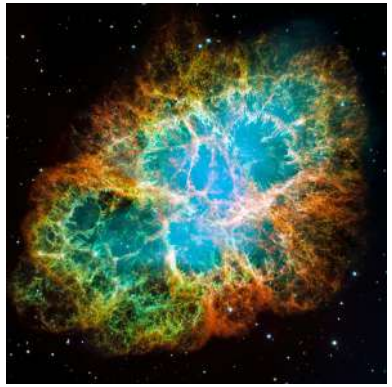


olemiss.edu

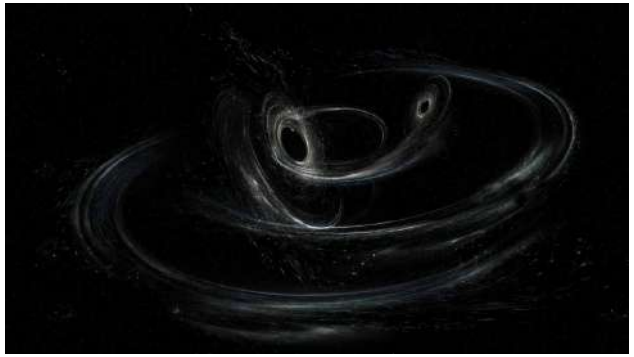




ESA and Planck Collaboration



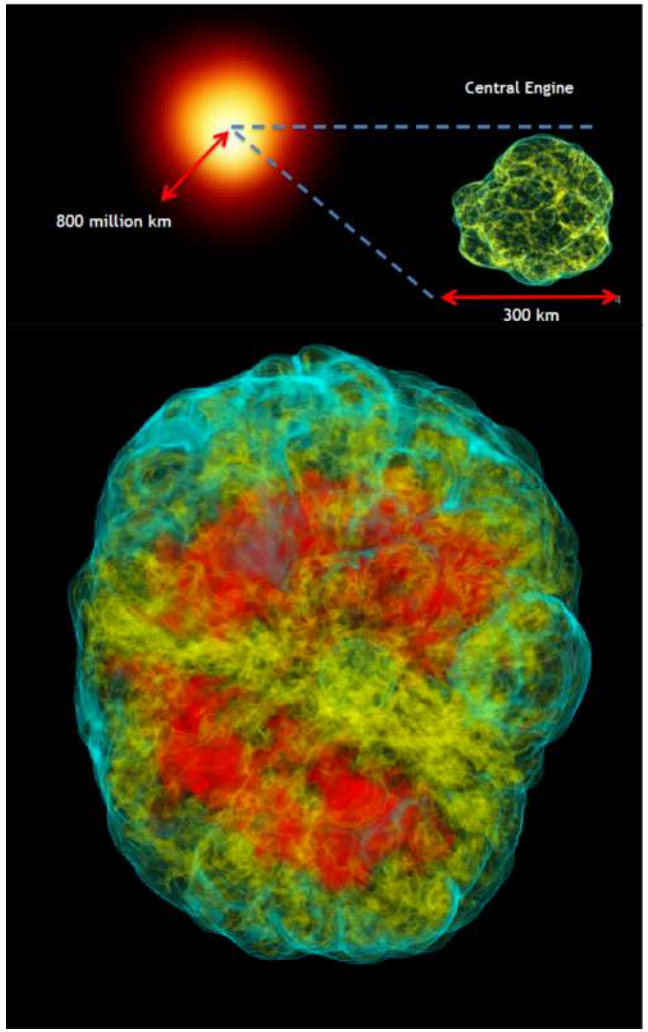
NASA, ESA, J. Hester y A. Loll



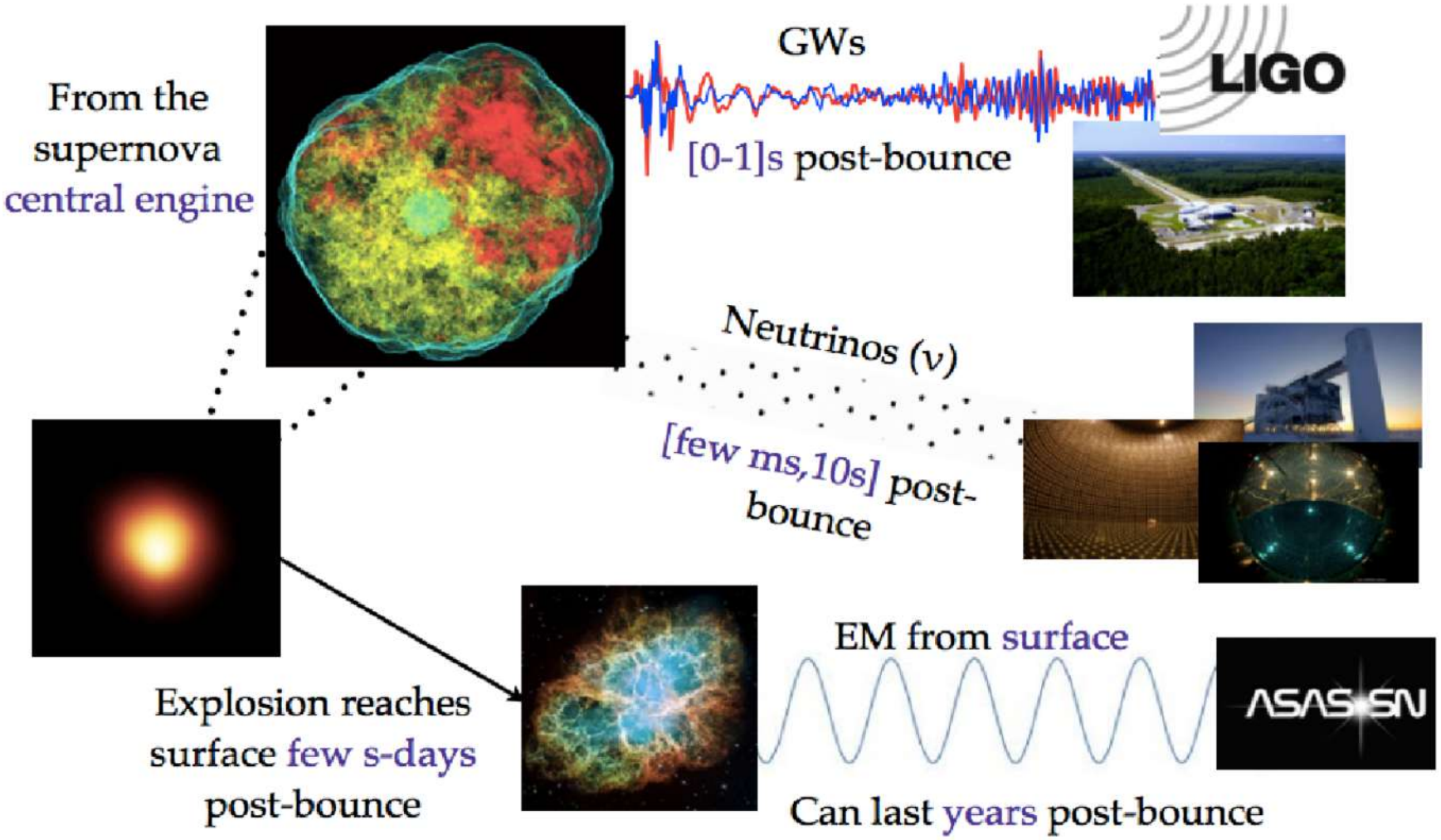
URORE SIMONNET/LIGO/CALTECH/MIT/SONOMA STATE

Next target: GW from core-collapse supernovae

- SN are exotic astrophysical objects
  - The last SN seen by human in the milky way was in 1604: **Kepper's SN**
  - The last SN known to have occurred in the milky way was about 300 years ago: **Cassiopea A**
  - The last notable SN in the vicinity of the milky way was in 1987: **SN1987A**
- Highly complex numerical simulations because their evolution mechanism
- The next frontier in the multi-messenger astrophysics is the observation of CCSNe (EM+Neutrinos+**GW**)



CCSNe Multimessenger astronomy



Motivation

- Theoretical and numerical analysis of GW fromCBC, gamma-ray bursts, supernovae, cosmological models and multimessenger astronomy in CCSNe
- Detection and reconstruction of GW from CCSN signals using cWB
  cWB Pipeline Operation
- Machine and deep learning methods to identify glitches and to enhance confidence, and to identify rotating progenitor types
- Parameter estimation and identification of CCSNe GW features (e.g., HFF, SASI, core-bounce)
- Dissemination and outreach activities of the GW astronomy, and promote the participation of more women and minorities

Methodology

- Implement and tune numerical codes with hydrodynamics and neutrinos equations to compute solutions of CCSN that yield to GW templates.
- Development of a new method, based on machine/deep learning, for the search and detection of GW from CCSN based on a novel multi-channel convolutional neural network (CNN) architecture. Implementation of methods and performance tests.
- Use the available software cWB and PyCBC to obtain and analyze the interferometer data from the LIGO, VIRGO and KAGRA observatories.
- Identification of CCSN event candidates of GW that are detected and reported by astronomers using electromagnetic observations.
- To do collaborations with groups in particles physics in the search of neutrinos, gamma rays, x rays, optical y radiofrequencies signals between other in MMA.

