IFT – CIEMAT Meeting

Juan Garcia-Bellido (Virgo – IFT Madrid)

1st December 2022

IFT-Madrid Virgo group

Name	Teaching	FTE	Author	Student/Postdoc	Topical Fractions
Juan Garcia-Bellido (Professor)	Yes	60%	Yes	No	CBC (20%), SGWB (10%), Bursts (20%), Cosmo (%10)
Savvas Nesseris (Permanent Staff)	Yes	50%	Yes	No	Bursts (40%), CBC (10%)
Ester Ruiz Morales (Professor)	Yes	50%	Yes	No	CBC (40%), DA (10%)
Sachiko Kuroyanagi (Tenure-track Staff)	No	50%	Yes	No	SGWB (50%)
George Alestas	No	100%	Yes	Postdoc	CBC (100%)
Jose Francisco Nuño	No	100%	Yes	PhD student	INST (50%), DA (50%)
Gonzalo Morras	No	100%	Yes	PhD student	INST (50%), DA (50%)
Santiago Jaraba	No	100%	Yes	PhD student	INST (50%), DA (50%)

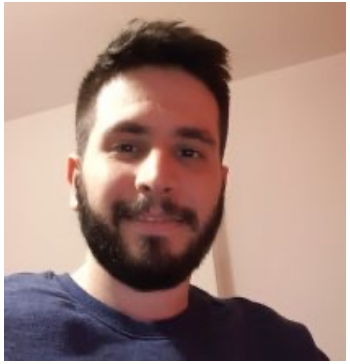
PBH, GW and Machine Learning group

Members:

Dr. Savvas Nesseris
Permanent staff member at IFT
Member of Euclid

Research interests:
Cosmology, dark energy,
modified gravity, machine learning,
gravitational waves,
primordial black holes.

Dedication: 50%



Dr. George Alestas
Postdoc at IFT-UAM

Experience:
Cosmology Group

Research interests:
gravitational waves, inflation

Dedication: 100%

Responsible of the Machine Learning group of IFT:
https://projects.ift.uam-csic.es/ift-ai-hpc/
http://members.ift.uam-csic.es/savvas.nesseris/

CBC population analysis group

Members:

Prof. Ester Ruiz Morales
Professor of Physics at UPM
Associate Researcher at IFT

Experience:
Working groups for LHC physics
Collaboration with CMS (2001-2006)
Member of LISA

Research interests:
Cosmology, inflation, gravitational waves, primordial black holes.

Dedication: 50%

Mr. José Francisco Nuño Siles
PhD student at IFT-UAM
4 year FPI fellowship at IFT

Supervisor:
Prof. Juan Garcia-Bellido

Research interests:
Gravitational waves, primordial black holes, bayesian population analysis

Dedication: 100%

Bursts (hyperbolic encounters) analysis group

Members:

Prof. Juan Garcia-Bellido
Professor of Physics at IFT-UAM

Experience:
DESGW Collaboration (2005-)
Euclid Mission (2011-)
Member of LISA

Research interests:
Cosmology, Inflation, gravitational waves, primordial black holes, close hyperbolic encounters, Multimessenger, Tests of GR.

Dedication: 60%

Mr. Gonzalo Morrás
PhD student at IFT-UAM
4 year FPU Fellowship at IFT

Supervisor:
Prof. Juan Garcia-Bellido

Research interests:
Gravitational waves, primordial black holes.
Close hyperbolic encounters

Dedication: 100%

Stochastic GW Background analysis group

Members:

Dr. Sachiko Kuroyanagi
Tenure-track staff at IFT-UAM

Experience:
KAGRA Collaboration (2015-)
(Co-chair SGWB group)

Research interests:
gravitational waves, inflation, cosmic strings

Dedication: 50%

Mr. Santiago Jaraba
PhD student at IFT
4 year FPI fellowship at IFT

Supervisors:
Prof. Juan Garcia-Bellido
Dr. Sachiko Kuroyanagi

Research interests:
Gravitational waves, numerical relativity,
Close hyperbolic encounters

Dedication: 100%

IFT Virgo group

Human Resources:

- 2.1 FTE Senior (4 people) with main background as Theoretical Cosmologists
  Relevant expertise on Experimental Collaborations (DES, PAU, DESI, KAGRA, etc.)

- 4 FTE Junior (1 Postdoc + 3 PhD) willing to dedicate a significant amount of time
  to Commissioning, Data Acquisition and Detector Noise characterization.

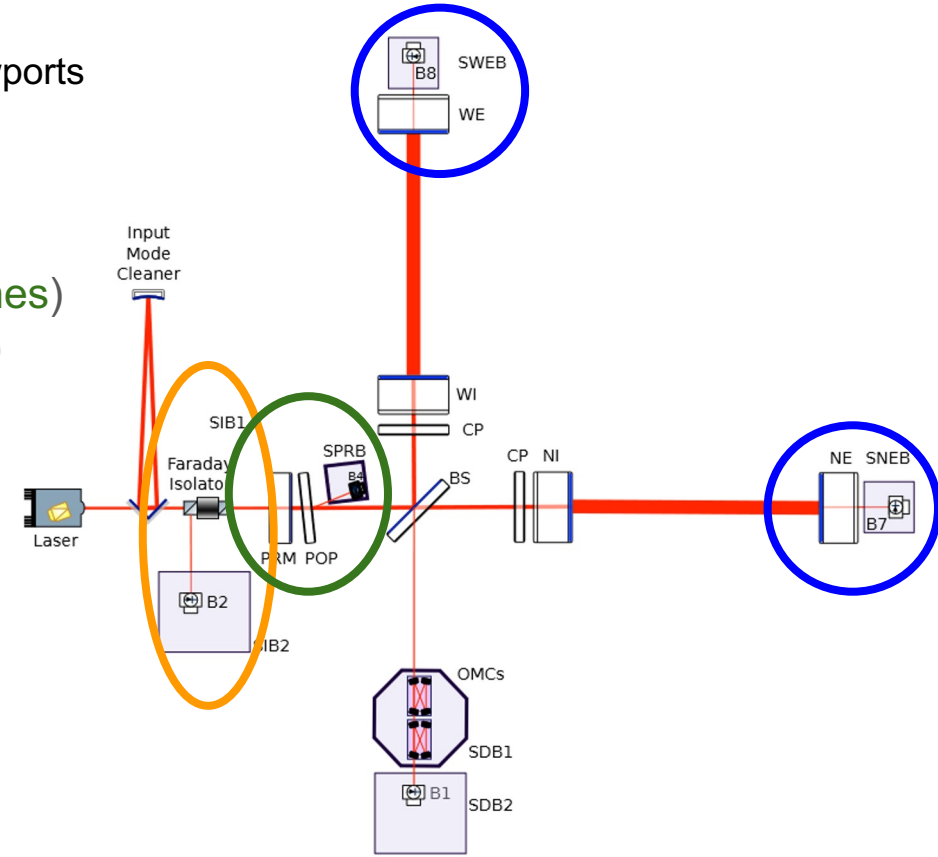
Contributions to Working Groups in Virgo:

