Université
Paris Cité

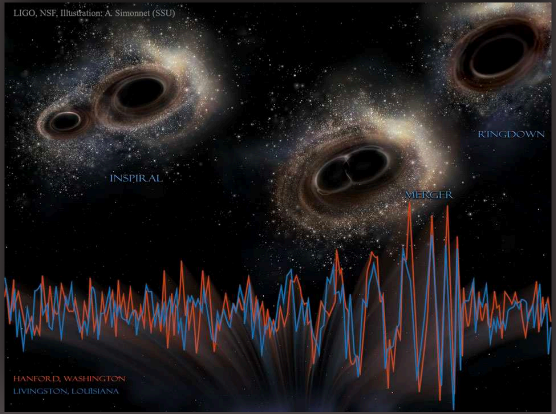
The Gravitation team at APC

Quentin Baghi

Atelier API "Ondes gravitationnelles et objets compacts"
October 10th, 2024

Layout

1. Overview of the group
2. Highlights on ground-based GW astronomy
3. Highlights on space-based GW astronomy
4. Highlights on pulsar timing arrays



1. Overview of the group

Permanents

1. BABAK S. (DR2) LISA, VIRGO, PTA
2. BAGHI Q. (MCF) LISA
3. BARSUGLIA M. (DR1) VIRGO, ET
4. CHASSANDE-MOTTIN E. (DR1) VIRGO, ET
5. PLAGNOL E. (Emeritus) LISA
6. PORTER E. (DR2) ET, VIRGO
7. HALLOIN H. (MCF) LISA
8. CAPOCASA E. (MCF) VIRGO, ET

