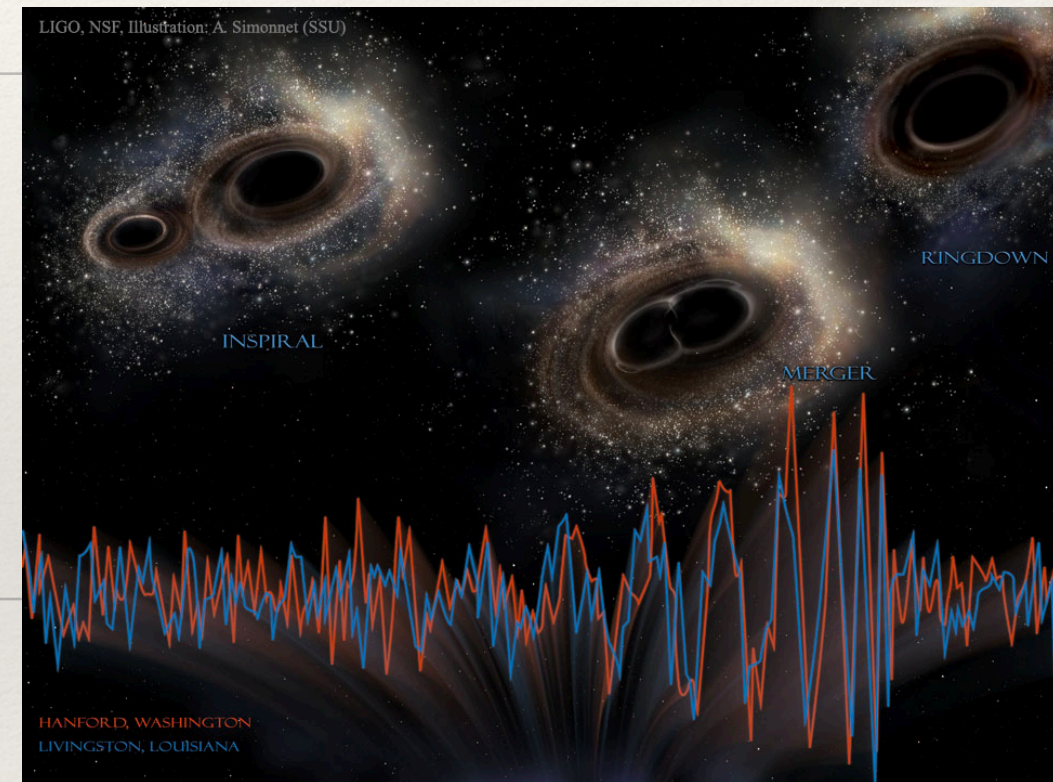




# Gravitation group @APC

Conseil Scientifique APC

Stas Babak



March 2020



# Gravitation group

Permanent	Position	Project
BABAK Stanislav	DR2	LISA, VIRGO, PTA
BARSUGLIA Matteo	DR2	VIRGO, ET
CHASSANDE-MOTTIN Eric	DR2	VIRGO
PLAGNOL Eric	Emeritus	LISA
PORTER Edward	DR2	VIRGO, ET
HALLOIN Hubert	MCF	LISA
PETITEAU Antoine	MCF	LISA, PTA
CAPRINI Chiara	CR	Theory, LISA
STEER Daniele	PR	Theory, VIRGO

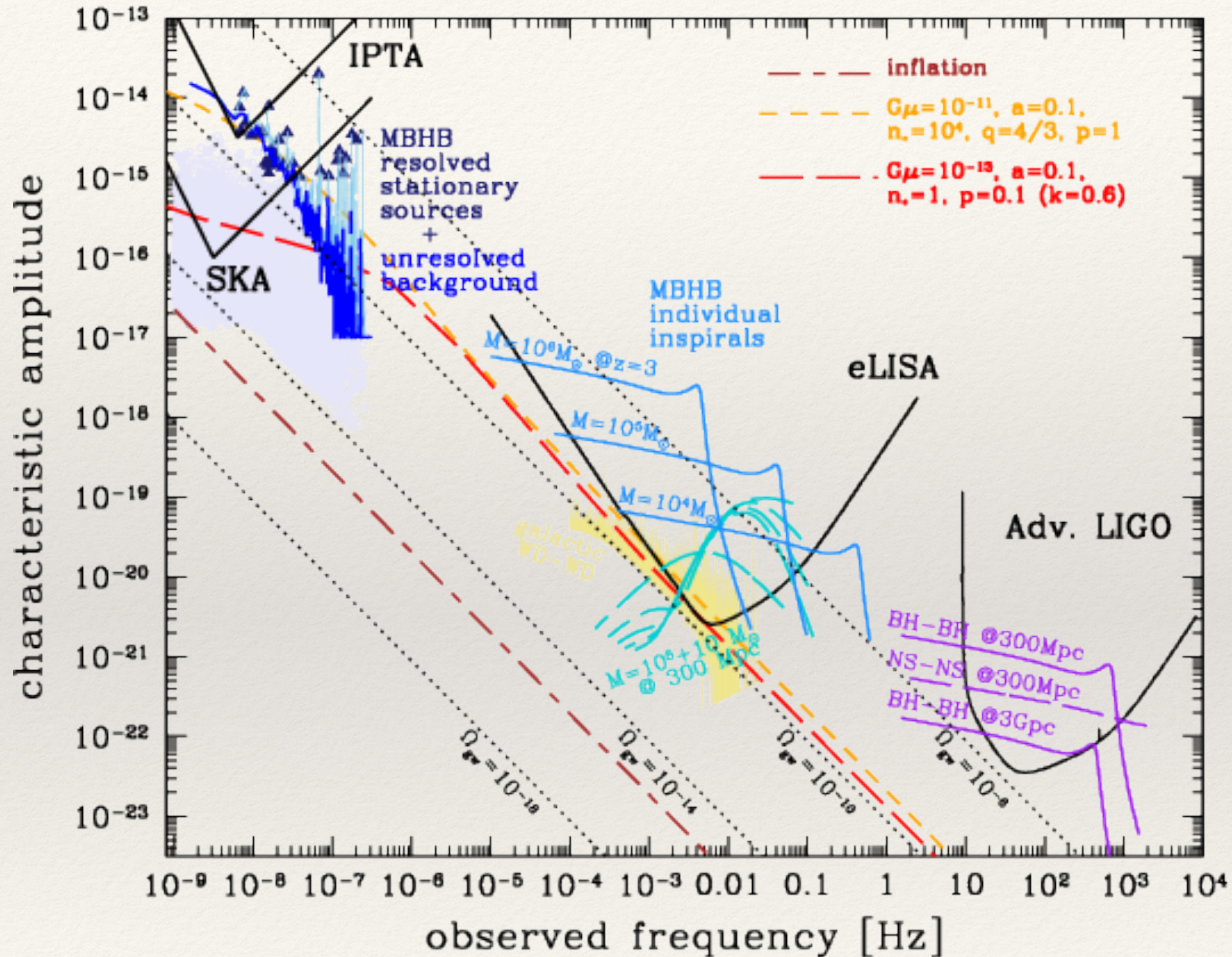
Post docs	Duration	Project
BAIRD Jonathon	2019 / 2020	VIRGO
HAEGEL Leila	2020	VIRGO
INCHAUSPE Henri	2020 / 2021	LISA
FORTIN Francis	2020	(ATER)
KARNESIS Nikos	2018 / 2020	LISA
MARSAT Sylvain	2018 / 2020	LISA, VIRGO
TROVATO Agata	2018 / 2020	VIRGO
MASTROGIOVANNI Simone	2019 / 2020	VIRGO

PhD	Start	Project
ARENE Marc	2017	VIRGO
CHALUMEAU Aurelien	2018	PTA
DAM Quang Nam	2019	LISA
FALXA Mikel	2019	PTA, LISA
NGUYEN Catherine	2018	VIRGO+
TOUBIANA Alexandre	2018	LISA
VIDAL Leon	2019	LISA





# Gravitational Waves across frequency



[Credits A. Sesana]





# VIRGO(+) and ground-based GW astronomy

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## Responsible (APC): Eric Chassande-Motin

### *5 Permanent members:*

- Matteo Barsuglia 100% (optical design, R&D squeezing)
- Danièle Steer 70% (cosmology, cosmic strings)
- Edward Porter 90% (CBC co-chair, astrophysical inference)
- Stanislav Babak 50% (testing GR, waveform modelling)
- Eric Chassande-Mottin (chef de groupe, search for transient, cosmology)

### *6 post docs*

- Agata Trovato 100% (open data testing validation)
- Sarah Antier 50% (multimessenger)
- Leila Haegel 100% (testing GR waveform modelling)
- Simone Mastrogiovanni 100% (cosmology, testing GR)
- Sylvain Marsat 40% (waveform modelling)
- Jonathon Baird 80% (optical design), 20% (data analysis)