- INSTR: Commissioning run O4 & Instrumentation: Noise Characterization & Modelling

- CBC: Data Analysis (Bayesian Inference & Population Analysis). Multimessenger.
- Bursts: Data Analysis (Waveforms & Conv. Neural Networks). CHE Detection pipeline.
- SGWB: Data Analysis (Backg. charac., search pipeline for anisotropies & polarization.)

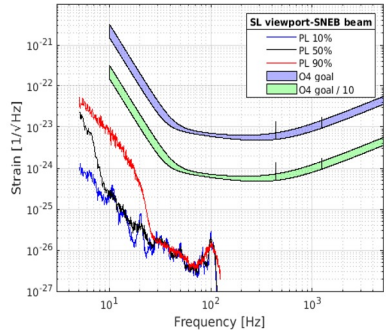
Virgo Commissioning - Technical Noise Investigation

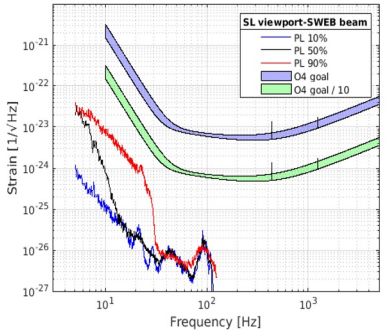
- Task: Investigation of Scattered light noise from viewports
- Members (PhD students):
  - Santiago Jaraba (End benches)
  - Gonzalo Morrás (Power Recycling benches)
  - Jose Francisco Nuño (Injection benches)
- Supervisor: Maria Concetta Tringali
  (with the help of Antonino Chiummo, Irene Fiori,
  Romain Gouaty & Michal Was)

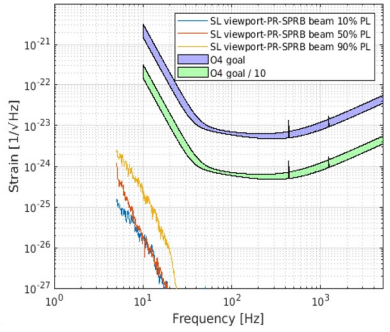


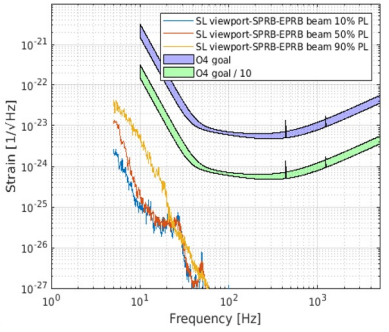
Virgo Commissioning - Technical Noise Investigation

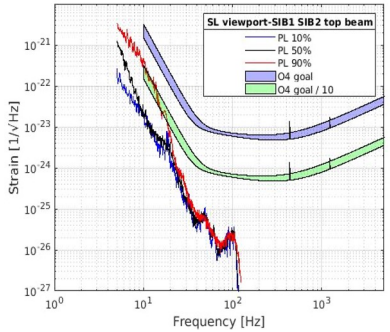
- We obtained noise projections from the different viewports.
- Noise from End and Power Recycling benches:
  - Preliminary projections are below O4 noise budget.
  - It has already been presented in Technical Noise meeting: VIR-0028A-22.
  - Scheduled tasks to perform noise injections **on-site** and validate noise projections.
- Noise from Injection benches:
  - Preliminary projections are above O4 noise budget. Investigations still ongoing.
  - **On-site** work scheduled.