- PETITEAU A. (CEA) 20%
- STEER D. (Prof) Theory
- CHATY S. (Prof) HEA

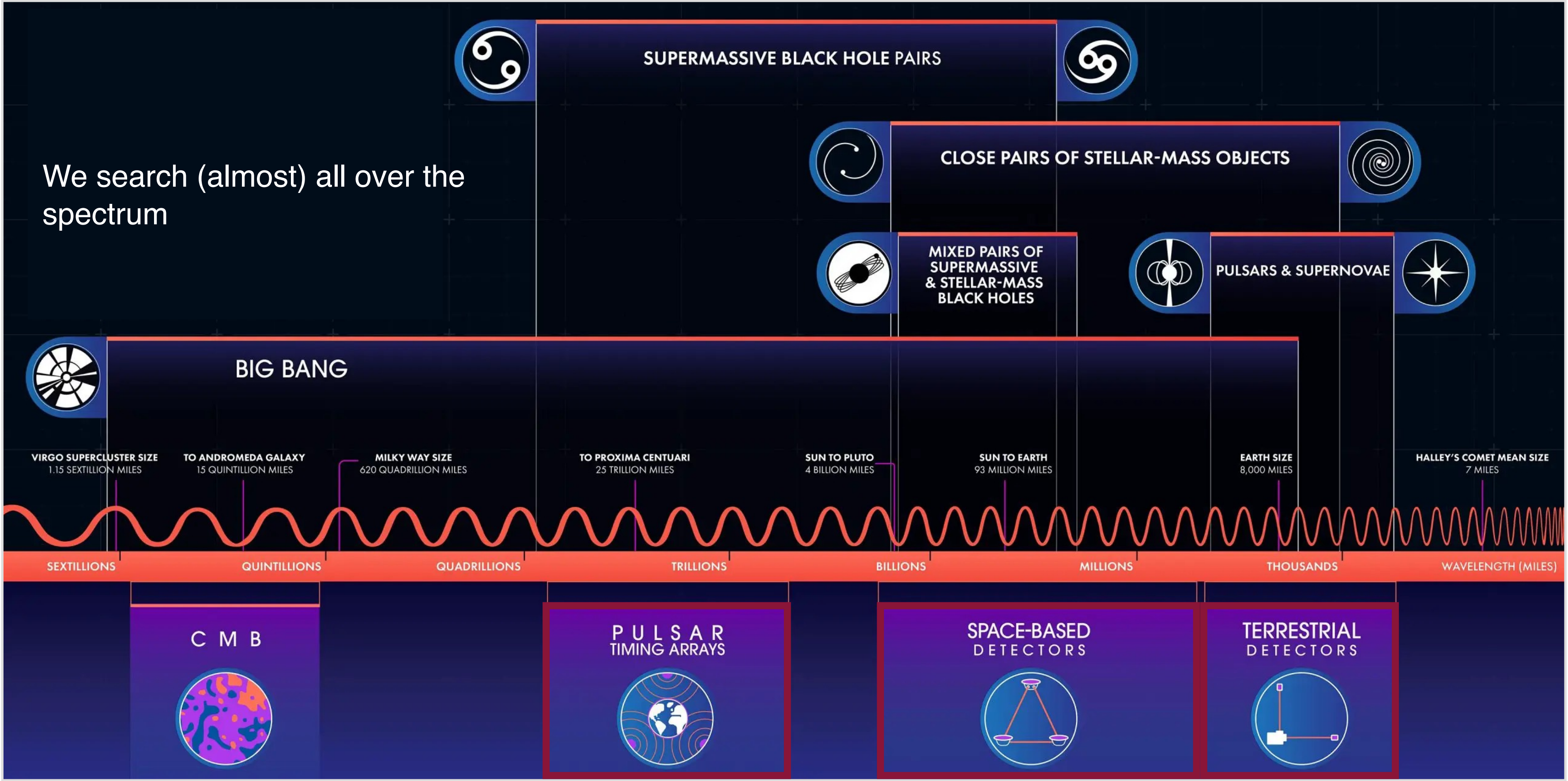
Postdocs

1. FRANCHINI N. VIRGO, LISA
2. MANGIAGLI A. LISA
3. VIDAL L. Moon
4. ZHAO Yu. VIRGO, ET
5. DIAZ MENDES Wanda (sonification)

PhD students

1. QUELQUEJAY H. (PTA, LISA)
2. DENG S. (LISA)
3. HARER Sh. (LISA)
4. PERRET J. (VIRGO, ET)
5. DING J. (VIRGO, ET)
6. VINCENT M. (LISA)

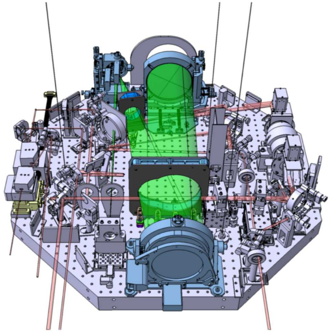
1. Overview of the group



2. Highlight of ground-based GW astronomy

Instrumental development for Virgo

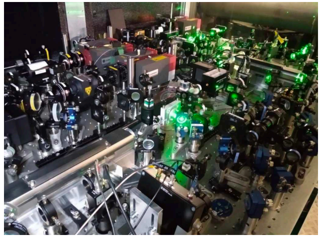
- Design, construction, testing, and integration of "mode-matching" telescopes for Advanced Virgo+
- Contribution to the commissioning (squeezing, controls and optical characterization) (Barsuglia, Capocasa, Daumas, Ding, Zhao)




Buy+ CQG 2017

R&D for ground-based detectors

- First demonstration of “frequency dependent squeezing” in GW detectors in the ~100 Hz region.
- Contribution to implementation to Virgo
  (Barsuglia, Capocasa, Ding, Zhao)



Zhao+ PRL 2020

2. Highlight of ground-based GW astronomy

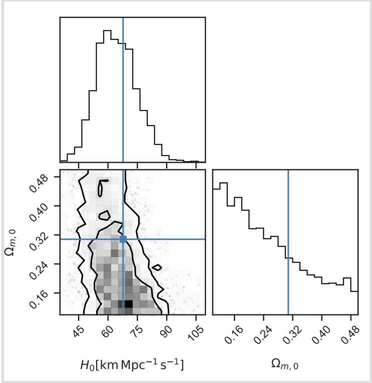
Interpretation of GW observations

(Mastrogiovani, Chassande-Mottin, Steer, Leide, Haegel, Barsuglia)

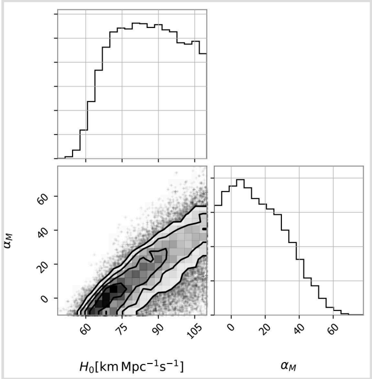
- Inference of cosmological parameters using GW source population properties (“IcaroGW”)
  → Joint inference of GW population and cosmological parameters