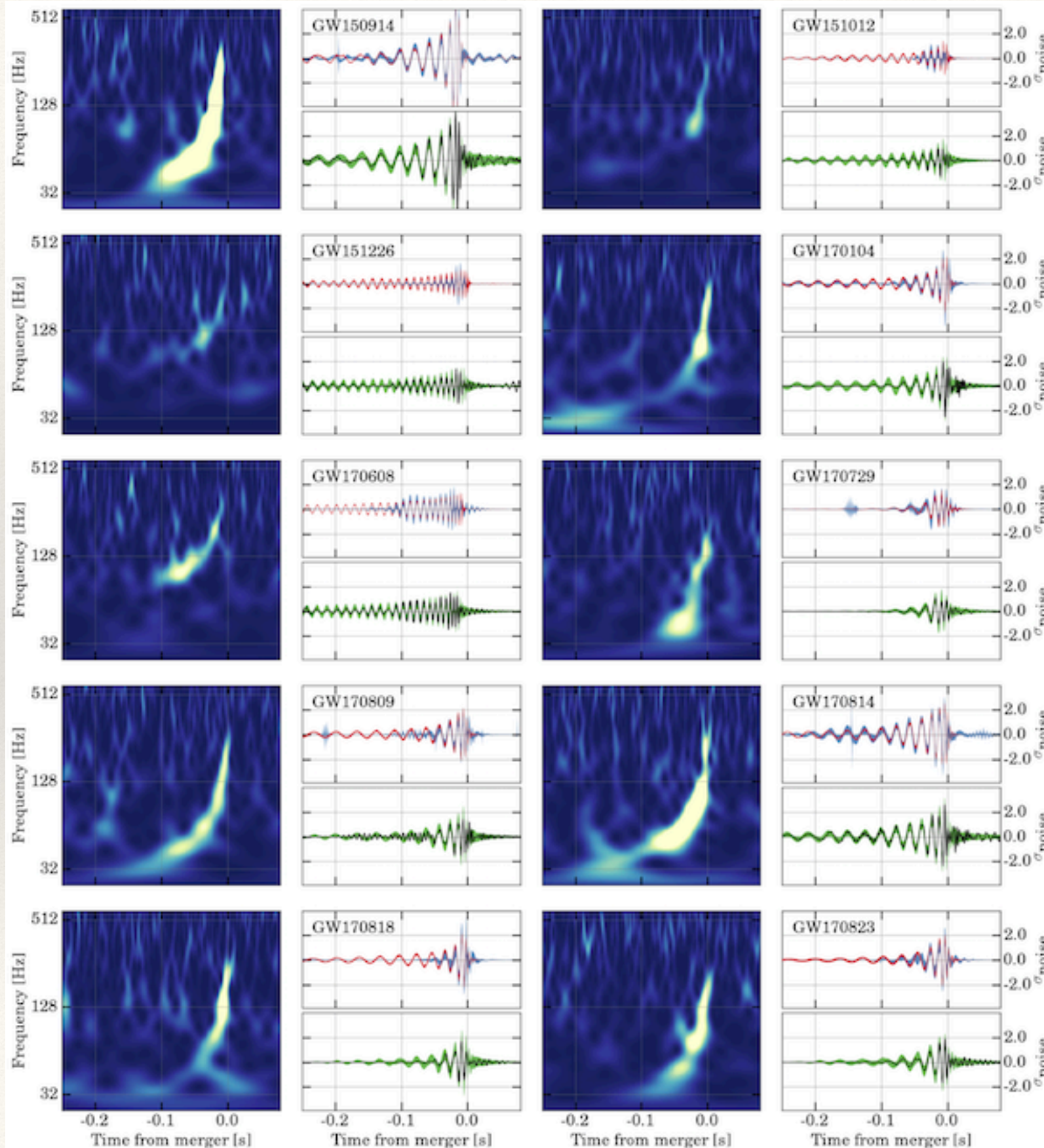
### *3 PhD*

- Catherine Nguyen, squeezing and R&D EPR, 100%
- Marc Arene, Bayesian data analysis, 100%
- Pierre Auclair, cosmic strings, 20%





# Results from O1-O2 runs

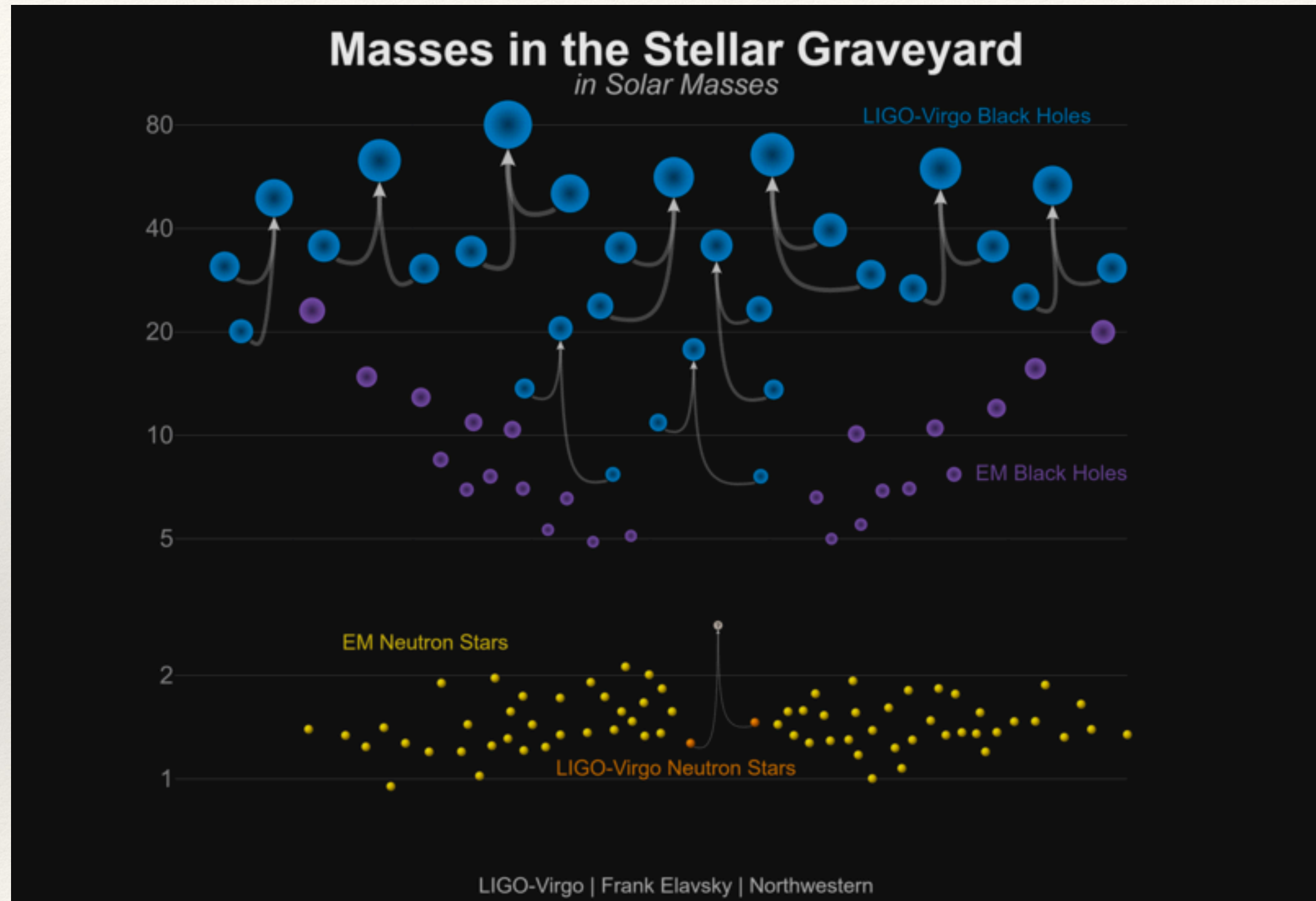


- The first GW catalogue:
  - 10 GW signals from black hole binaries and
  - 1 binary neutron star merger
- The e/m counterpart was associated with the BNS merger





# O1-O2 catalogue of merging binaries



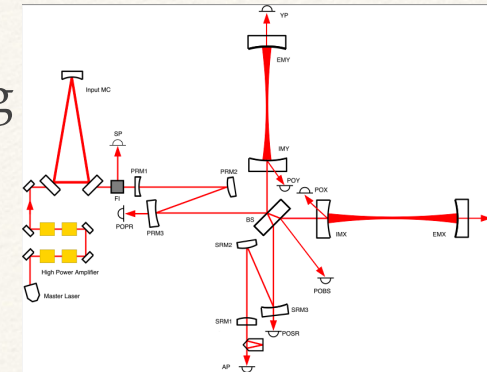


# Ground based GW astronomy

**AdVirgo+**: Optical design, system design, operation optimization, frequency dependent squeezing

**ET:** squeezing , optical /system design, quantum nondemolition, Computing

(J. Baird (CDD), C. Nguyen (Doct), M. Barsuglia (DR), E. Porter (DR))



## Data analysis and waveform reconstruction:

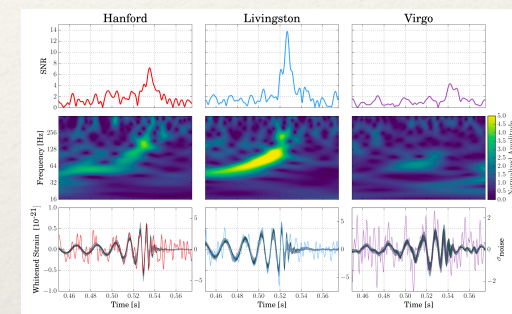
# Bayesian parameter inference, testing GR, Cosmology using standard sirens

(S. Mastrogiovanni (CDD), M. Arene (Doct), E. Porter (DR), E. Chassande-Mottin (DR),

