

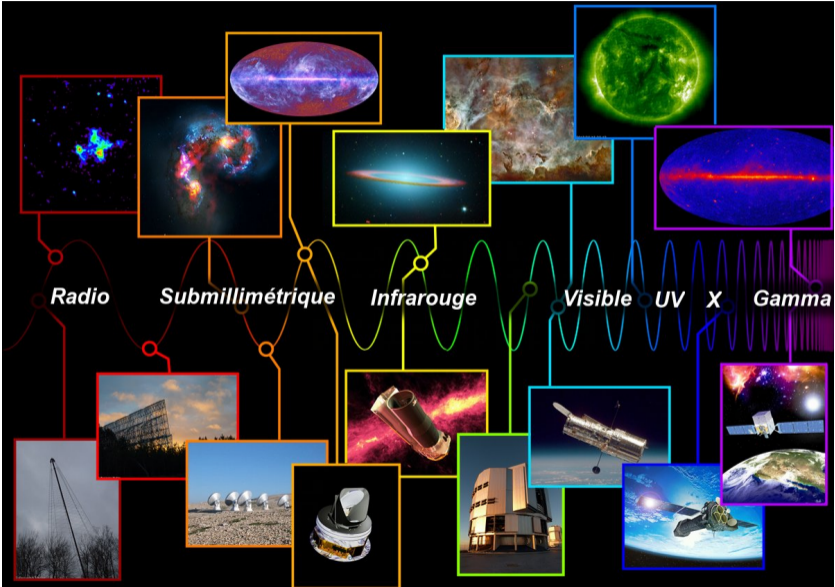
LISA Data Analysis Pipeline: – From Instrument to Parameter Estimation – Highlight on prompt localisation