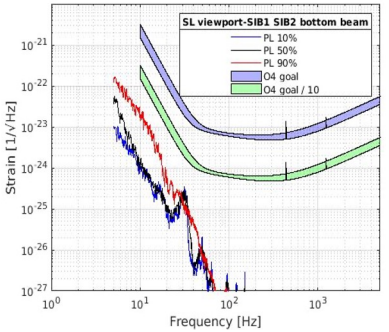






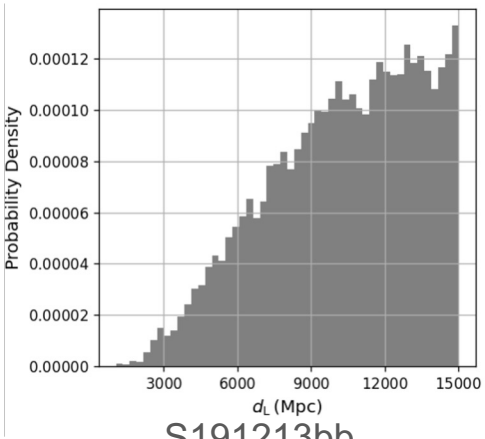




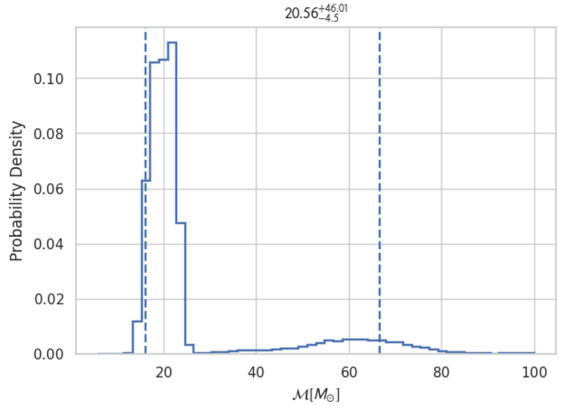


O3b Catalog PE

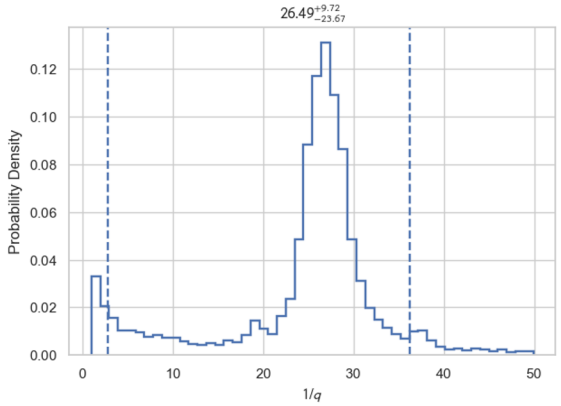
- Participants: Jose F. Nuño & Gonzalo Morrás
- As a part of the O3b Catalog LVK effort, we performed Preliminary PE o selected candidates. Namely:
  - cWB-only events as discussed in Appendix F of the Catalog Paper, in particular: S191213bb, S200218al, S200224o, S200326af
  - One of the bimodal events GW200322_091133
  - Extreme mass-ratio event ($q = 0.038^{+0.005}_{-0.004}$) GW191219_163120



S191213bb



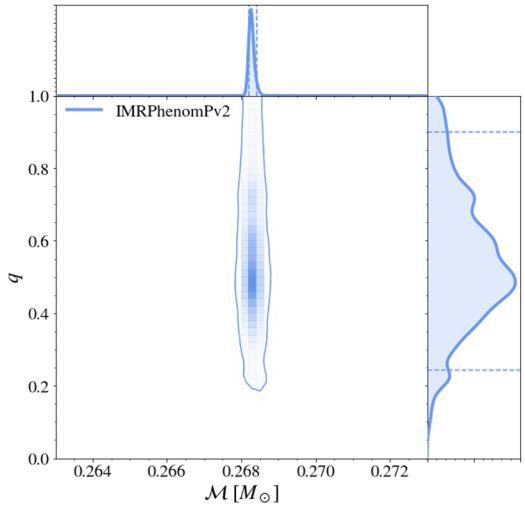
GW200322_091133

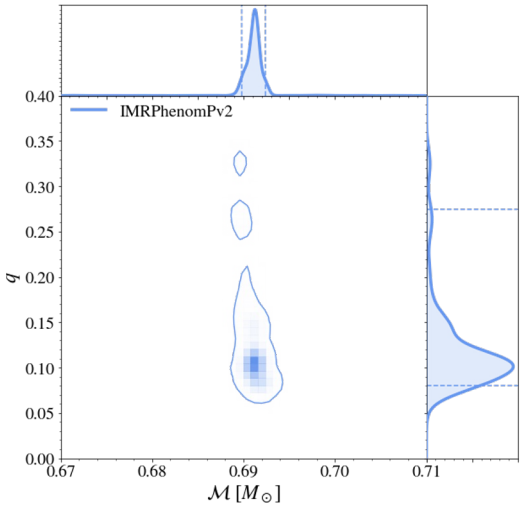


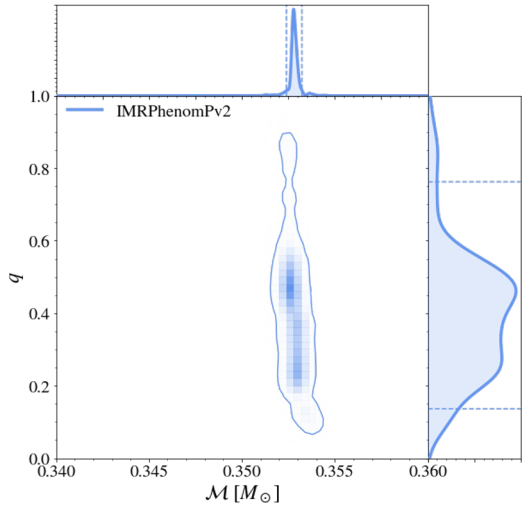
GW191219_163120

O3b SSM Candidates Follow Up

- Participants: Juan García-Bellido, Gonzalo Morrás, Jose F. Nuño & Ester Ruiz
- As a part of the O3b Subsolar Mass collaboration paper a follow up study including Parameter Estimation was performed on the most significant triggers and presented in the CBC call (LIGO-G2200095)







SSM-O3b LVK paper Editorial Team

SSMO3b paper (Participants: Ester Ruiz Morales & Juan Garcia-Bellido)

- Coordination of SMM O3b weekly sessions
- Review of different steps: Seaches, Efficiencies, VT, Rates, Bounds
- Comparison with previous searches in Chirp mass.
- Extended mass models: Interpretation of event rates and bounds in (m_1, m_2) plane

Plans for SSM-O4

1.- For SSM searches (Participants: JGB, ERM, GM, JFN):

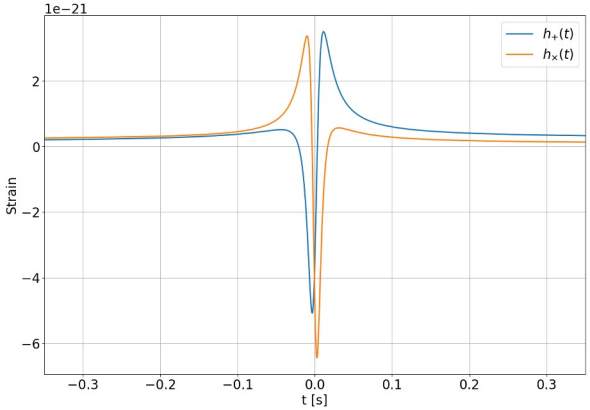
- Understand the properties of noise and its role in SSM-O4 triggers.
- Compute reliable FAR estimates of an event in the different pipelines.
- Develop detection statistics techniques specific for SSM-O4 binaries.