- Inference of cosmological parameters in modified theories of gravity
  → Joint inference of non-GR parameters responsible for dispersion and cosmological parameters

S. Mastrogiovanni+ PRD 2020



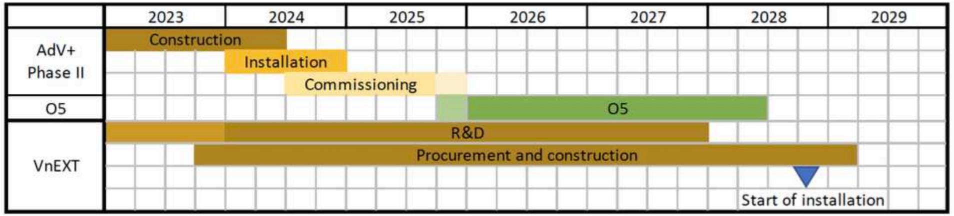
S. Mastrogiovanni+ PRD 2021



2. Highlight of ground-based GW astronomy

Contribution to Virgo_nEXT

Participation to the Virgo concept study and R&D plan:
Additional factor of 2 in sensitivity wrt Advanced Virgo+.
(Barsuglia, Capocasa)



Virgo nEXT, A Concept Study, The VIRGO Collaboration, 2022

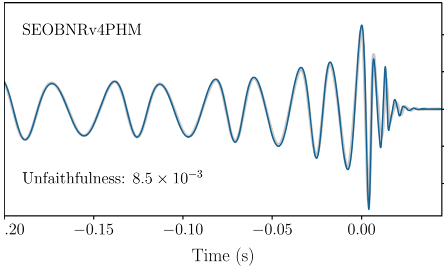
Contribution to Einstein Telescope

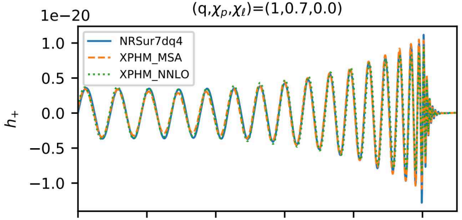
Squeezing, R&D on squeezing techniques for a detuned (ET-LF) interferometer (ANR “Quantum-FRESCO project”)
(Barsuglia, Capocasa, Ding, Zhao)

Waveform modelling

- Modelling GW signal from merging black hole binaries
- Used in O3 parameters inference
  (S. Marsat, C. Garcia-Quiros, L. Haegel, C. Cano, S. Babak)

Ossokine+ PRD2020
Pratten+ PRD 2021



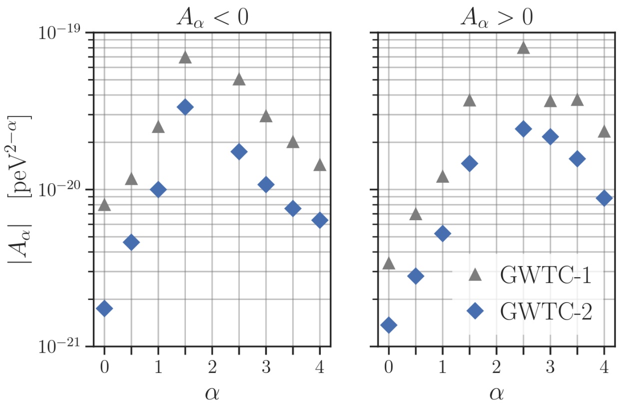


2. Highlight of ground-based GW astronomy

Data analysis and signal reconstruction

- Bayesian parameter inference, follow up of special events (L. Haegel, E. Porter, S. Babak, M. Arene, J. Perret)
- Cosmology using standard sirens (K. Leyde, E. Chassande-Mottin, L. Haegel)
- Machine learning techniques (L. Haegel, C. Cano, E. Chassande-Mottin, J.Perret)
    - Waveform generation, glitch/signal classification
- Testing GR (L. Haegel, S. Babak, N. Franchini)
    - Dispersion of GWs in massive gravity and Lorentz invariance violation
    - “No-hair” theorem with ringdown