Yves Lemière

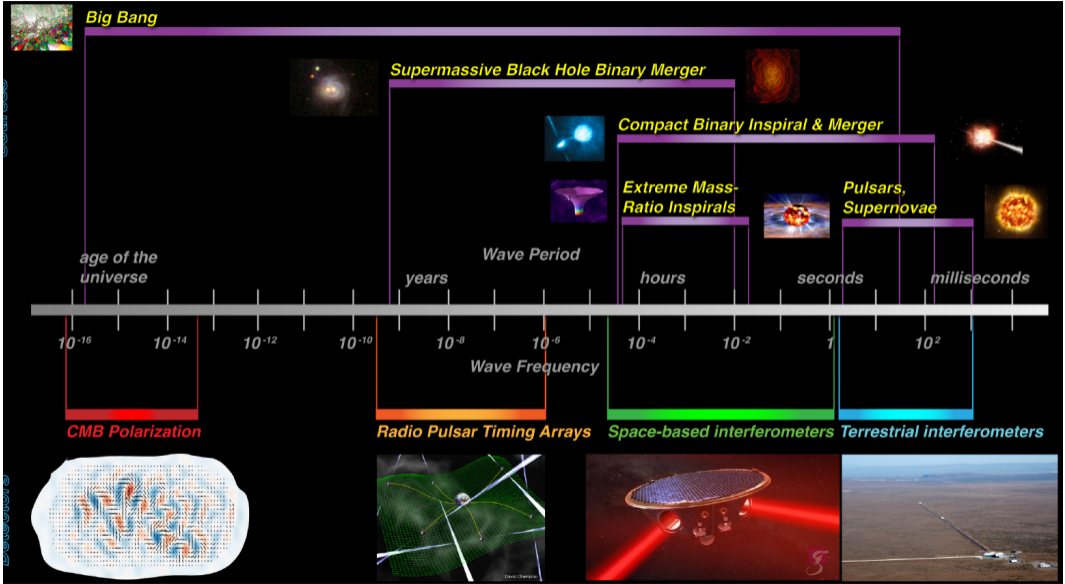
2026/06/04



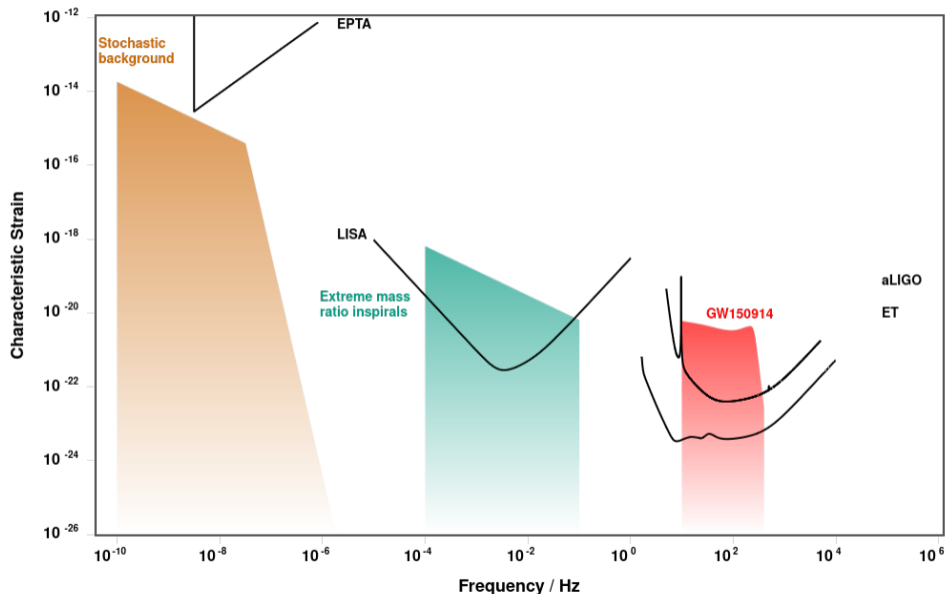
Astronomy overview



LISA and the GW scope



LISA and the GW scope



Science Objectives

– Definition Study Report –



- SO1** Study the structure of the Milky Way Galaxy (binary stars)
- SO2** From the origins to the merger of Massive Black Holes
- SO3** Probe environments of Black Holes using EMRIs
- SO4** Understand the astrophysics of stellar-mass Black Holes (complementary to ground-based)
- SO5** Validity of the General Relativity ([see talk A. Cogež](#))
- SO6** Probe the rate of expansion of the Universe
- SO7** Stochastic GW backgrounds and their implications for the early Universe ([see talk M. Stamenkovic](#))
- SO8** GW bursts and unforeseen sources ([see talk S. Baimukhametova](#))

Physical objects

- **Massive Black Holes Binary :**
MHBHB merger $\approx 100/\text{year}$
(SO2, SO5, SO6)



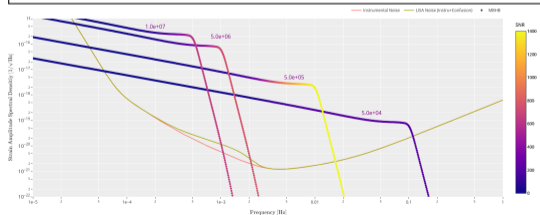
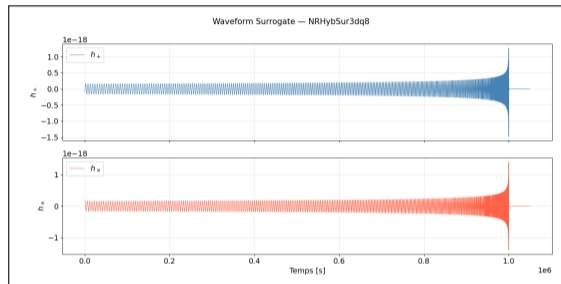
ESA/HUBBLE, NASA

<https://www.elisascience.org/>

<https://lisa-science-explorer.in2p3.fr/>

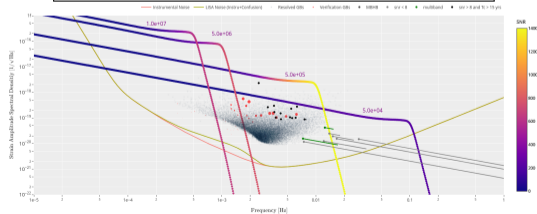
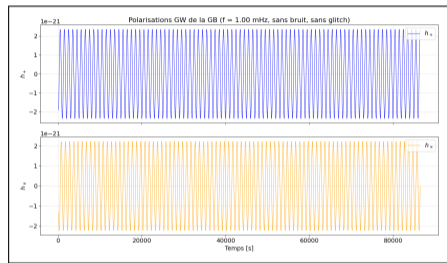
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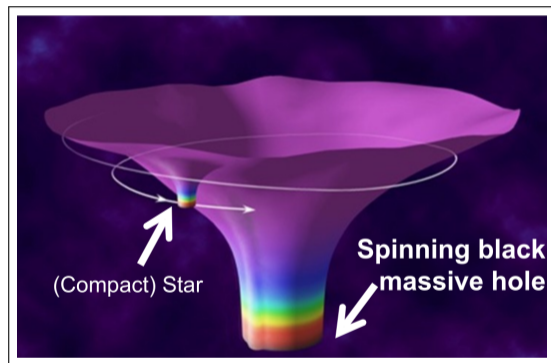
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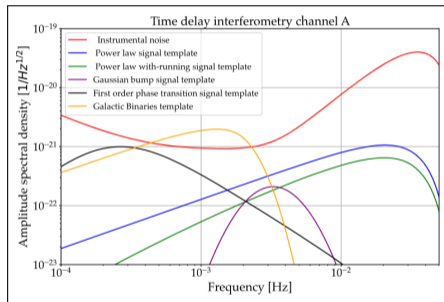
<https://www.elisascience.org/>