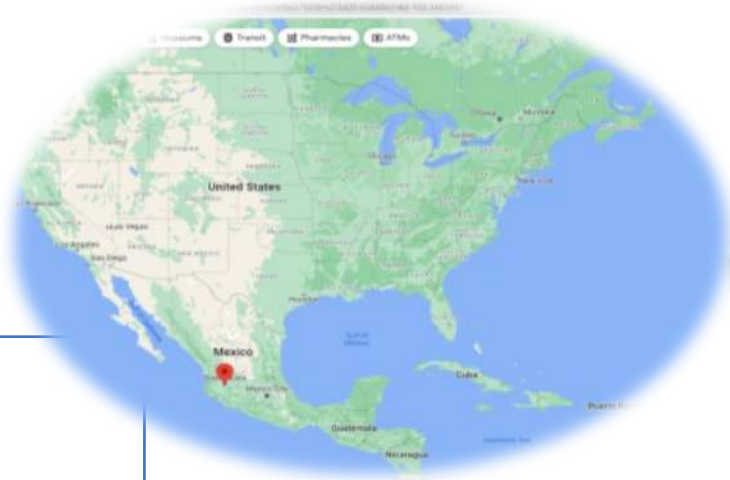
Scientific contributions

- Close limit aproximations using Teukolsky formalism
- Obtaining gravitational waves from inspiral binary systems using LIGO data
- Residual neural networks to classify the high frequency emission in core-collapse supernova gravitational waves
- A search for distinctive footprints of compact binary coalescence within alternatives theories of gravity

- Machine and deep learning models to identify and reduce noises
- Theory and simulations of GW from long gamma-ray burst jet
- Post-Newtonian Gravitational Waves with cosmological constant Λ from the Einstein-Hilbert theory

https://inspirehep.net/authors/1069404

Our group



Guadalajara, Jalisco

- Located in west of Mexico
- 2nd biggest city in Mexico
- Known as the Silicon Valley of Mexico
- Guadalajara is 60 km from Tequila town

University of Guadalajara, CUCEI

- 2nd biggest university of Mexico
- 16 campus in México, 140,348 alumni
- Undergraduate, Master and Ph. D. program in Physics
- Strong physics and mathematics faculty

UNIVERSIDAD DE GUADALAJARA

Tecnologico de Monterrey

- Top 3 University in Mexico
- 24 campus in México, 94,420 alumni
- Undergraduate, Master and Ph. D. program in Computer Science
- Multi-campus university

Tecnológico de Monterrey

GWDAMX

Eight undergraduate student (future graduate students)

UNIVERSIDAD DE GUADALAJARA

Tecnológico de Monterrey

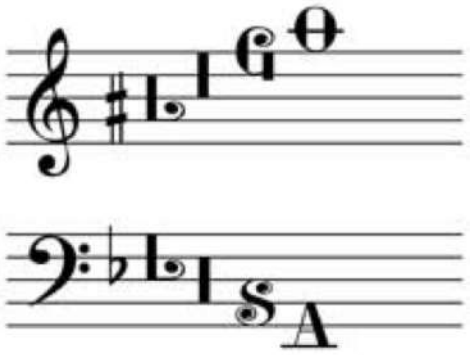
CONAHCYT

Future plans

- Consolidation of the *Grupo Latinoamericano de Análisis de Datos en Ondas Gravitacionales* *(Current interactions with students and scientists from Mexico, Colombia, and Chile)*
- To recruit undergraduate, graduate student, postdoctoral and professor researchers
- To promote gravitational waves research in more Mexican Universities of México and Latinoamerica
- To realize numerical simulations of CCSN
- To motivate Mexican and latin-american young girls and boys (emphasis in marginalized sectors) to study STEM careers
- Outreach activities for general public with talks and workshop

The importance of gravitational waves

- Test and verify general relativity (alternative theories)
- Learn more about known sources (or unknow)
- Explore the dark part of the universe
- A new era start: Multimesenger astronomy



- Gravitational Wave astronomy is a multidisciplinary research field,
- These research let you learn theoretical models,
  data analysis, numerical simulations techniques and experimental applications
- Many exciting issues and open problems!

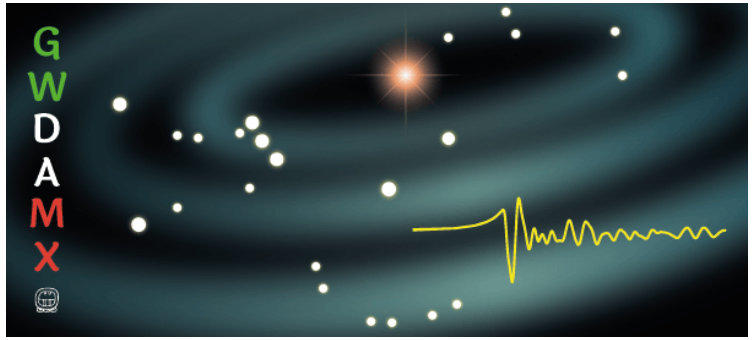
Albert Einstein plays Gravitational Waves

bobonart

Expectations

Command and control center

Interferometric Lab



Thanks all for your attention!

Dr. Claudia Moreno

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https://www.facebook.com/grupoondasgravitacionales

http://gravitationalwaves.mx