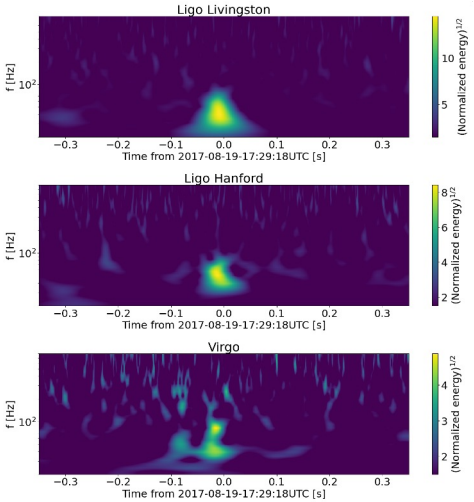
2.- Follow up with PE only the most relevant SSM-O4 event candidates

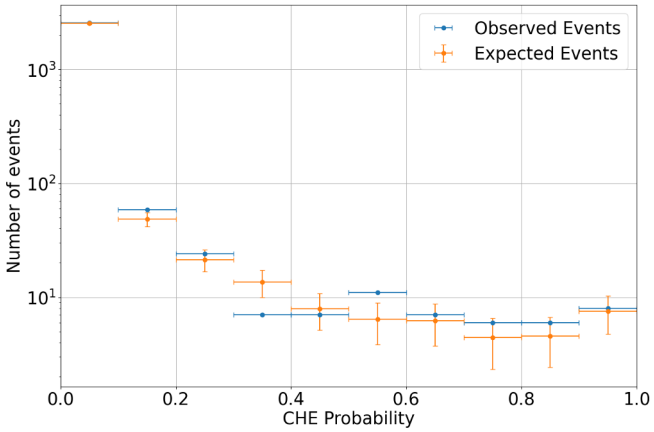
3.- PBH's: Propose population studies based on thermal history model

Search for Close Hyperbolic Encounters (CHEs)

- Participants: Gonzalo Morrás, Juan García-Bellido & Savvas Nesseris
- In arXiv:2110.08000 we developed a PN waveform for CHEs and used it to look for them in O2 data using an in-house Burst+CNN pipeline.
- Future plans: to make the waveform available to LVK with the new waveform interface & participate in the O4 eBBH+CHE collaboration search.





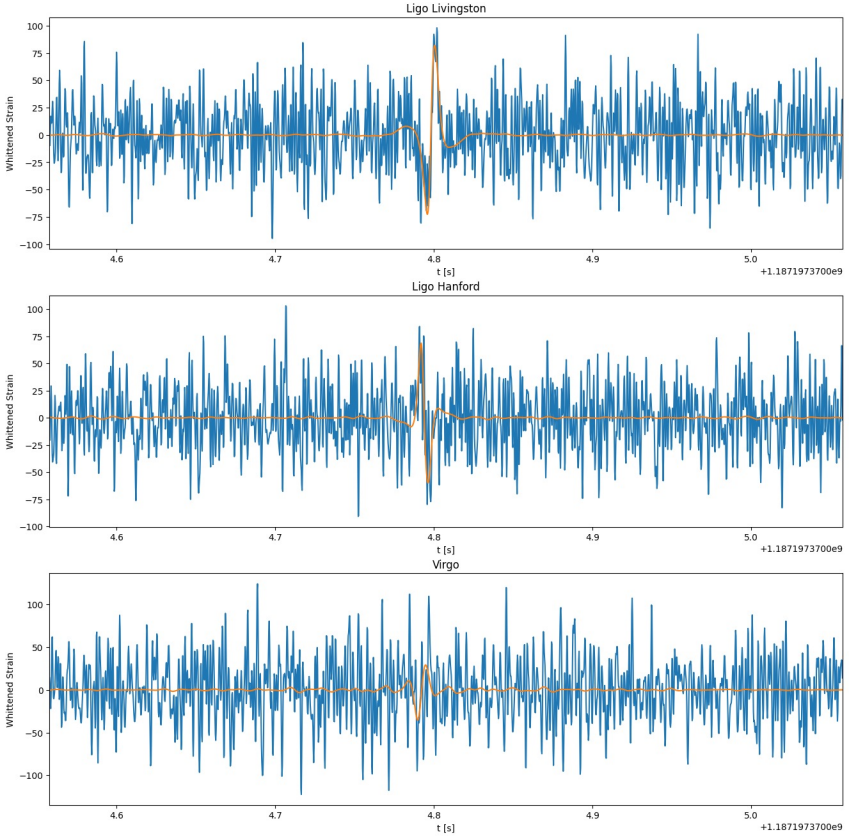


Examples CHE injected events (small & large SNR)