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Astrophysical/Cosmological (SO7)
first-order cosmological phase transition,
Cosmics strings

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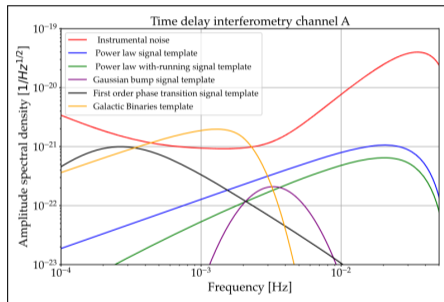
Physical Review D 109, 042001 (2024)

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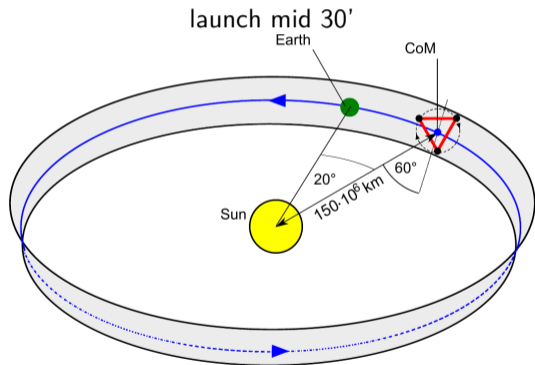
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Too many signals : Challenge accepted by LISA, ET/CE

Laser Interferometer Space Antenna – LISA –

see talk : E.Savalle

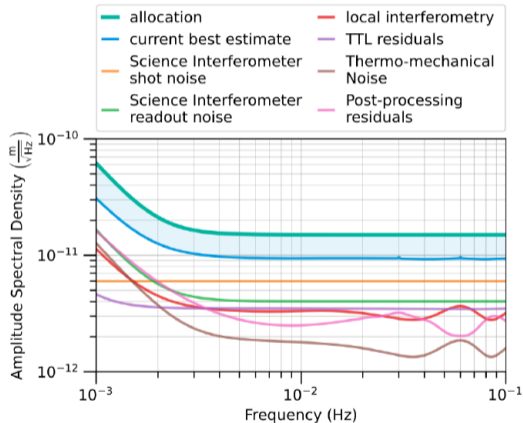
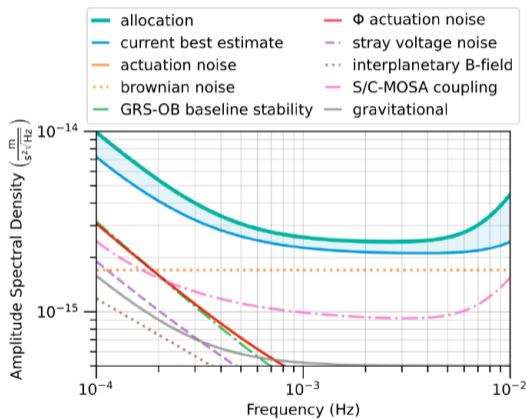


LISA constellation

- \simeq equilateral triangle
 - ▶ $2,5 \cdot 10^6$ km \simeq 8 s
 - ▶ ± 20000 km et ± 10 m/s (Doppler)
- 6 lasers
 - ▶ Heterodyn Interferometer
 - ▶ Signal (10^{-21}) vs Noise (10^{-13})

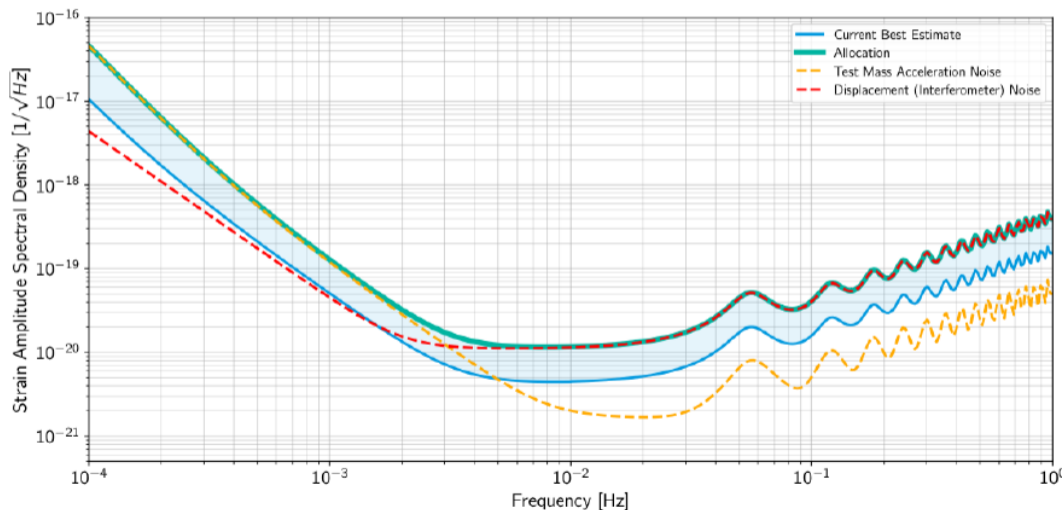
<https://lisa.pages.in2p3.fr/consortium-userguide/acronyms.html>