L. Haegel 2023



Open data science

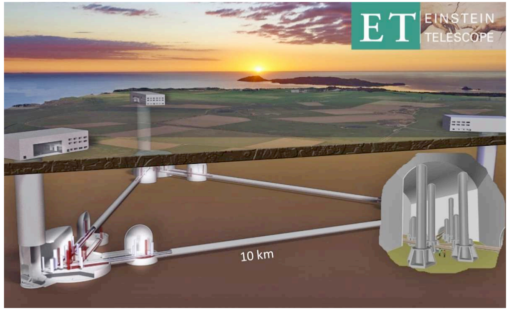
Preparation, validation and release LVC data (E. Chassande-Mottin, A. Trovato)

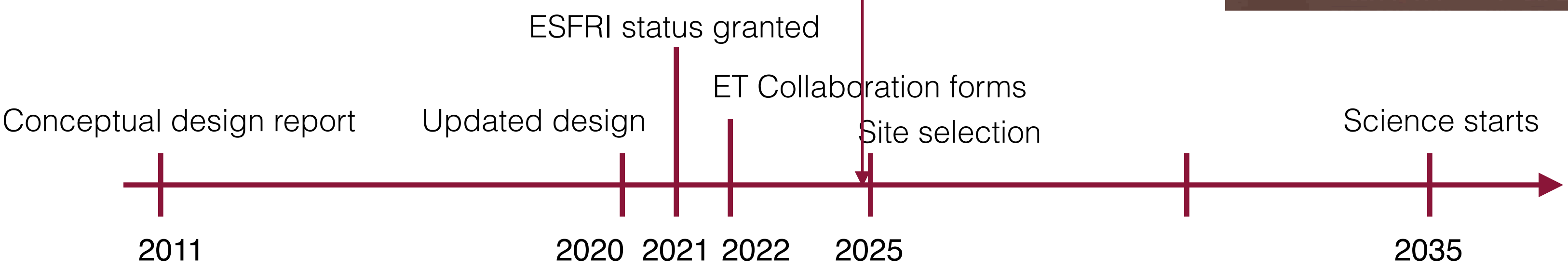
Gravitational Wave Open Science Center

2. Highlight of ground-based GW astronomy

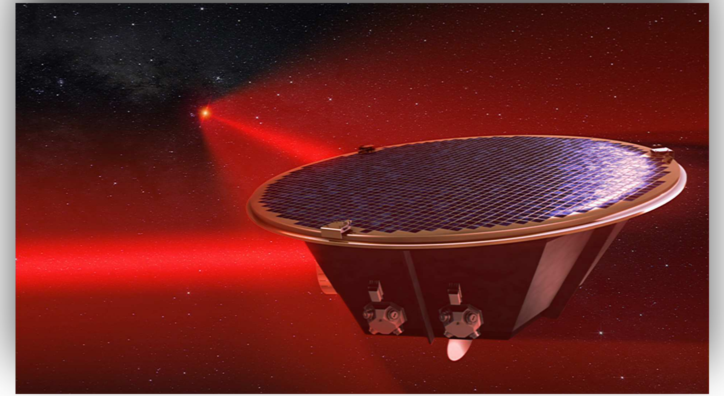
Involvement in Einstein Telescope

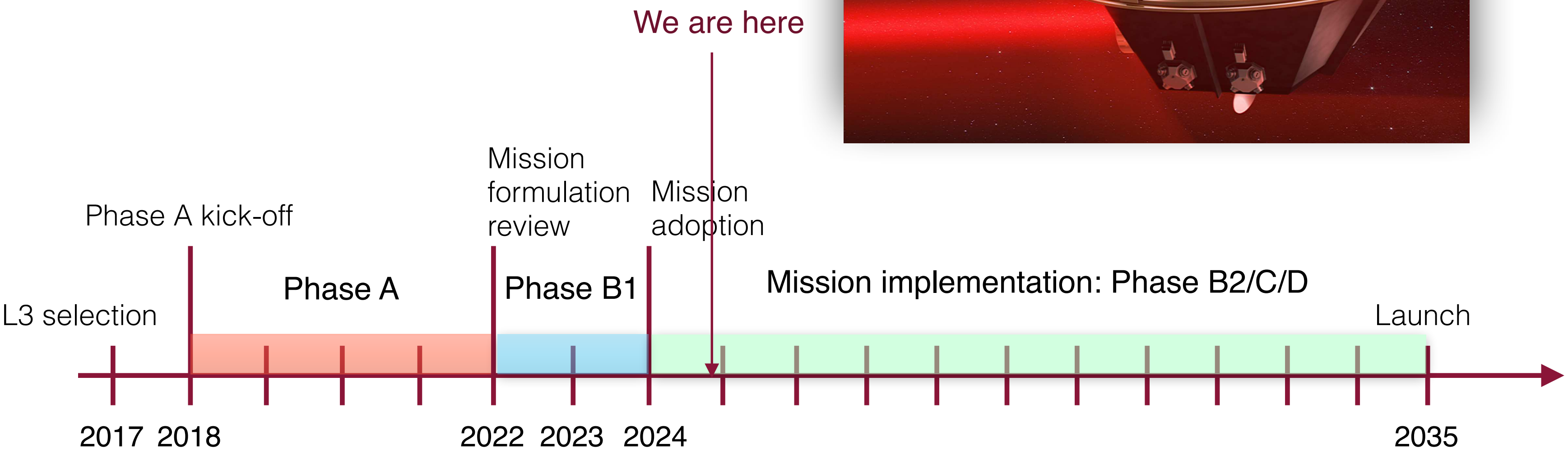
- M. Barsuglia contributed in structuring the French community. Is also responsible for the Virgo/ET master project at IN2P3
- E. Porter is co-chair of ET Observational Board
- Contribution to the project office (risks and layout)
- Squeezing, quantum noise reduction