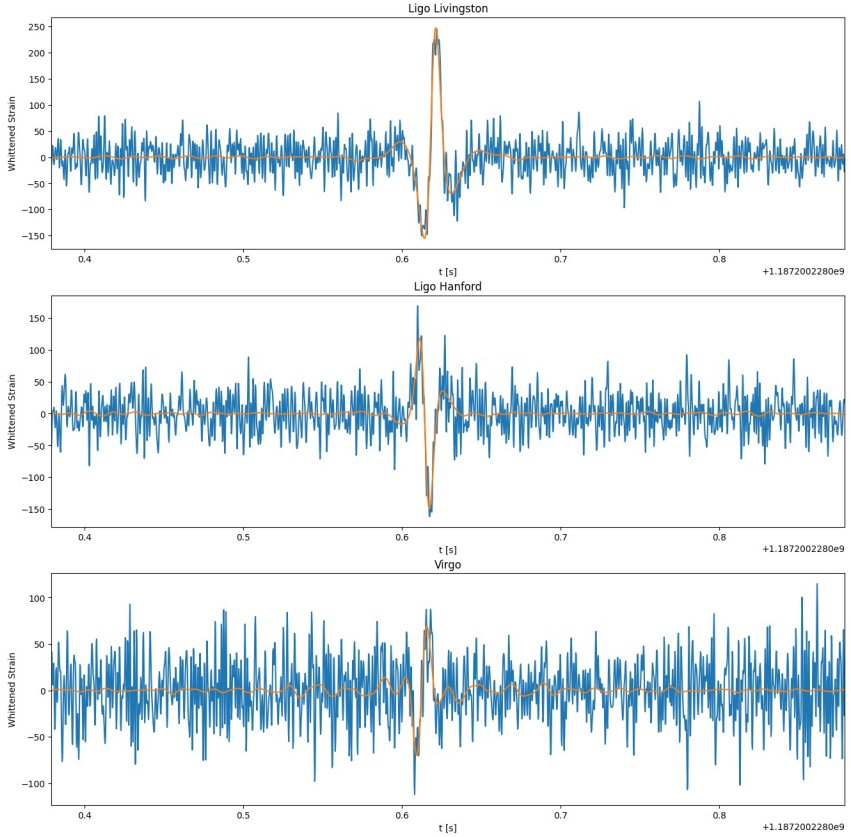
PPN-1.5 waveforms

De Vittori et al. (2014)

SNR = 5.0

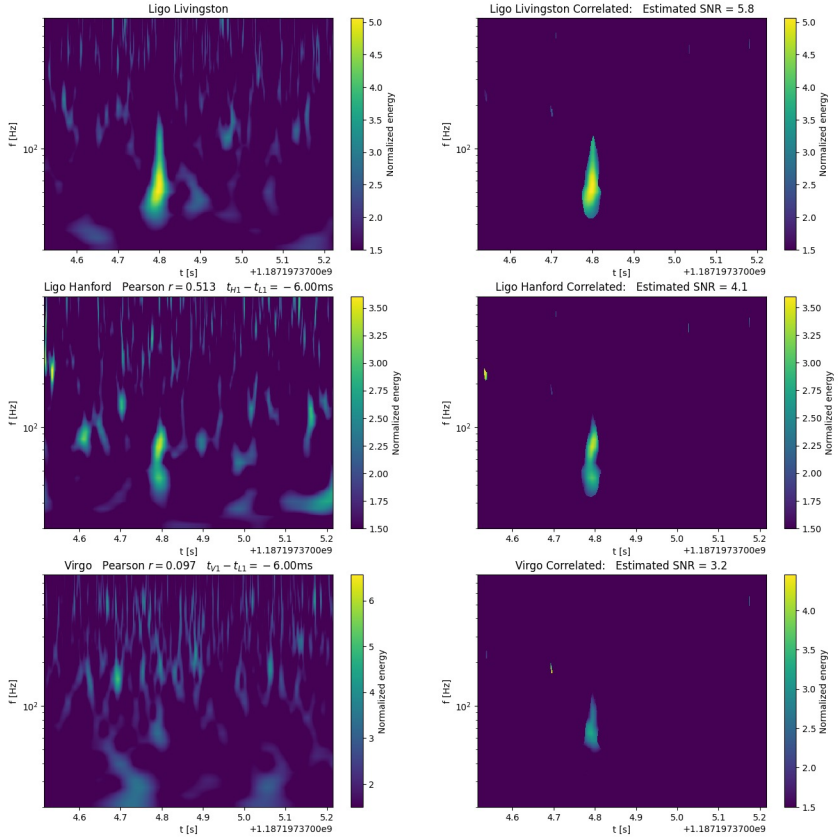


SNR = 16.0

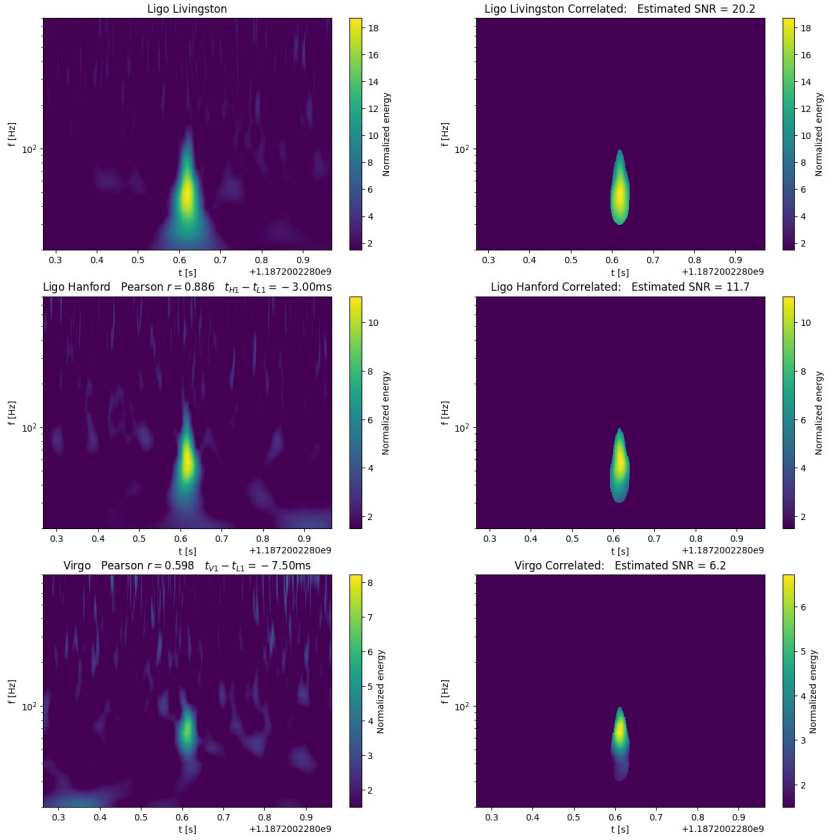


Examples CHE injected events (small & large SNR)