Laser Interferometer Space Antenna – LISA –

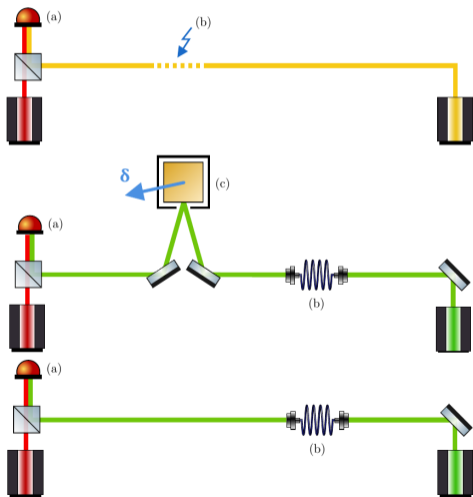


In a perfect world : stationary gaussian noises ...

Laser Interferometer Space Antenna – LISA –



Principle of mesure



Science channel

$$s_{12} = D_{12}p_{21} - p_{12} + \dots$$

- GW + Noises
- Distance between optical benches (OB)

Test Mass channel

$$\varepsilon_{12} = p_{13} - p_{12} + \dots$$

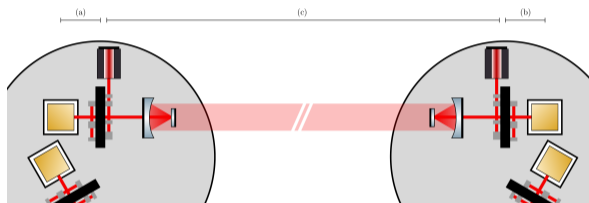
- Noises (Laser, OP, fibre)
- Distance from OB to Test Mass (TM)

Reference channel

$$\tau_{12} = p_{13} - p_{12} + \dots$$

- Noises (Laser, OP, fibre)

Principle of mesure

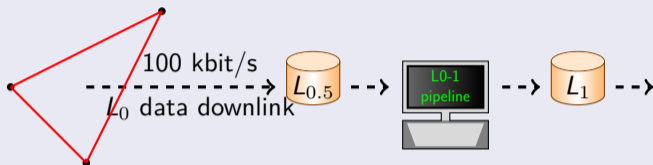


$$d(\text{TM}/\text{TM}) = d(\text{TM}/\text{OB})_{\text{local}} + d(\text{OB}_{\text{local}}/\text{OB}_{\text{dist}}) + d(\text{OB}/\text{TM})_{\text{dist}}$$

Expected signal

→ $\delta d(\text{TM}/\text{TM}) \approx pm$ at $\approx \text{mHz}$ ($T = 1000 \text{ s}$)

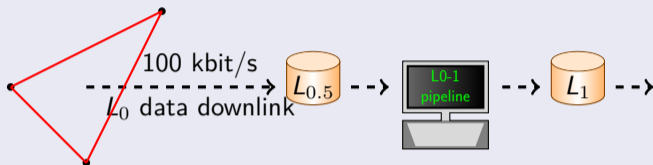
Data processing at ESA



L0 : Raw DATA

- Phasemeters at 4 Hz
- System monitoring
- Gravitational reference sensor
- S/C orbits

Data processing at ESA



L0 : Raw DATA

- Phasemeters at 4 Hz
- System monitoring
- Gravitational reference sensor
- S/C orbits

L1 : noise corrected DATA

- Calibrations
Interpolation filters, TTL^a corr., ...
- Clock synchronisation
- **TDI**