S. Babak (DR))

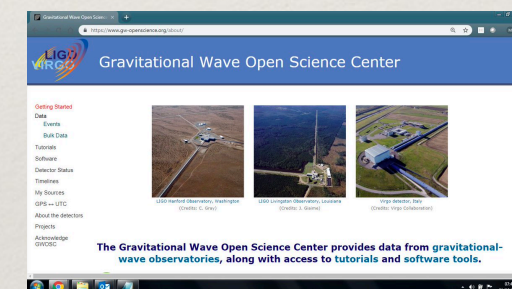
## Machine learning techniques

(A. Trovato (CDD), L. Haegel(CDD), E. Chassande-Mottin (DR))



## Open data science:

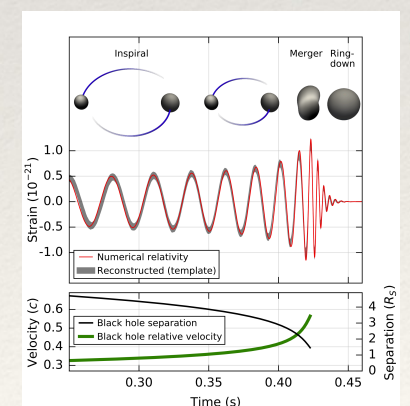
## Preparation, validation and release LVC data (A. Trovato (CDD), E. Chassande-Mottin (DR))



## Waveform modelling:

# Modelling GW signal from merging black hole binaries

(S. Marsat (CDD), L. Haegel (CDD), S. Babak (DR), E. Porter (DR))





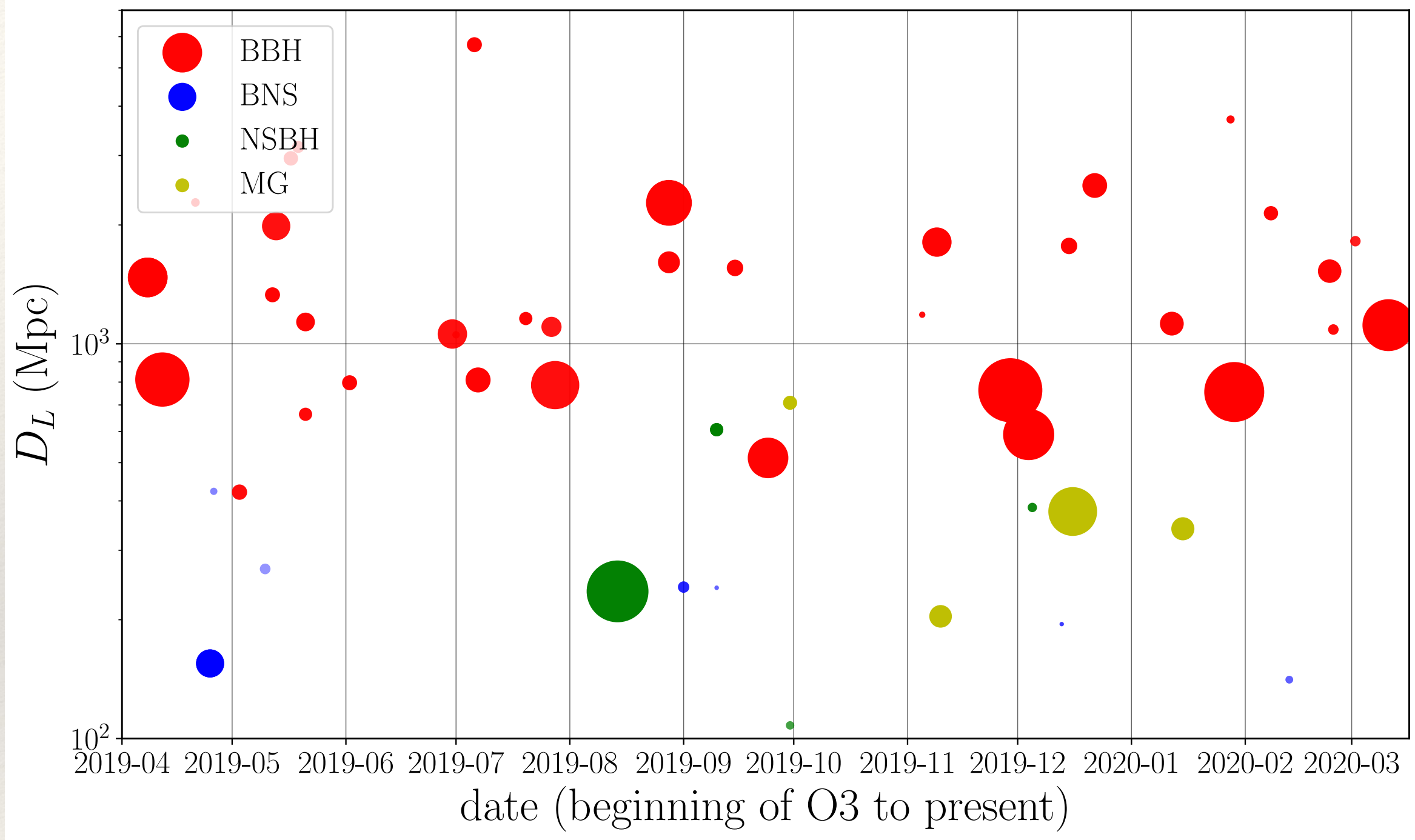
# O3: current status

BBH: 36

BNS: 7

NSBH: 4

Mass Gap: 4



Size corresponds to statistical significance

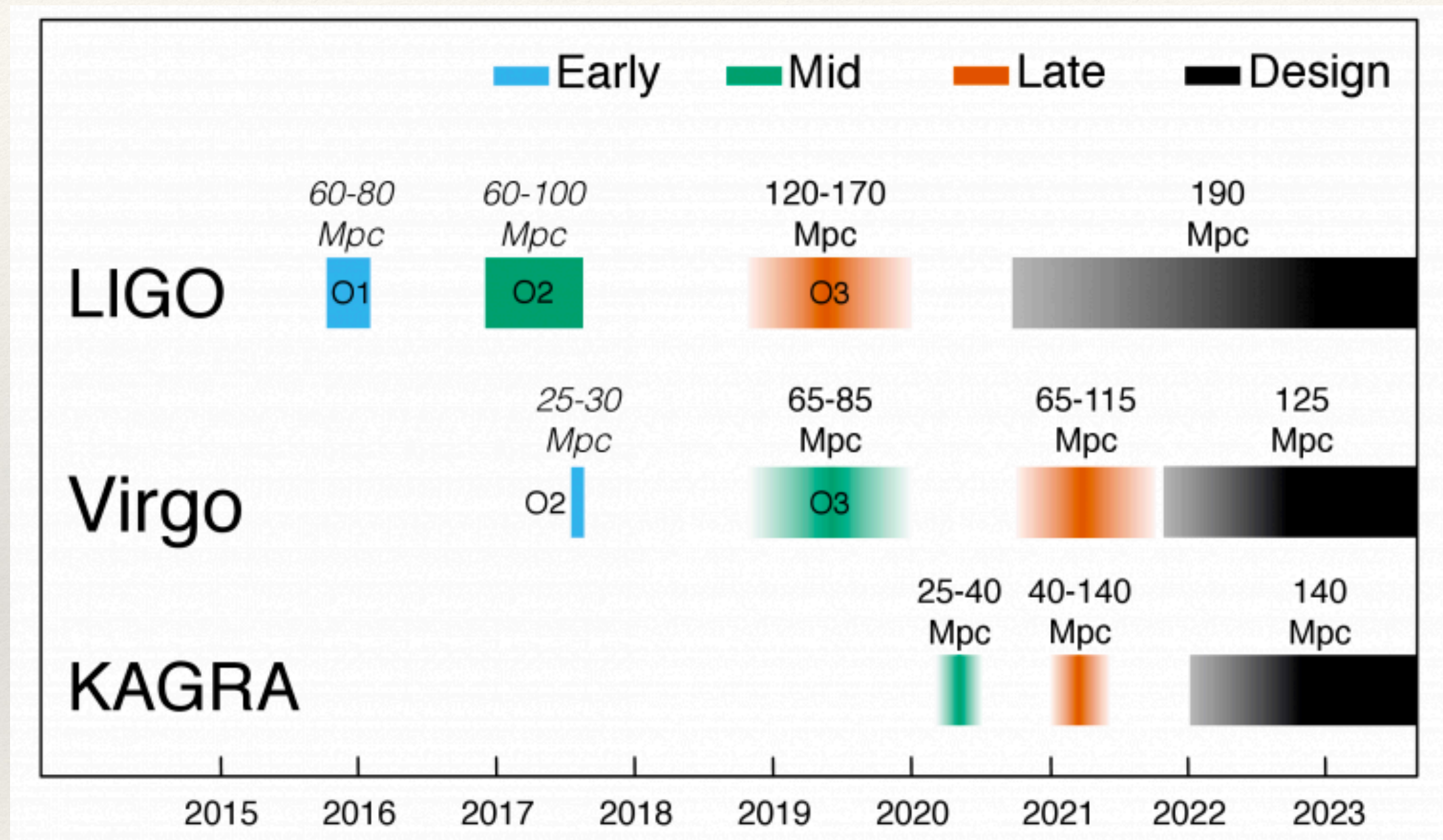
Transparency corresponds to classification confidence





# O3 and beyond

Planned observing runs and sensitivity (average distance for binary NS signal)





# LISA project

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**Responsible: A. Petiteau/Ch. Caprini (Theory), H. Halloin (Instrumental)**