Injected Event 2/10: $m_1 = 4.370 M_\odot$ $m_2 = 0.392 M_\odot$ $j_0 = 0.734$ $b_0 = 100GM$ $R = 1\text{Mpc}$
$SNR_{L1} = 3.9$ $SNR_{H1} = 2.7$ $SNR_{V1} = 1.6$ $SNR_{tot} = 5.0$



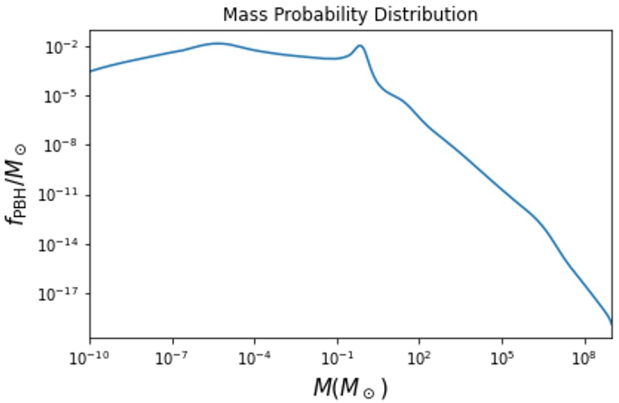
Injected Event 8/10: $m_1 = 5.898 M_\odot$ $m_2 = 2.063 M_\odot$ $j_0 = 0.780$ $b_0 = 100GM$ $R = 1\text{Mpc}$
$SNR_{L1} = 13.4$ $SNR_{H1} = 7.6$ $SNR_{V1} = 4.4$ $SNR_{tot} = 16.0$

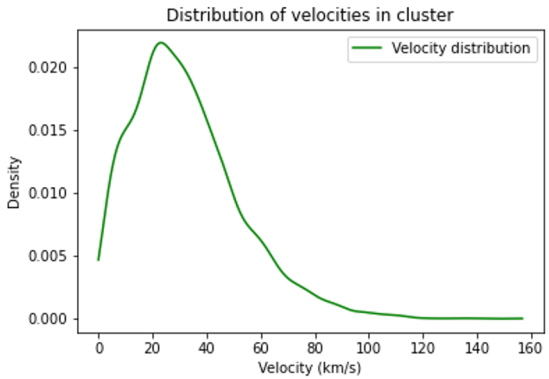


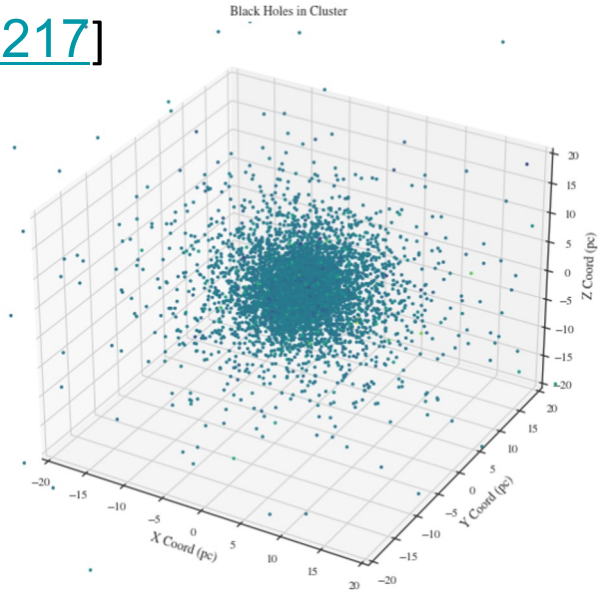
Numerical BH Cluster Simulation

(Jose Francisco Nuño Siles)

- Understand implications of PBHs conforming the totality or a fraction of the DM inside dense clusters in the outskirts of galaxies
- Observables: BBH Merger rate, CHE encounter rate, distribution of binary population parameters…
- Nbody6++GPU as integrator to be used and initial conditions based on a phenomenological thermal history model [1906.08217]