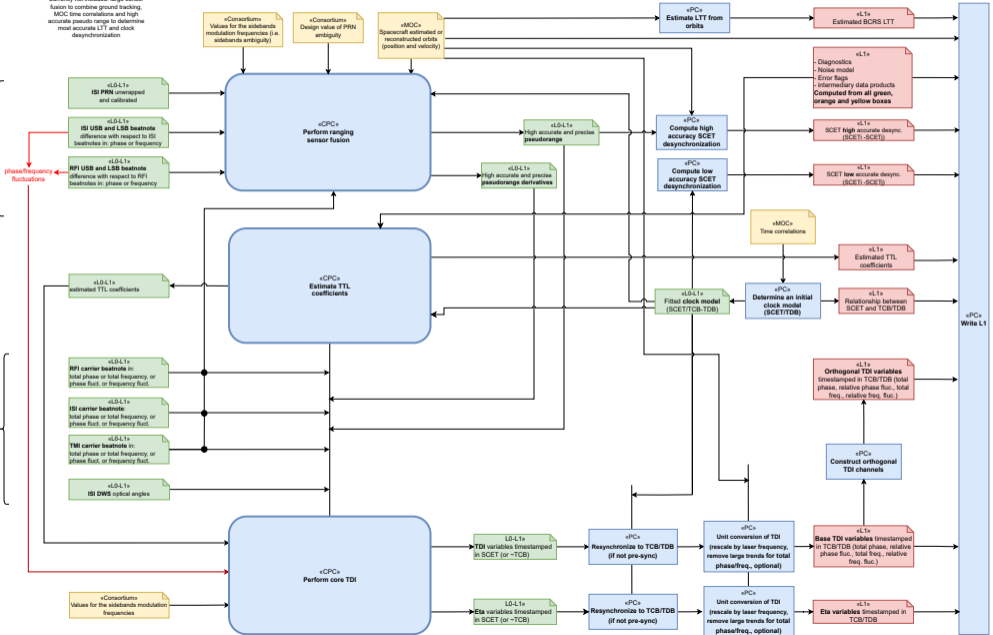
^aLISA Non-Linear Dynamics and Tilt-To-Length Coupling

Work in progress : Lolipops package for the L0L1PrOcessing elementS

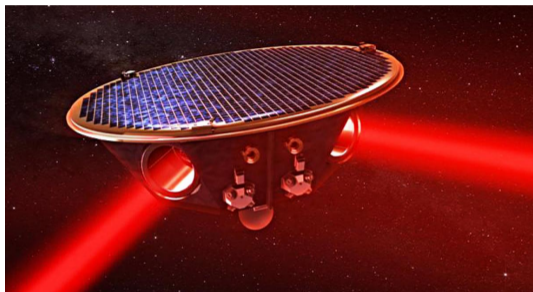
Currently not included: large sensor fusion to combine ground tracking, MOC time correlations and high accurate pseudo range to determine most accurate LTT and clock desynchronization

From "local calibration"

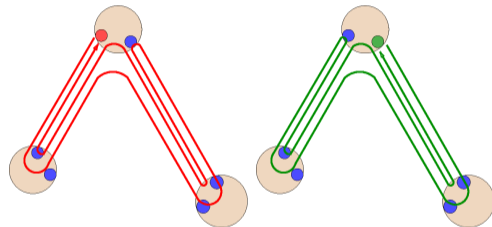
From "local calibration"



Time Delay Interferometer– TDI –



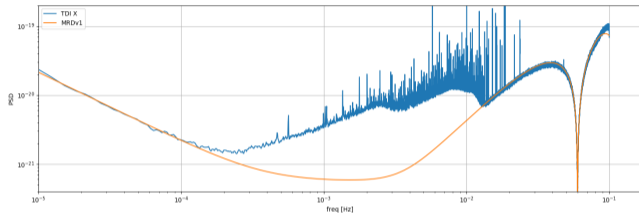
Virtual interferometer and noise cancelation



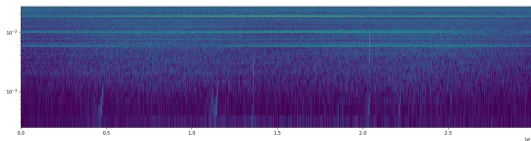
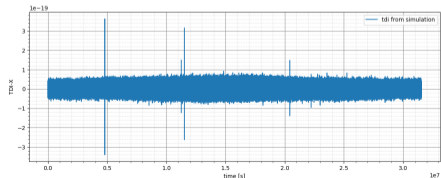
TDI – second generation

$$X_{2.0} = (1 - \mathcal{D}_{33'2'2}) [(\eta_{1'} + \mathcal{D}_{2'}\eta_3) + \mathcal{D}_{2'2} (\eta_1 + \mathcal{D}_3\eta_{2'})] - (1 - \mathcal{D}_{2'233'}) [(\eta_1 + \mathcal{D}_3\eta_{2'}) + \mathcal{D}_{33'} (\eta_{1'} + \mathcal{D}_{2'}\eta_3)]$$

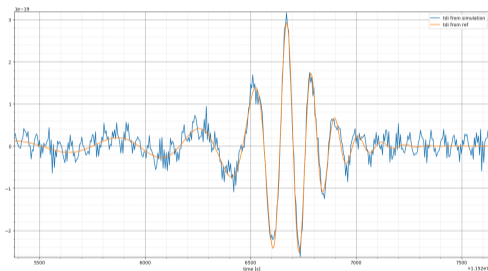
The parameter estimation : from L1 to L2 Data