## *7 Permanent:*

- Antoine Petiteau 50% (LISA Board, LISA PI-France, Distributed Data Processing Centre lead)
- Hubert Halloin 50% (LISA AIVT lead, LISA System Engineering Office)
- Chiara Caprini 50% (LISA Cosmology working group lead)
- Eric Plagnol 100% (LISA PathFinder data analysis)
- Edward Porter 10% (LISA data analysis, waveform validation lead)
- Stanislav Babak 50% (LISA data challenge lead, LISA data pipeline lead, LISA data analysis tools lead)
- Daniele Steer 10% (Modelling stochastic GW signal)

## *4 post docs.*

- Nikos Karnesis 100% (LISA data analysis: gaps, stochastic GW, binary systems)
- Sylvain Marsat 50% (LISA data analysis, waveform modelling)
- Henri Inchauspe 100% (LISA data analysis, noise non-stationarity)
- Francis Fortin 50% (Formation of binary systems)

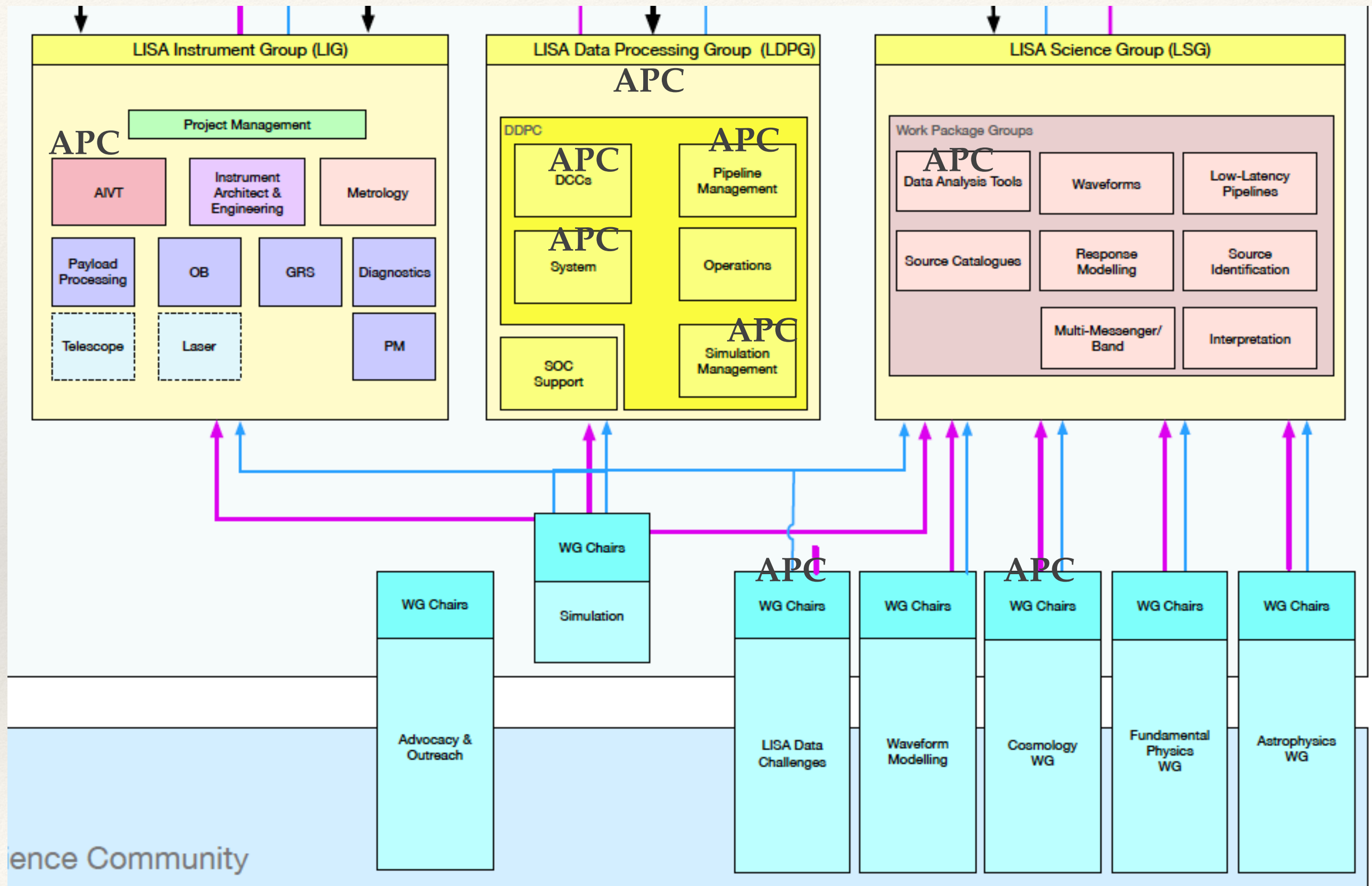
## *4 PhD*

- Alexandre Toubiana 100% (LISA data analysis, Testing GR, LISA astrophysics)
- Leon Vidal 100% (“LISA on table” design study)
- Dam Quang Nam 100% (LISA time delay interferometry, LISA simulator)
- Mikel Falxa 30% (LISA data analysis: Galactic binarie)





# APC role in LISA project





# LISA' time line



June 2017: Selection of LISA as L3 with anticipated launch at 2034

May 2018: Phase A kick-off

— 2018 - 2020 Mission Phase A (formulation)

spring 2020: Formulation review (end of Phase A)

> 2020 Mission Phase B1

**Slides by 9 months**

2023: Mission Adoption

> 2024: Mission Implementation (Phase B2 / C / D)

< 2034: Launch

> Launch: 6.5 years of operation (with potential extension)



# LISA @APC

## LISA data analysis:

Detection methods, Bayesian parameter estimation, testing GR

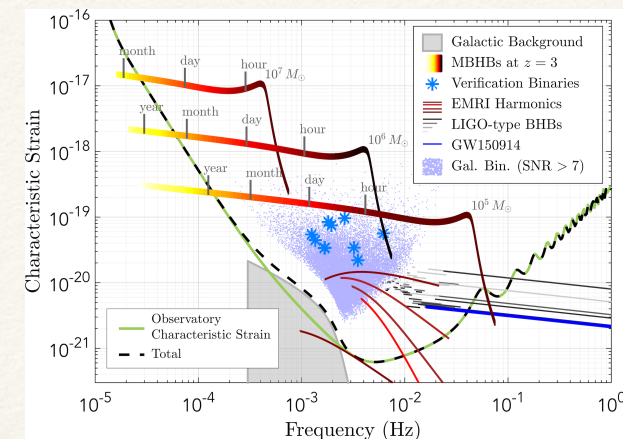
S. Marsat (CDD), N. Karnesis (CDD), H. Inchauspe (CDD),

A. Toubiana (Doct), M. Falxa (Doc), S. Babak (DR), A. Petiteau (MCF), E. Plagnol (Emer)

## LISA simulator:

Development of LISA simulator with accent on TDI, LISA performance study

H. Inchauspe (CDD), Dam Nam (Doc), J. Martino (IR), A. Petiteau (MCF)

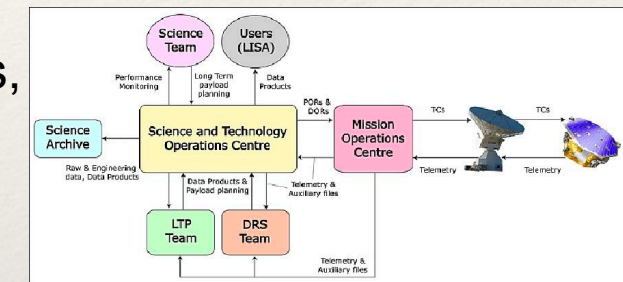


## Building Distributed Data Processing Center:

Analysis pipeline development, Simulating of LISA data, assessment of data analysis methods, prototyping catalogues creation, ...

H. Inchauspe (CDD), Dam Nam (Doc), M. Lejeune (IR), C. Cavet (IR), A. Boucaud (IR),

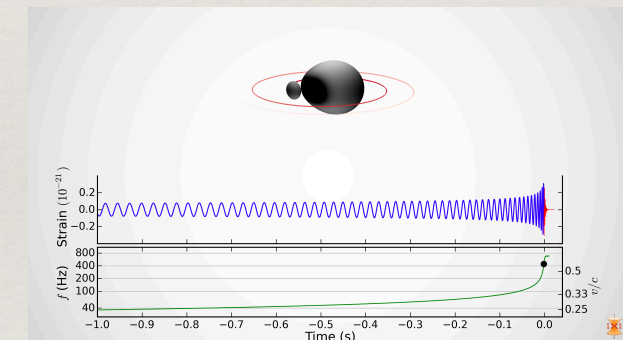
A. Petiteau (MCF), S. Babak (DR)



## Waveform Modelling:

Modelling merging MBHBs, Extreme mass ratio inspiral, stochastic signal.