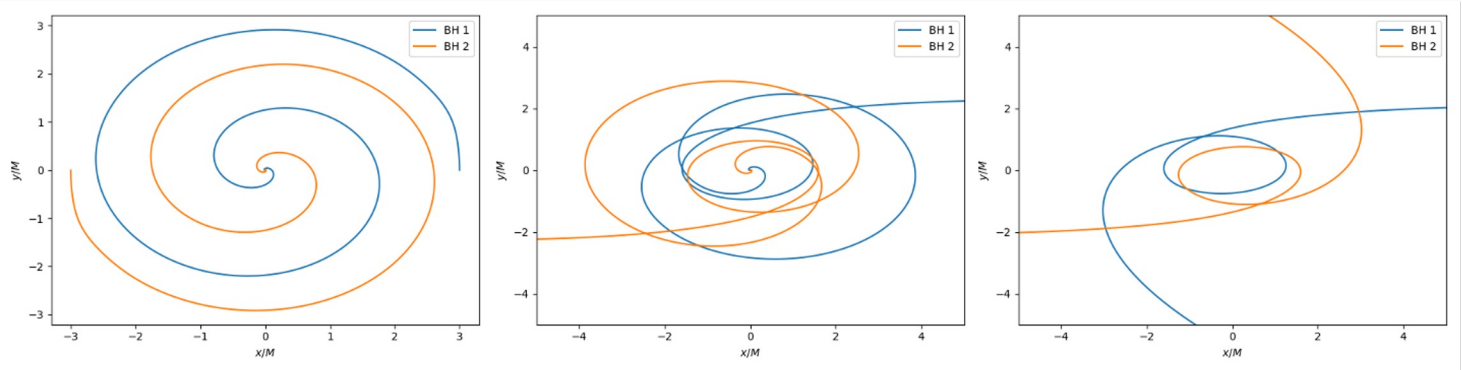


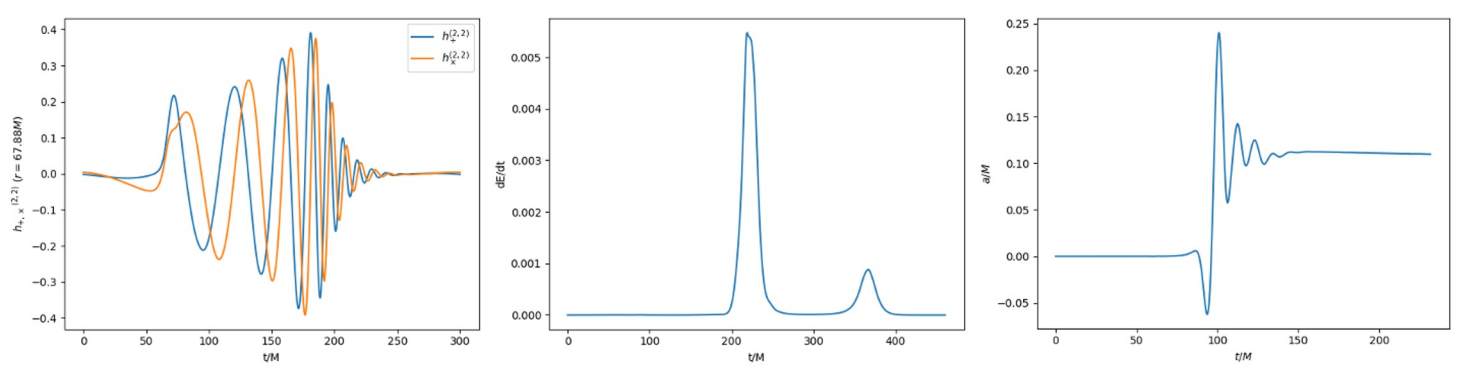


Numerical Relativity with Einstein Toolkit

(Santiago Jaraba)

- Standard merger
- "Double" event
- Hyperbolic encounter





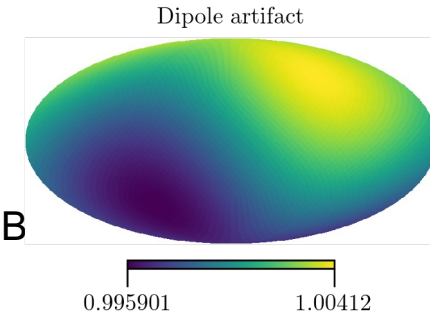
GW strain

Radiated power

Induced spin

Santiago Jaraba: work within stochastic group

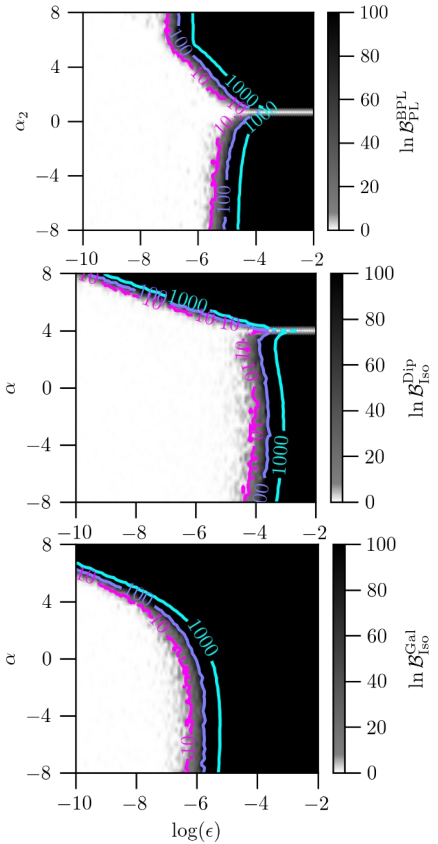
- Participation in Plm-targeted anisotropic PE formalism project, led by Leo Tsukada.
- Git repository: git.ligo.org/leo.tsukada/sgwb_sphpe
- Main contributions (details in slides with project updates):
  - Idea and implementation of formalism to speed up the code in a factor ~10. A standard 1-hour run became a few minutes long.
    - Based on precomputing terms in advance to avoid these computations in each likelihood evaluation.
    - Great impact for everyone's runs in the project!
  - Derivation and implementation of dipole artifact due to Doppler shift on an isotropic SGWB, analogous to the one in the CMB



Santiago Jaraba: work within stochastic group

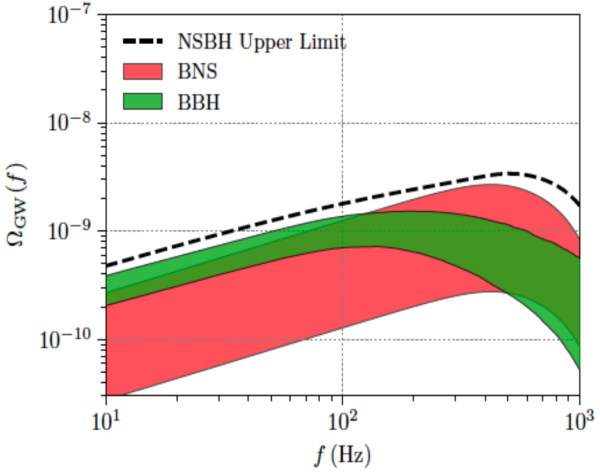
- Model selection analyses (is the code able to identify the model of the signal injected in the data?):
  - Broken power law vs power law spectrum.
  - Dipole artifact anisotropies vs isotropic.
  - Galactic plane anisotropies vs isotropic.
- More than 9000 PE runs per heatmap (plot of Bayes factor vs overall amplitude ε and power-law index α of injected signal).
- Results are ready, paper in preparation.