Exemple from LISA Data Challenges



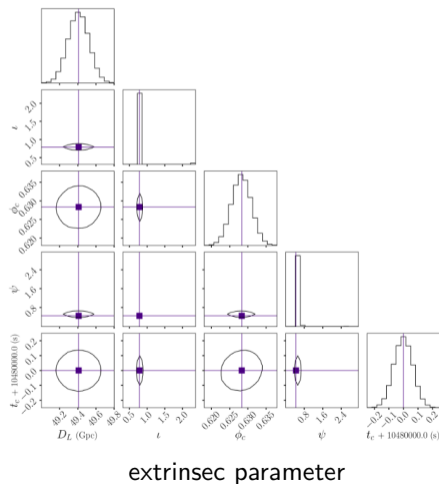
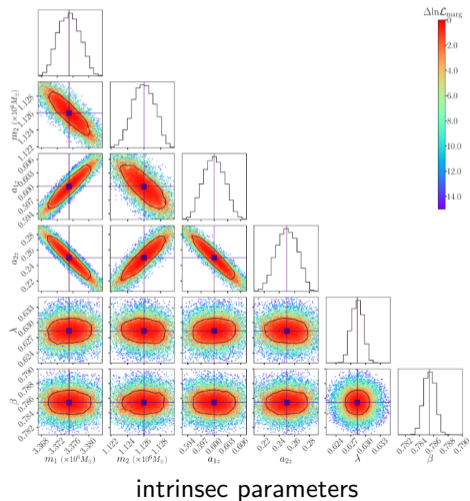
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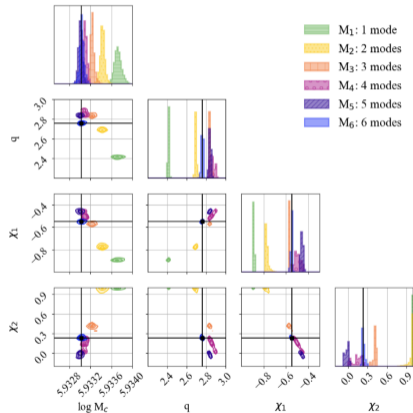
⇒ expensive parameters space exploration

- Frequentist approach
Match Filtering as a good starting point
- Bayesian approach
- Assuming signal independant from noise !
 $r(t) == d(t) - h(t)$ is left with gaussian noise

The parameter estimation : from L1 to L2 Data



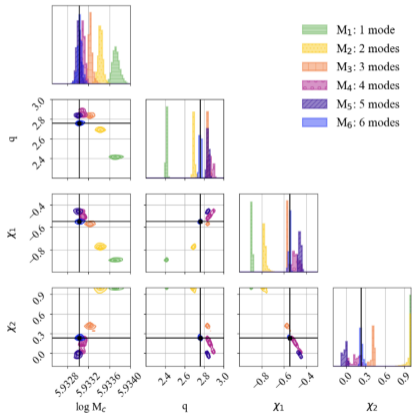
PE bias due to model



Parameter	True value	Estimated value with M_1 (with noise)	Estimated value with M_6 (with noise)
$\log M_c (M_\odot)$	5.93302	$5.93374^{+0.00019}_{-0.00016}$	$5.93304^{+0.00009}_{-0.00010}$
q	2.759	$2.414^{+0.012}_{-0.012}$	$2.759^{+0.013}_{-0.023}$
χ_1	-0.549	$-0.888^{+0.009}_{-0.008}$	$-0.549^{+0.011}_{-0.021}$
χ_2	0.232	$0.996^{+0.004}_{-0.018}$	$0.231^{+0.057}_{-0.030}$

Chantal Pitte thesis (2024)

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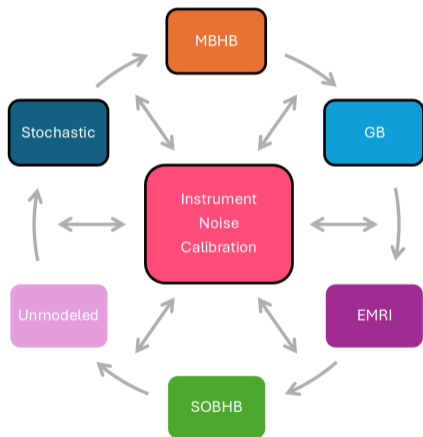


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⇒ Not only concerning the MBHB (EMRIs, Noise, SGWB, Burst ...)