S. Marsat (CDD), S. Babak (DR), Ch. Caprini (CR), E. Porter (DR), D. Steer (MCF)



## Assembly Instrument, Verification and Testing:

Phasemeter, Signal acquisition, mechanics, environment, optical design

A. van de Walle (CDD), L. Vidal (Doc), H. Halloin (MCF), T. Zerguerras (IR), J. Martino (IR),

P. Prat (IR), Eric Breelle (IR), Jean-Pierre Baronick (IR), Corinne Juffroy (IR)

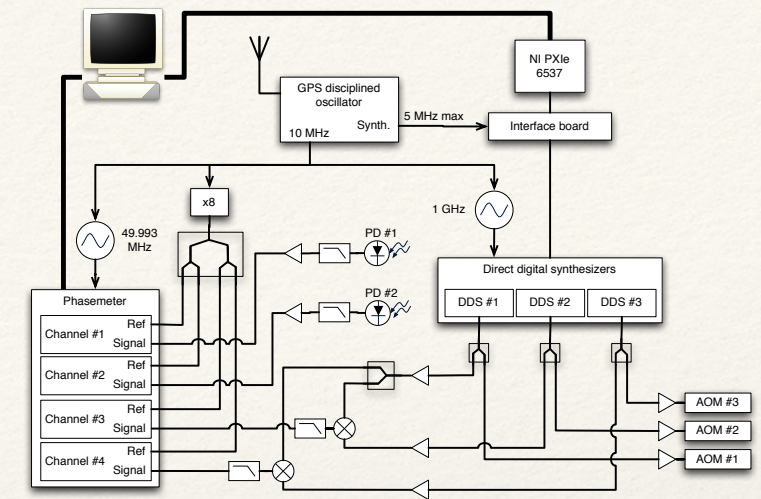




# LISA@APC: instrumentation

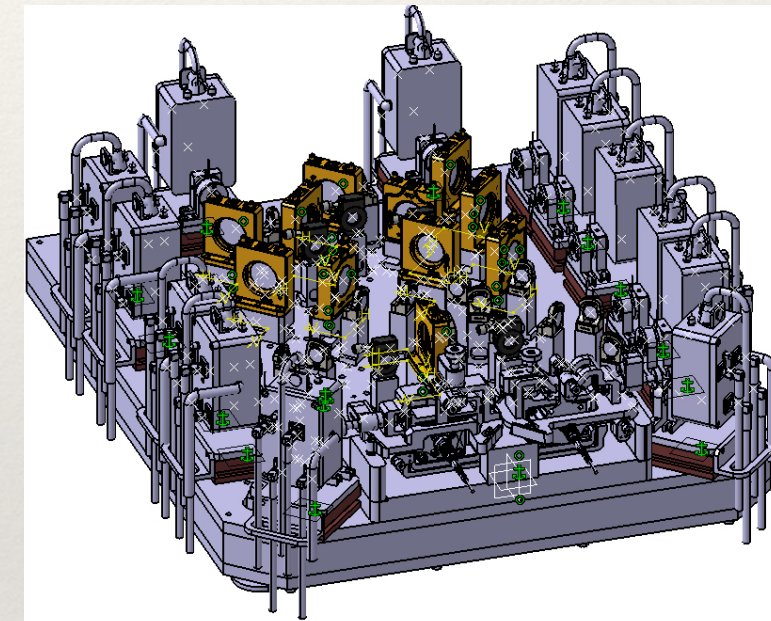
## LISA On Table (LOT) experiment

generating LISA-representative photodiode signals  
(e.g. for TDI testing) (*L. Vidal, P. Prat, H. Halloin*)



## Metallic and Zerodur Interferometers (MIFO/ZIFO)

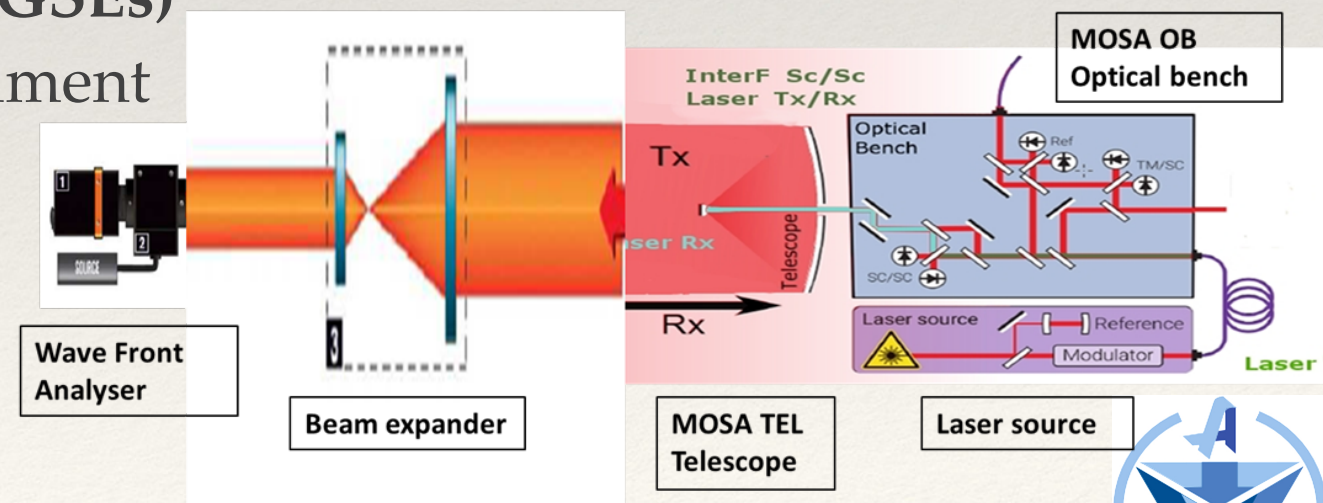
# Prototyping optical benches and methods for LISA instrument integration (*A. van de Walle, Th. Zerguerras, P. Prat, G. Monier, J. Martino, C. Juffroy, W. Bertoli, F. Cortavarria, S. Dheilily, H. Halloin*)



# LISA Optical Ground Support Equipments (OGSEs)

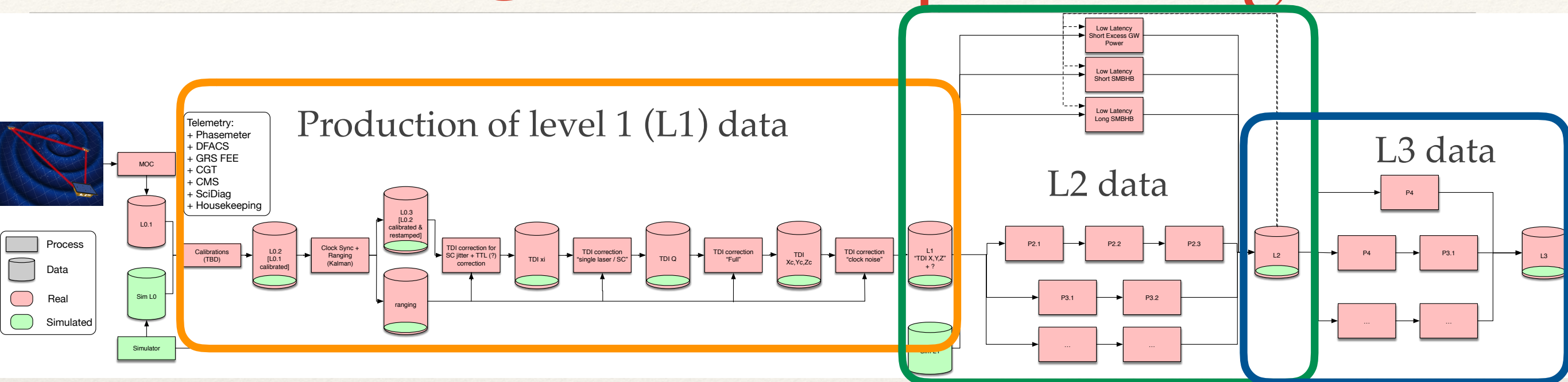
## Designing and sizing the OGSEs for LISA Instrument tests (starting in 2025).

(Th. Zerguerras, A. Laupin-Vinatier, H. Halloin)





# LISA@APC: data processing



Calibration, laser & clock  
noise reduction

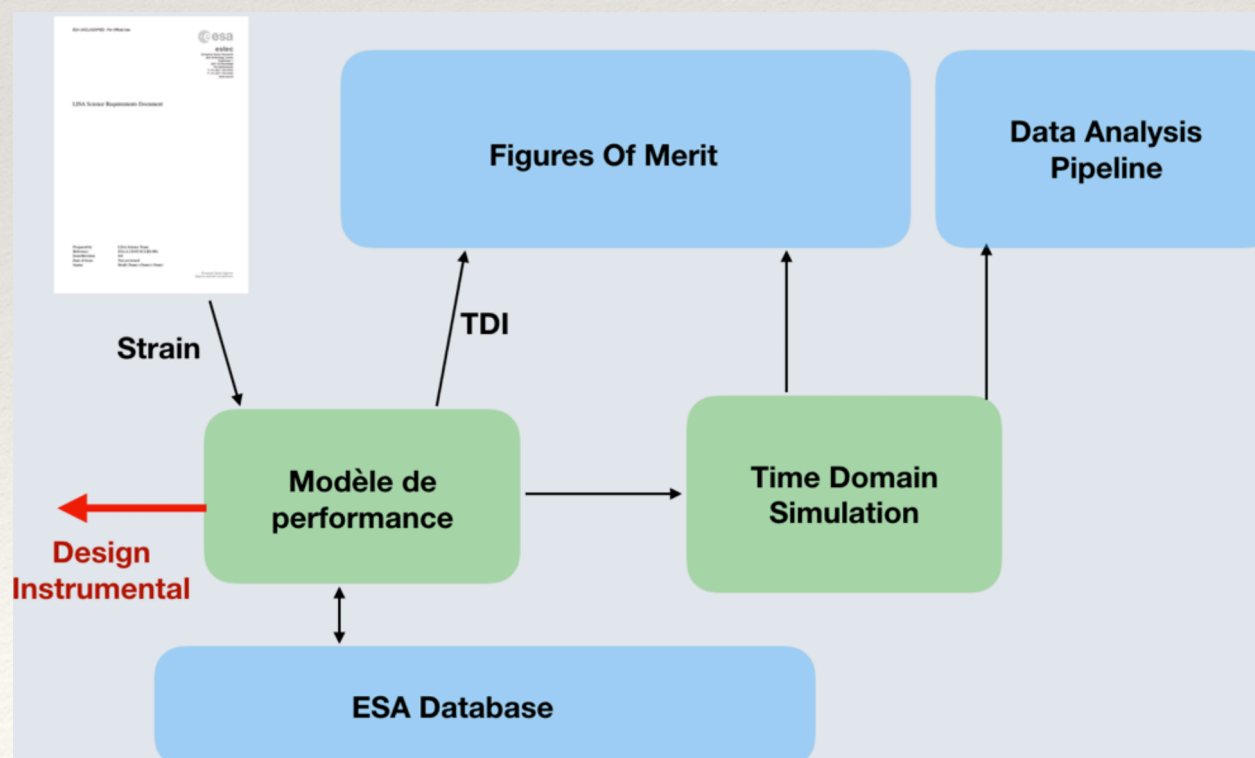
(H. Inchauspe, Dam Nam, J. Martino,  
A. Petiteau)