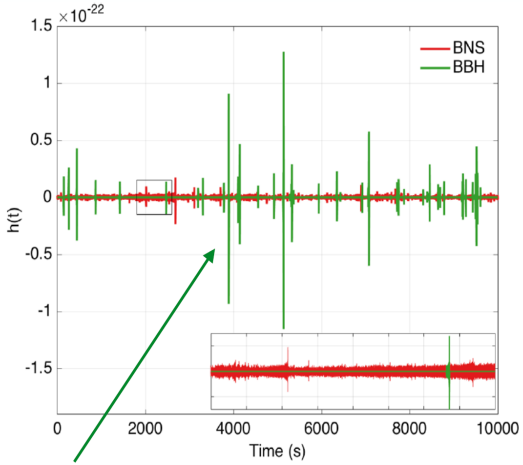
- Plans to contribute further within the recently formed Anisotropic stochastic subgroup.
- Ongoing projects with Juan, Sachiko and Matteo on SGWB.



Detection method for a popcorn GW background

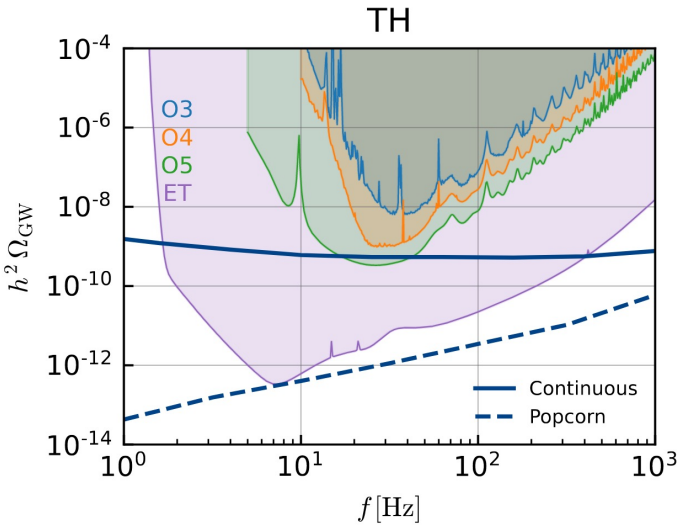
BBH events form the so-called popcorn GW background.





BBH events do not overlap one anothe

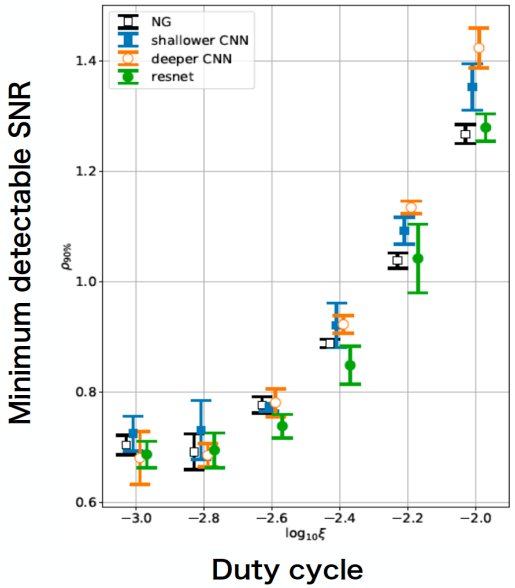
(Sachiko Kuroyanagi,
Juan Garcia-Bellido
& Matteo Braglia)



Detection methods considered in the Stochastic group

1. CCI (Cross-Correlation search for Intermittent backgrounds)
2. TBS (The Bayesian Search)
3. Machine Learning

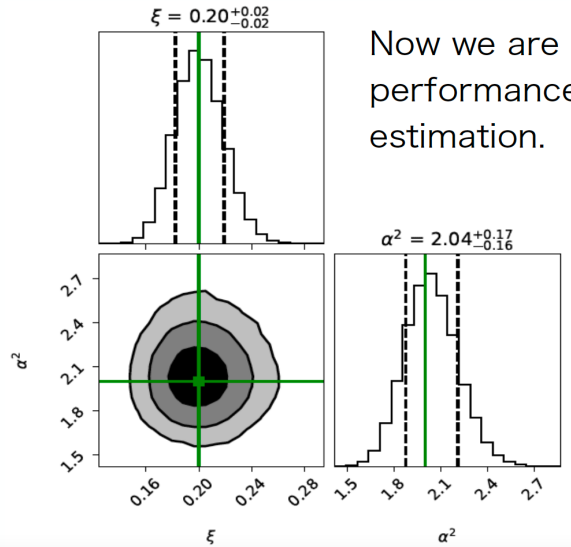
Machine Learning for a popcorn GW background



We apply convolutional neural network (CNN) to analyze a popcorn background.

Three different CNN algorithms are tested for toy-model data. The Resnet method performs as good as in method 1. We also found that it remarkably reduces computation time.

Method	Speed-up factor
Maximum likelihood	1
Shallower CNN	1.6 x 10^5
Deeper CNN	4.8 x 10^4
Residual network	5.9 x 10^4



Now we are also testing the performance of parameter estimation.

(Sachiko Kuroyanagi & Matteo Braglia)

IFT Virgo Group

Summary:

- 2.1 FTE Senior (4 people) Theoretical Cosmologists; expertise in large Collaborations
- 4 FTE Junior (1 Postdoc + 3 PhD) Commissioning & Detector Noise characterization.

Synergies with other Spanish Groups in Virgo Spain (CIEMAT, Valencia, IFAE, ICCUB).

Synergies with other Groups in Virgo (Brussels, NIKHEF, Lyon).

Participation in both LSS & GW Collaborations provides Multimessenger lever arm.

Members of IFT Center of Excellence with many connections worldwide.