Global fit strategy



- Noise characterisation
- Source identification
- Model parameters and uncertainties (PDF)
- Reconstructed WF + subtraction

Challenges

- ▶ Gaps^a and glitches
- ▶ Noises
- ▶ CPU/GPU^b
- ▶ Models, Multiplicity

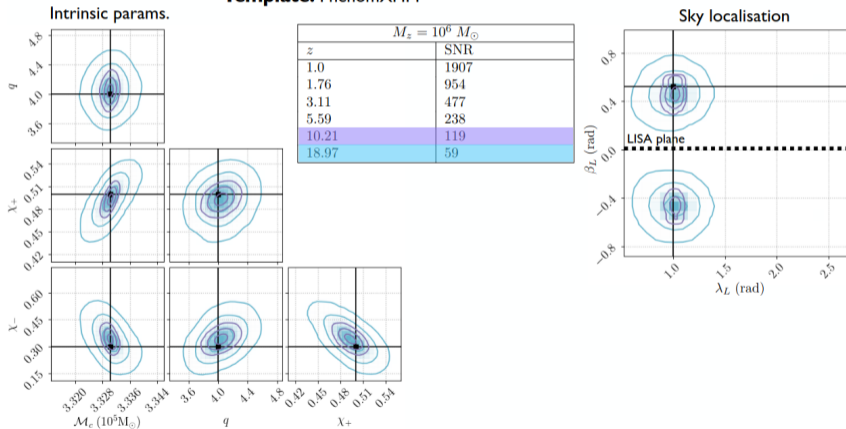
^a<https://arxiv.org/pdf/2605.13738>

^bPhys. Rev. D 111,024060

L3 Data/Catalogue : Mission end products to be served to the scientific community

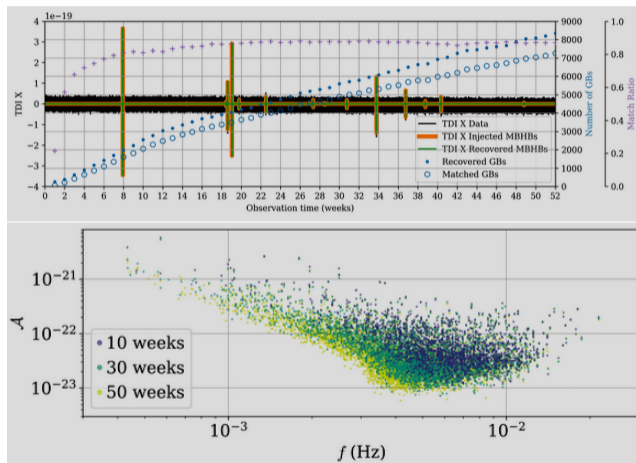
MBHB parameters estimation

- **Injection:** NRHybSur3dq8 $\{M = 10^6 M_\odot, q = 4, \chi_1 = 0.5, \chi_2 = 0.3\}$
- **Template:** PhenomXHM



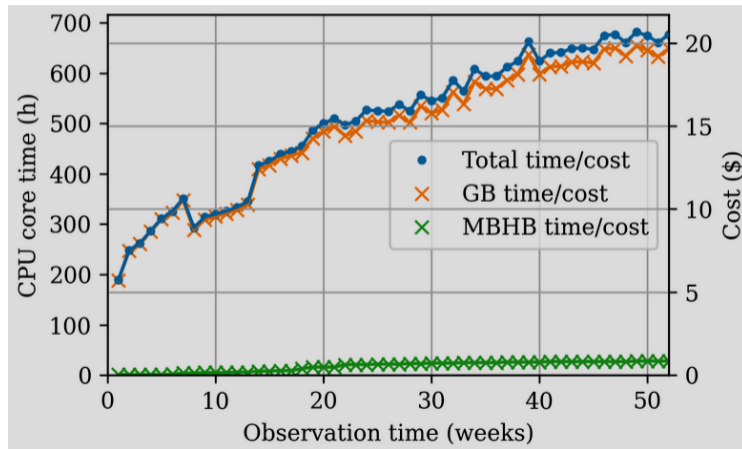
Sylvain Marsat

GBs parameters estimation



Phys. Rev. D 110, 024005

GBs parameters estimation



Phys. Rev. D 110, 024005

Computation cost challenge

Global fit context

Likelihood cost / evaluation

Number of evaluation to converge

→ Dominated by waveform computation

Usage of GPU ? MCMC process ? ML ?