Extraction of GW signals,  
noise modelling

(H. Inchauspe, Dam Nam, M. Lejeune, C. Cavet,  
S. Marsat, N. Karnesis, A. Petiteau, S. Babak)

Catalogues and science  
interpretation of the data

(S. Marsat, N. Karnesis, A.  
Petiteau, S. Babak)



Testing scientific performance  
during design study (Phase A)

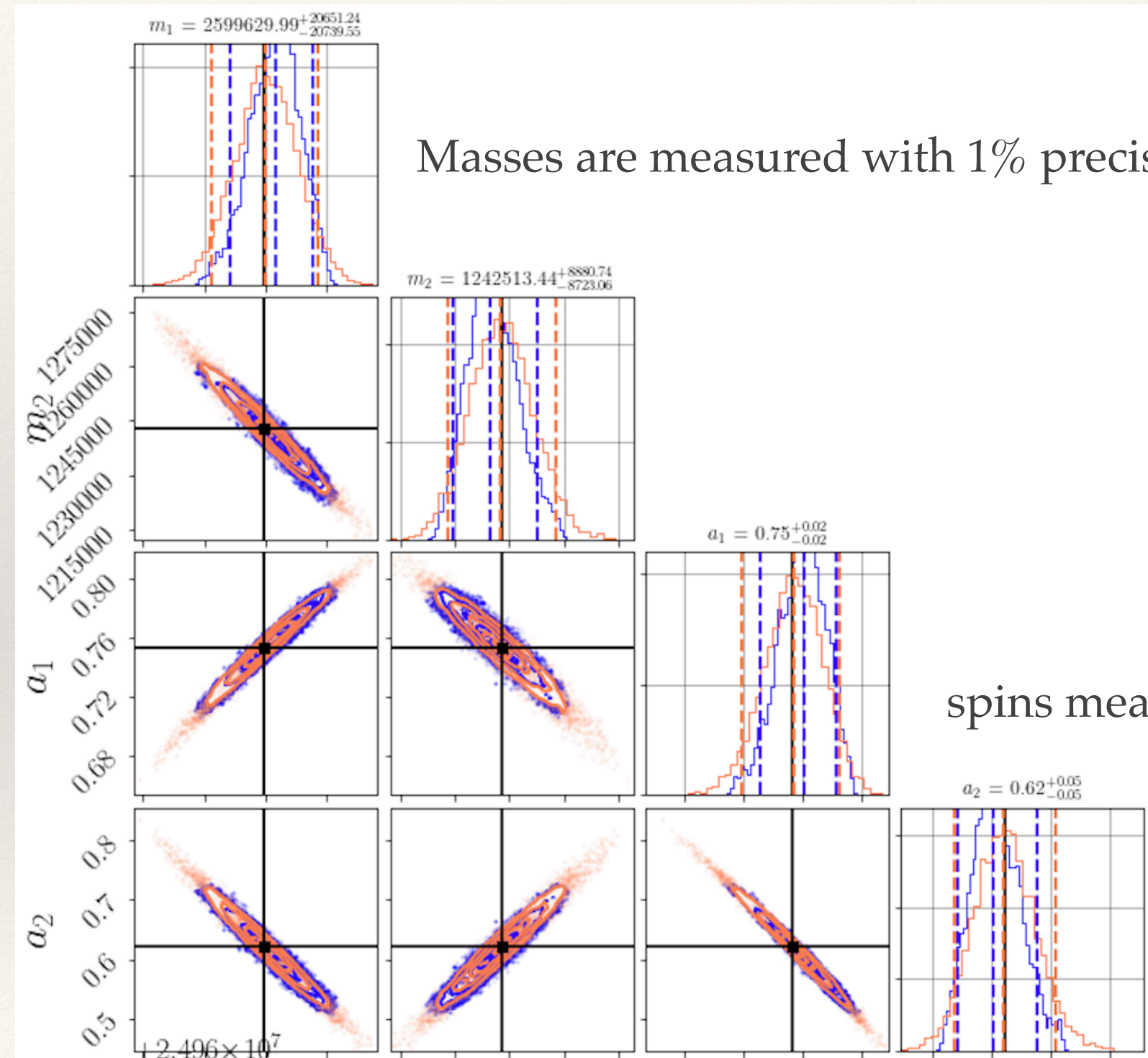
(H. Inchauspe, Dam Nam, M. Lejeune, C. Cavet,  
S. Marsat, N. Karnesis, A. Petiteau, S. Babak)