- Cosmology (standard sirens, dark sector, modified gravity theories)
- Inference of properties, formation and evolution of population of GW sources
- Multi-messenger astrophysics





3. Highlights of space-based GW astronomy: LISA





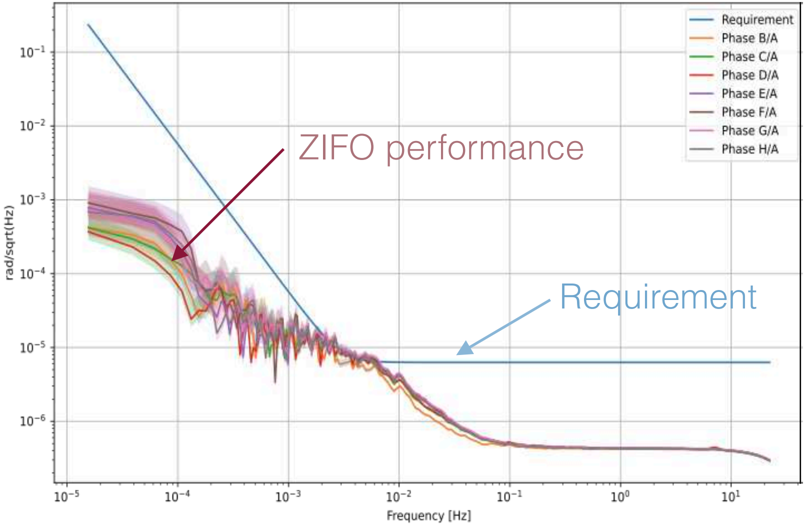
3. Highlights of space-based GW astronomy: LISA

Assembly, Integration, Verification and Testing (AIVT)

Prototyping AIVT optical test benches and designing the optical ground support equipments
(H. Halloin, T. Zerguerras, J. Martino, St. Dheilly, P. Prat, G. Monier, F. Cortavarria, W. Bertoli, C. Juffroy, M. Laporte, J. Lesrel, F. Cortavarria, M. Vincent, Sh. Harrer)

→ Metallic and Zerodur Interferometers (MIFO/ZIFO)