⇒ 1 year of resolvable events : [20:30] Mcpu.h

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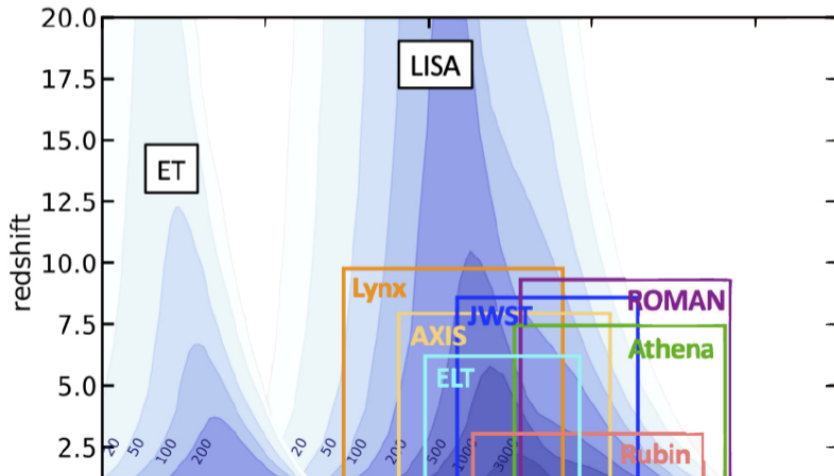
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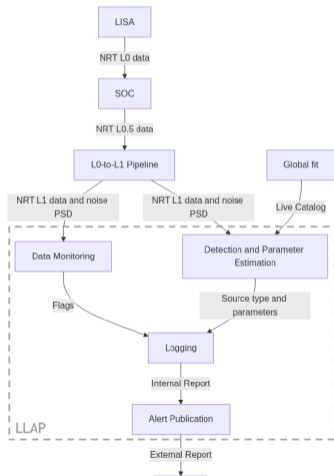
⇒ 1 year of resolvable events : $[20:30] \text{ Mcpu.h} \times \text{nb of pipelines} \times \text{nb of iteration} + \text{R\&D ...}$

Expected EM counterpart

Multi-messenger observation of MBHB :



From L1 to L2A (Low Latency Alert)



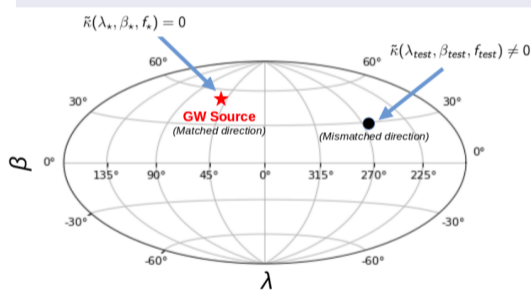
Low Latency

- Alert < 1 hour
- Localisation + chirp time
- Parameters if possible

method	PE
Nullstream method	sky loc.
Time-freq excess power	$t_C + M_C$
Based on global fit	$t_C + \text{intrinsic Params}$
Template bank	$t_C + \text{sky loc.} + M_C$
ML method	t_C

Nullstream channel for Low latency purpose

TDI nullstream for GW source localisation (R Costa-Barroso + H.Alexandre)



- Sky-dependent linear-combination

$$\lim_{(f, \lambda, \beta) \rightarrow (f^*, \lambda^*, \beta^*)} \kappa(f, \lambda, \beta) = 0$$

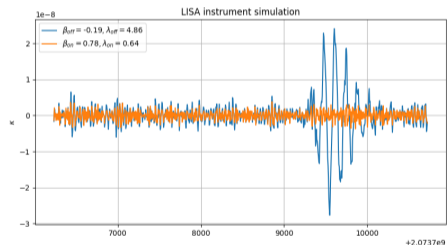
- Agnostic method
Validated for GB, MBHB, EMRIs
- To be optimized for Mojito challenge.

10.1088/1361-6382/addbbd

Coronagraphic time-delay interferometry: characterization and updated geometric prop.

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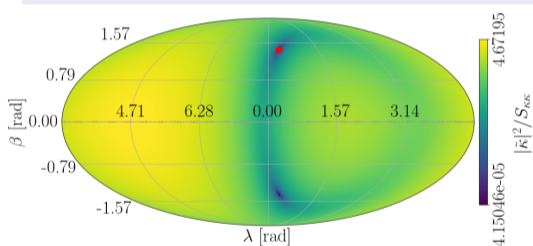
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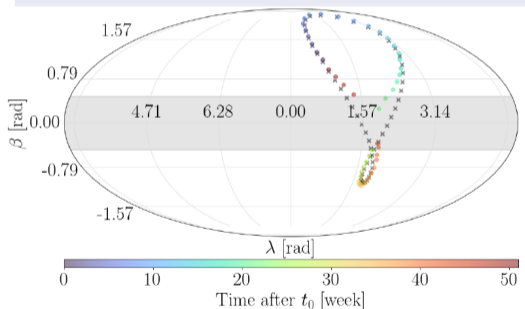
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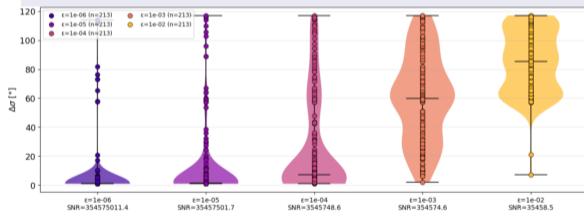
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Coronagraphic time-delay interferometry: characterization and updated geometric prop.

Summary

LISA will...

observe many GW signals → overlapping sources,
deal with noises (laser noise $10^8 > h(t)$) → TDI,
detect high SNR MBHB versus faint SGWB,
need tuned and fast GW template → ML, Jax...,
have to optimize tools to publish the end product catalog !

Stay tuned for LISA catalog !

Questions ?

Stay tuned for LISA catalog !

Questions ?