# LISA: observing GW in space

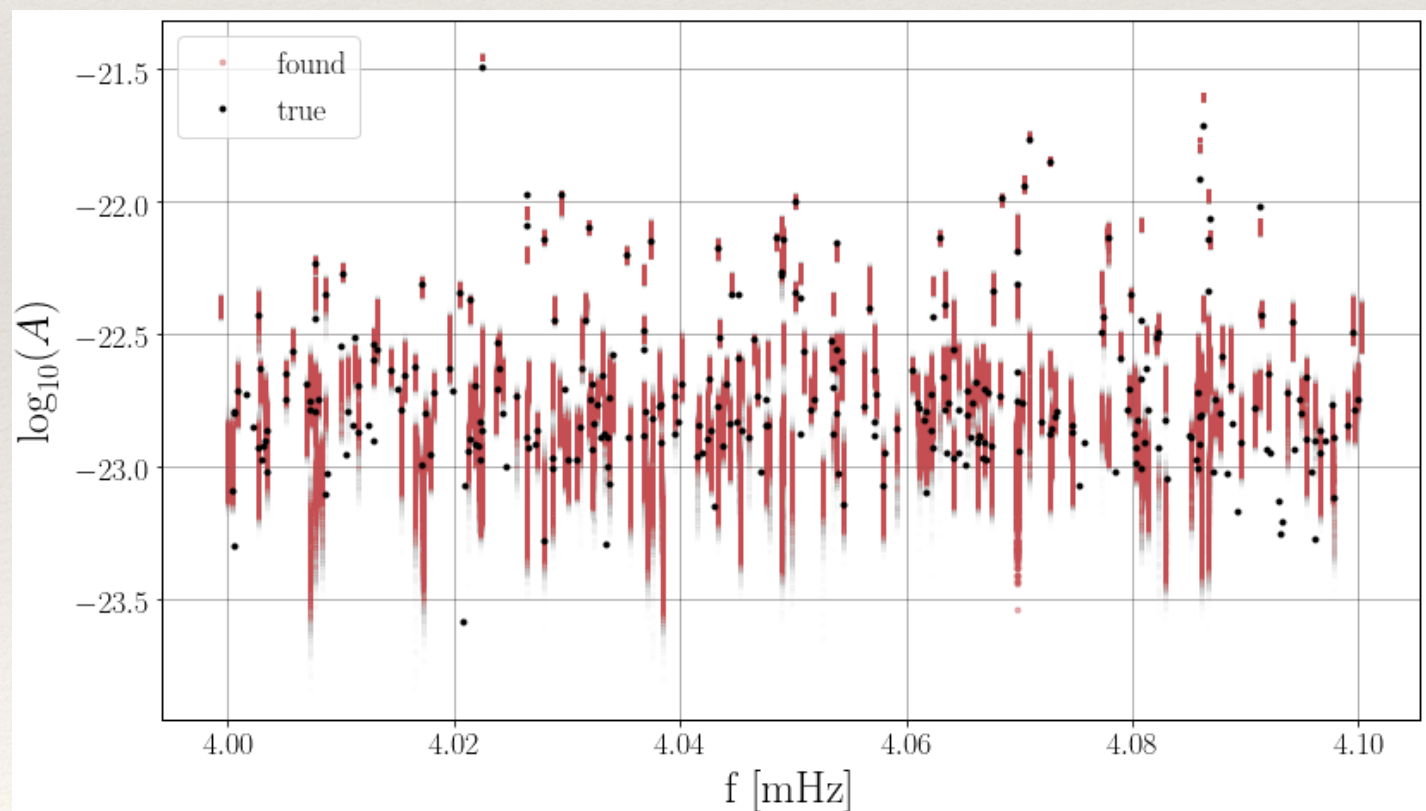
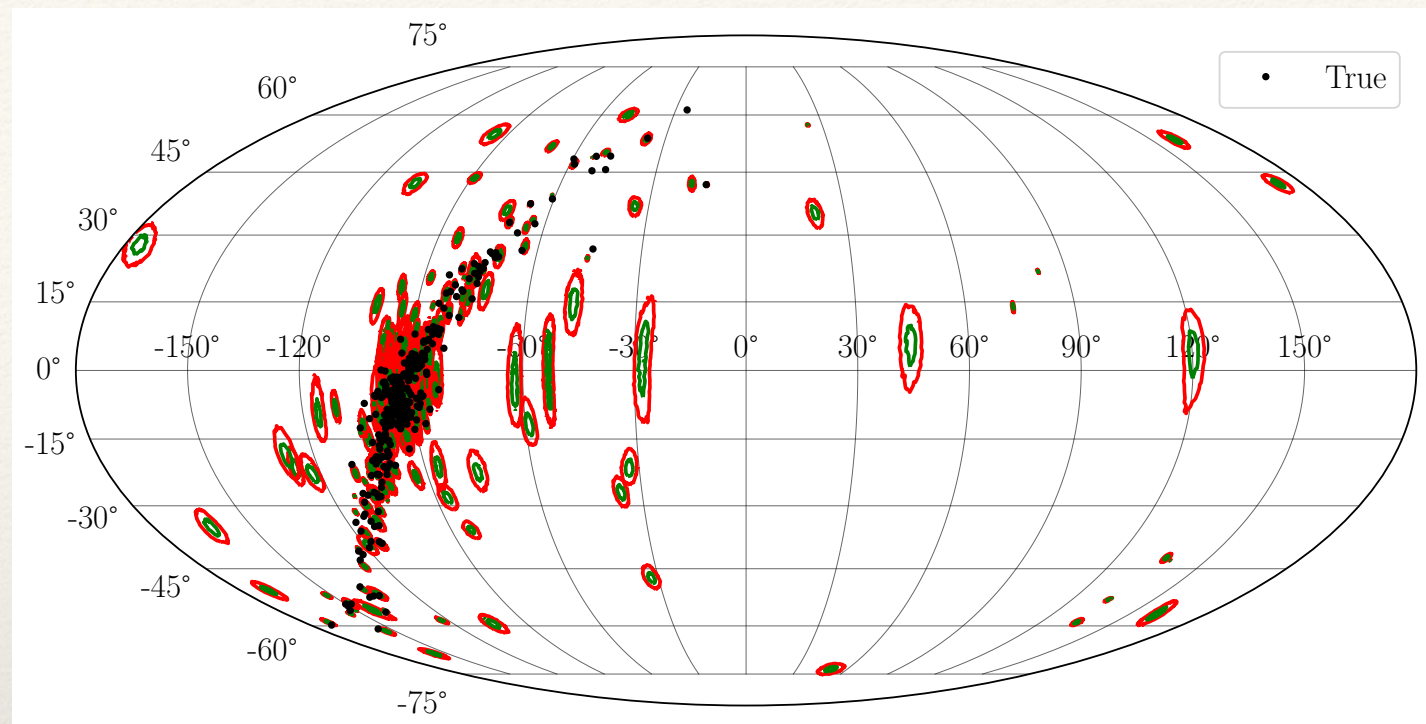
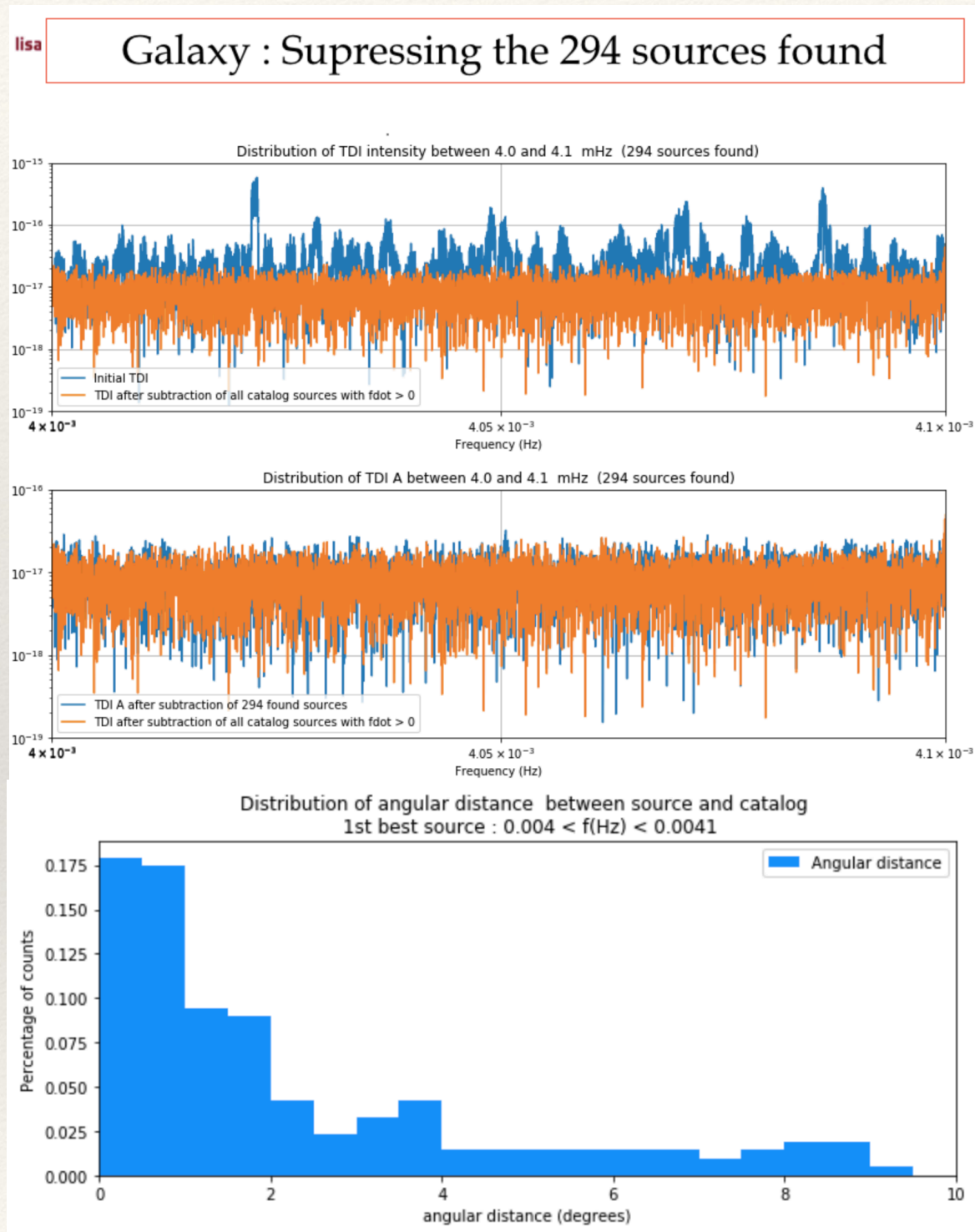
We organize the LISA data challenges:  
Simulation of LISA data, publishing it and analyzing the results





# LISA: observing GW in space

## Recovery of Galactic Binaries: 4-4.1 mHz band (*E. Plagnol*)





# PTA: pulsar timing array (Dim ACAV + ANR)

Responsible: A. Petiteau/S. Babak

## *2 Permanent:*

- Antoine Petiteau 15% (PTA data analysis)
- Stanislav Babak 15% (PTA data analysis)

## *2 PhD*

- Aurelien Chalumeau 100% (Ephemeris in PTA, data reduction and noise modelling)
- Mikel Falxa 70% (PTA data analysis: search for a population of supermassive black hole binaries)

## *On INSU side (Orleans/Nançay):*

- Gilles Theureau (1CL) 30% (Coordination)
- Ismaël Cognard (DR2) 20% (Instrument, Observation)
- Lucas Guillemot (Astron. Adjoint) 20% (Observation, data reduction)
- Siyuan Chen (CDD) 100% (PTA data analysis, astrophysics)
- 2x PhD students 100% (data reduction, data analysis)