→ Prototyping optical benches and methods for LISA instrument integration



3. Highlights of space-based GW astronomy: LISA

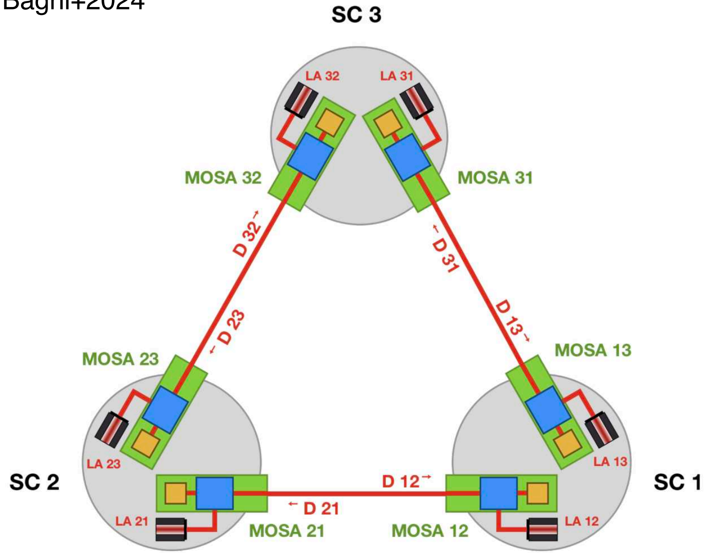
Noise reduction: time delay interferometry (TDI)

Bayle+ PRD2019, Nam+ PRD2022, Vallisneri+ PRD2020, Baghi+2024

- Laser frequency fluctuations form the dominant noise in LISA (due to unequal arms): requires time-delay interferometry = post-processing techniques to reduce it by many orders of magnitude

- We are leading in study/demonstration of TDI using simulated data and hardware (LISA on Table project). (J-B Bayle, Dam Nam, A. Petiteau, J. Martino, H. Halloin, L. Vidal, Sh. Harer, M Lilley)

- Alternative approaches to noise reduction: “TDI-infinity” or principal component interferometry (PCI) considering the matrices relating laser noises and measurements (Baghi, Babak, Petiteau)



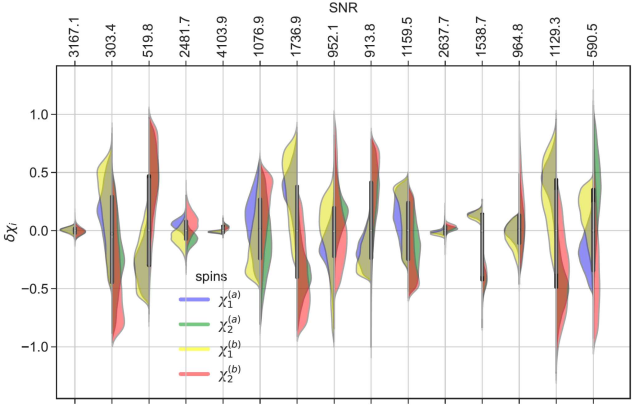
3. Highlights of space-based GW astronomy: LISA

Development of the distributed data processing center (DDPC)

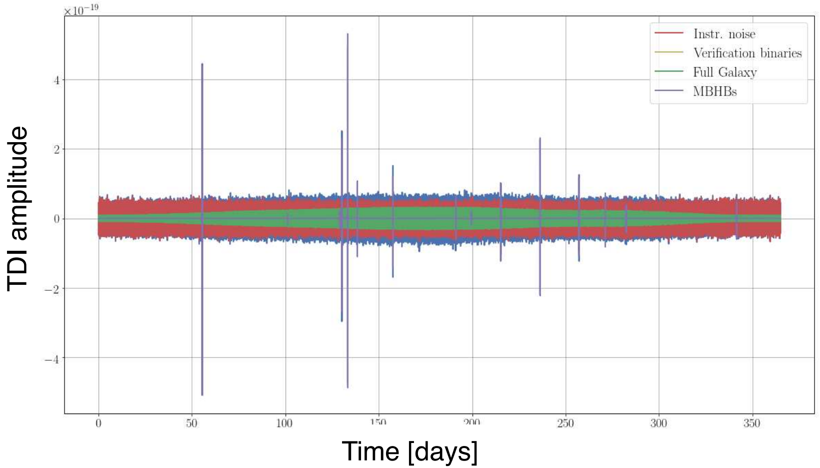
In particular, the global fit

- Millions of Galactic binaries, tens to hundreds merging MBHBs, EMRIs, SBBH, stochastic signals: signal dominated data
- Designed iterative data analysis algorithm, demonstrated its performance on simulated data

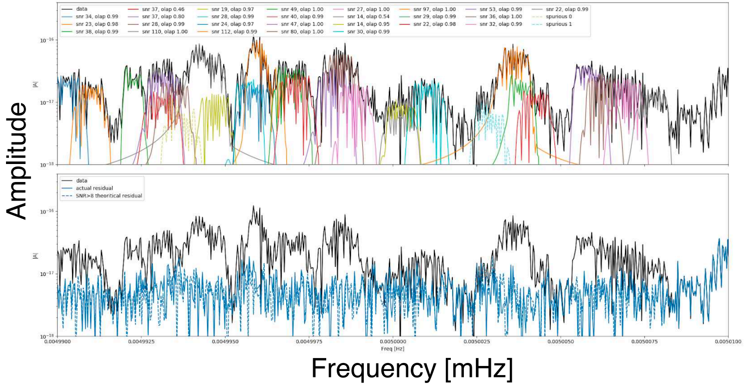
MBHB inference



Blended mock data

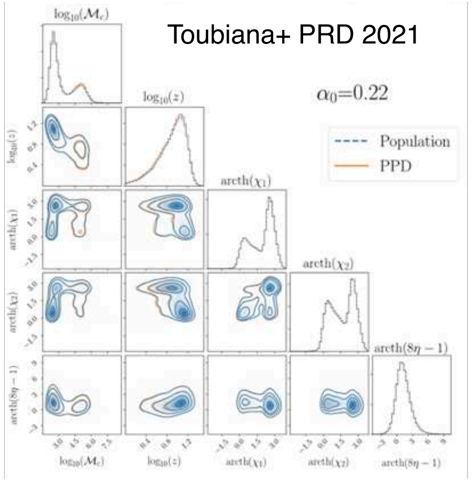


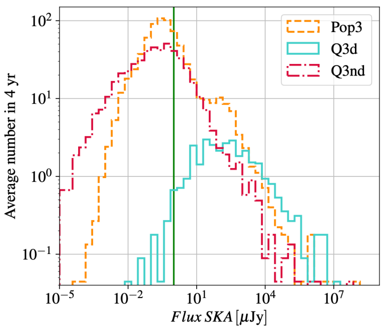
Galactic binaries inference



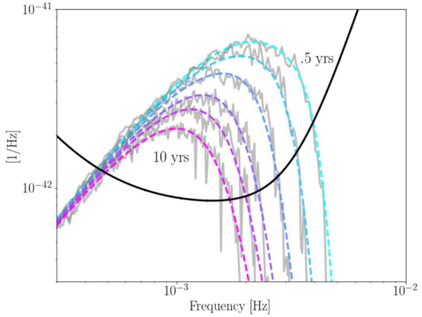
3. Highlights of space-based GW astronomy: LISA

- Inferring astrophysical models of formation and evolution of the population of GW sources (Toubiana, Babak, Mangiagli)
- Cosmology at high redshift, multi-messenger with MBHBs (Mangiagli, Marsat)
- Modelling stochastic GW signal from unresolved astrophysical population (Karnesis, Babak, Petiteau, Baghi)
- Multiband observation of stellar-mass black hole binaries (Toubiana, Marsat, Babak, Caprini)





Mangiagli+ PRD2022



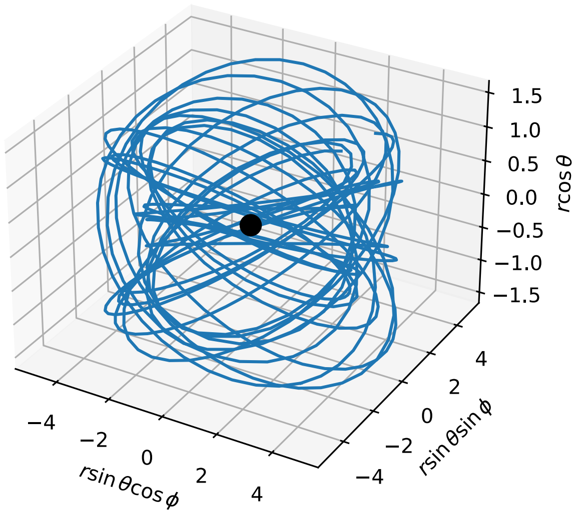
Karnesis+ PRD2021

3. Highlights of space-based GW astronomy: LISA

Extreme mass ratio inspirals detection and characterisation
(Babak, Korsakova, Baghi)