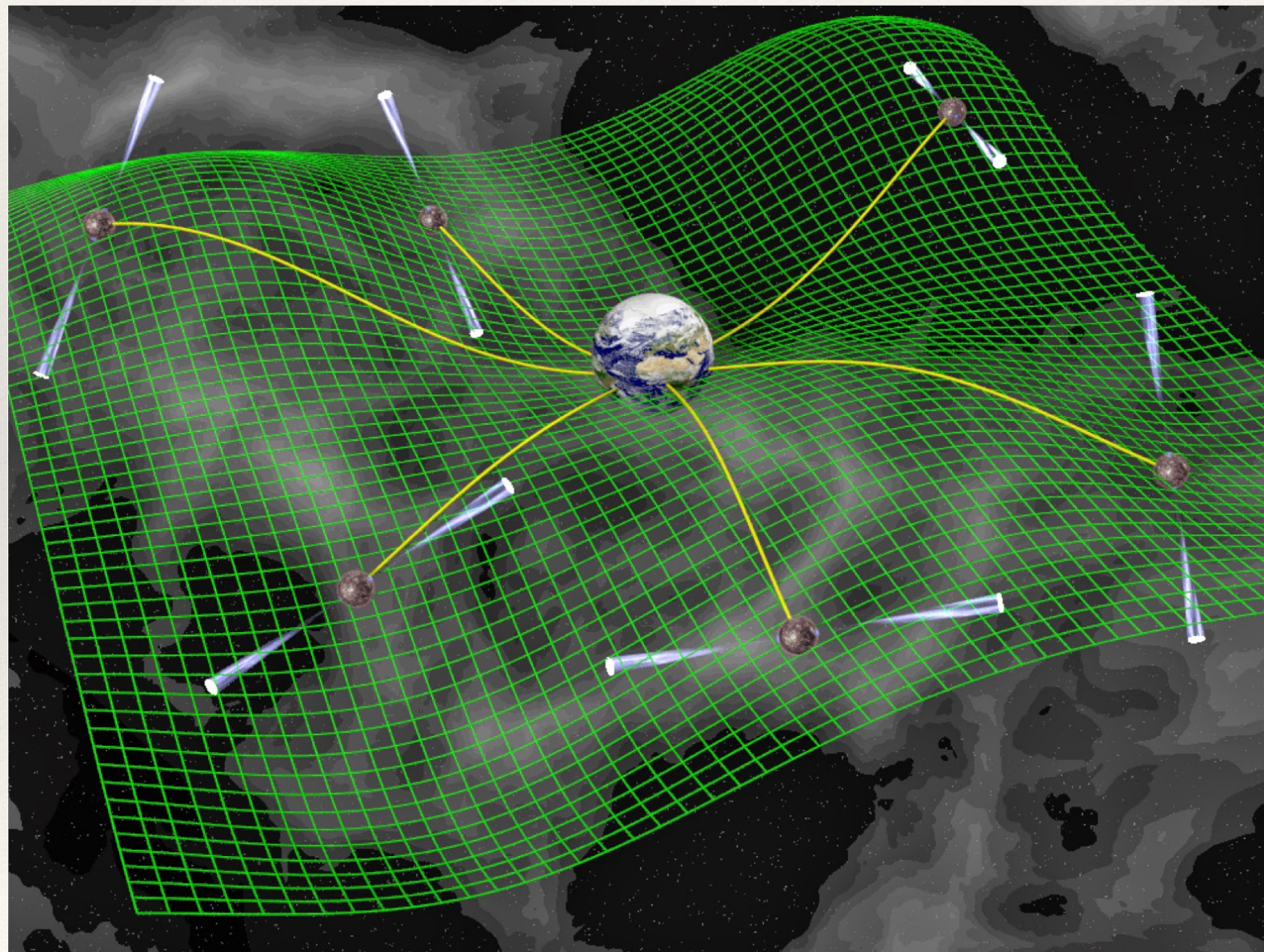
PTA-France





# Pulsar Timing Array: PTA

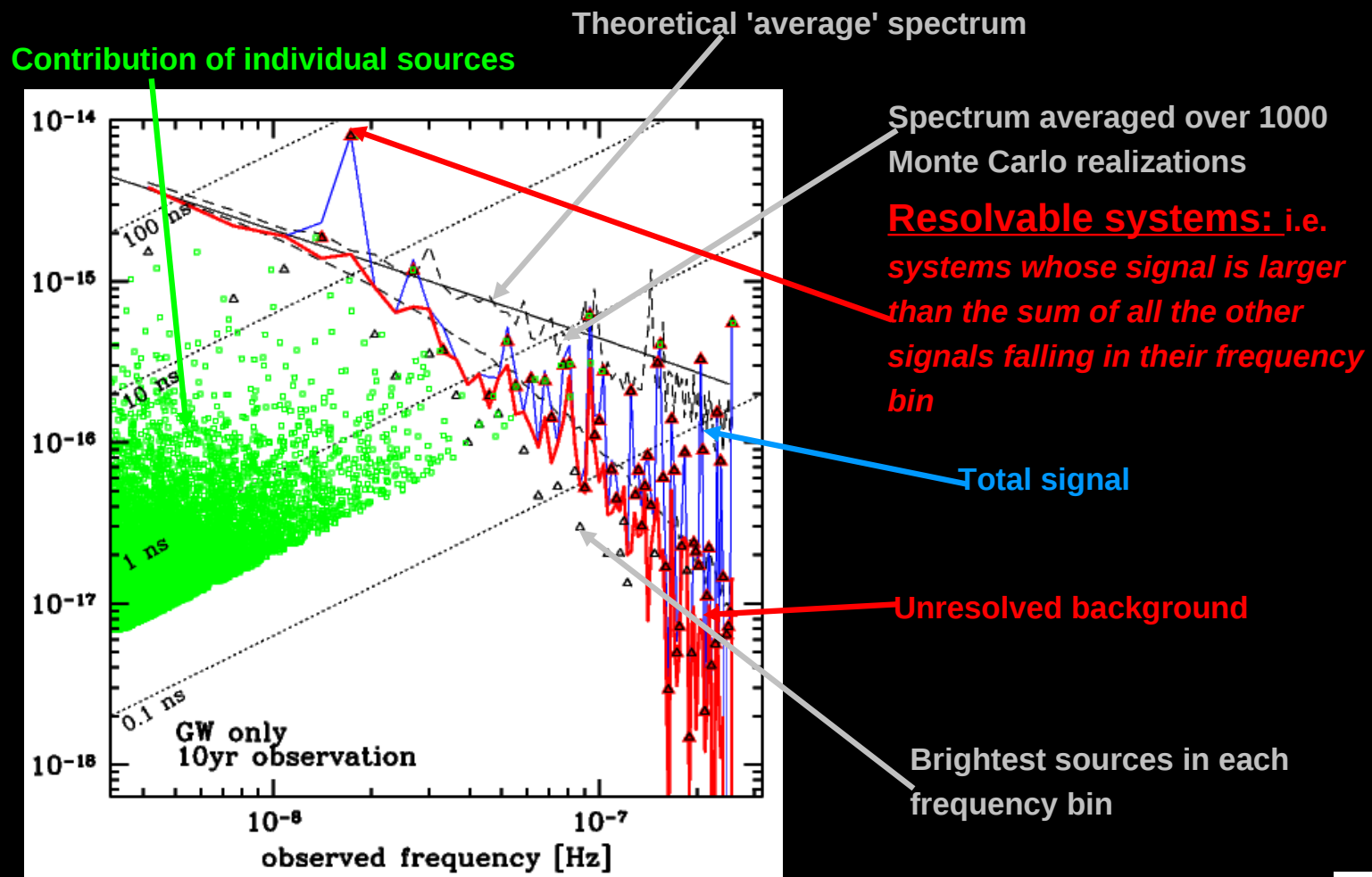
The main idea behind pulsar timing array (PTA) is to use ultra-stable millisecond pulsars as beacons for detecting GW in the nano-Hz range  $10^{-9}$  -  $10^{-7}$  Hz





# Population of Supermassive Black Hole Binaries

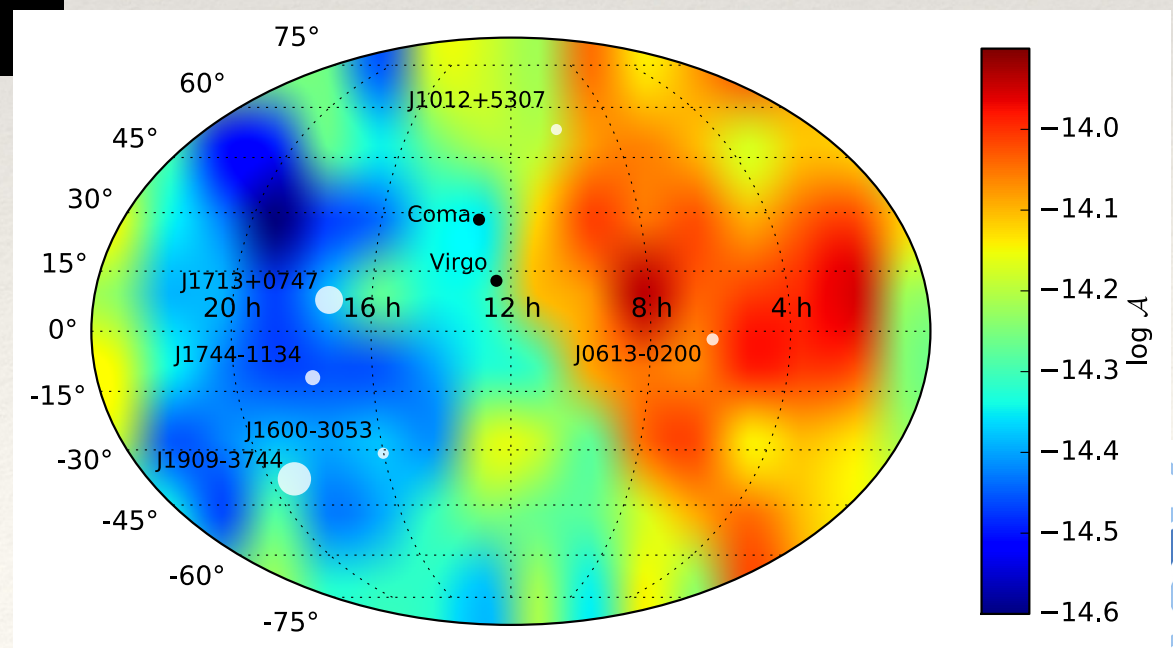
## Signal from a MBHB population



Superposition of multiple (overlapping) signals:

- Stochastic (possibly) anisotropic signal
- Individually resolvable (possibly) multiple signals
- Orbits could be eccentric

Application to IPTA, DR2- data set





# Einstein Telescope

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Matteo takes over...