- Huge challenges: complex waveforms with many harmonics
- Aims at developing efficient detection methods
- Based on compact representations using machine learning
- Detecting environmental effects or non-GR effects

$M = 1e6M_\odot$, $\mu = 10M_\odot$, $a = 0.9$, $p_0 = 4.0$, $e_0 = 0.2$, $\iota_0 = 0.3$



4. Highlights of pulsar timing arrays

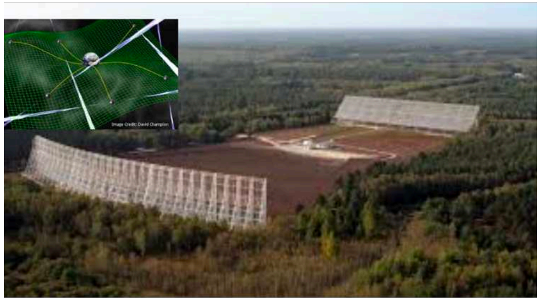
- The main idea behind pulsar timing array (PTA) is to use ultra-stable millisecond pulsars as beacons for detecting GW in the nano-Hz range 10^{-9} - 10^{-7} Hz

- Superposition of multiple (overlapping) signals:
  - Stochastic (possibly) anysotropic signal
  - Individually resolvable (possibly) multiple signals
  - Orbits could be eccentric

- Cosmic strings (collaboration with Theory group)

(M. Falxa, H. Quelquejay-Leclere, A. Chalumeau, S. Babak, A. Petiteau)

PTA-France



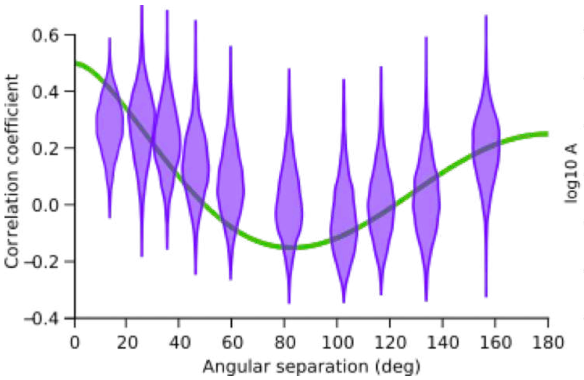
4. Highlights of pulsar timing arrays

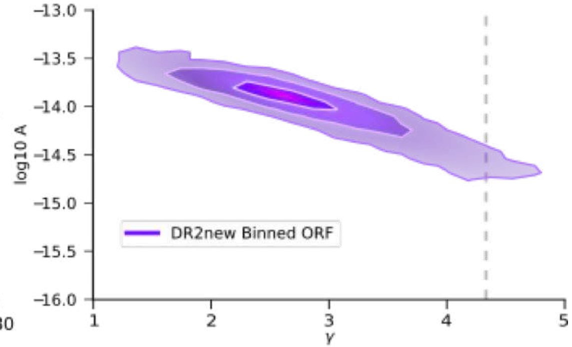
$$S_{\alpha\beta}^{SGWB} = \Gamma_{\alpha\beta}^{H-D} A_{GW}^{2} f^{-\gamma}$$

First evidence for GW signal in nanoHertz band

- Result of EPTA are consistent with NanoGrav
- Statistical significance ~3sigma
- Nature of the signal is yet to be determined
  - Could be stochastic GW
  - An individual binary is not excluded

Statistic	DR2full	DR2new	DRnew+
$\mathcal{B}^{HD}_{CURN}$	4	60 33(+Ephem)	65 43 (+Ephem)





Conclusions

—Virgo:

- We are involved in the interpretation of GW observations (O3, O4, O5)
- Participation to comissionning + Virgo_nEXT

— ET:

- Growing contribution (queezing + optical design)
- Mock data challenges

—LISA:

- Beam simulator development
- Building the global fit pipeline + new data analysis methods

—PTA:

- Towards the improvement of the GW detection : combining datasets
- Interpretation of the GW signal