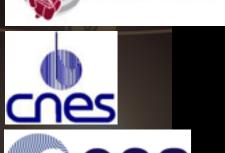


Stochastic Background detection in the context of LISAPathfinder first results and LISA simulation

Antoine Petiteau (APC – Université Paris-Diderot)

eLISA cosmology workshop - DESY Hamburg 20th October 2016





sa pathfinder



Outline

- LISAPathfinder results and LISA sensitivity
- Foregrounds
- Estimation of detectability of stochastic backgrounds
 - Power Law Sensitivity
 - Calibration of SNR and detectability
- LISA (proto-) Data Processing Center: tools available

Next steps:

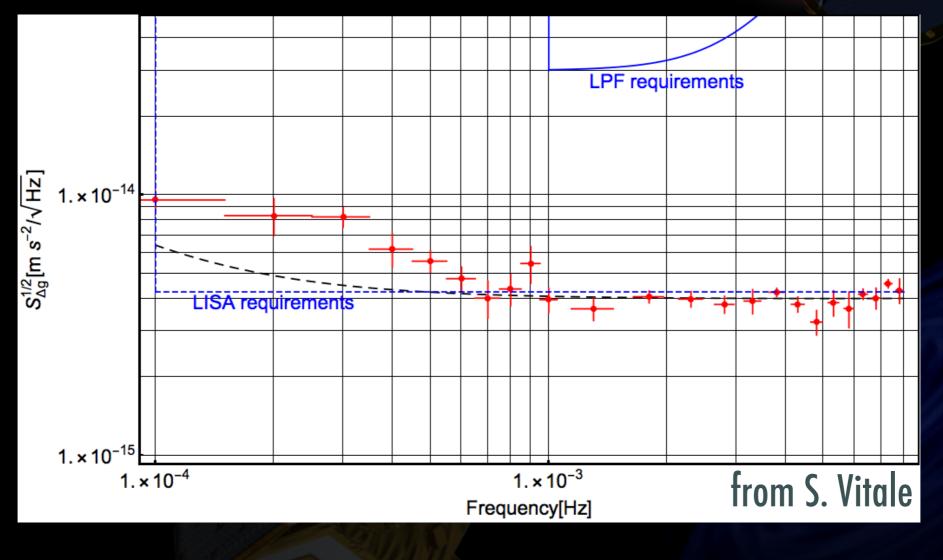
- Simulation & data analysis
- Conclusion







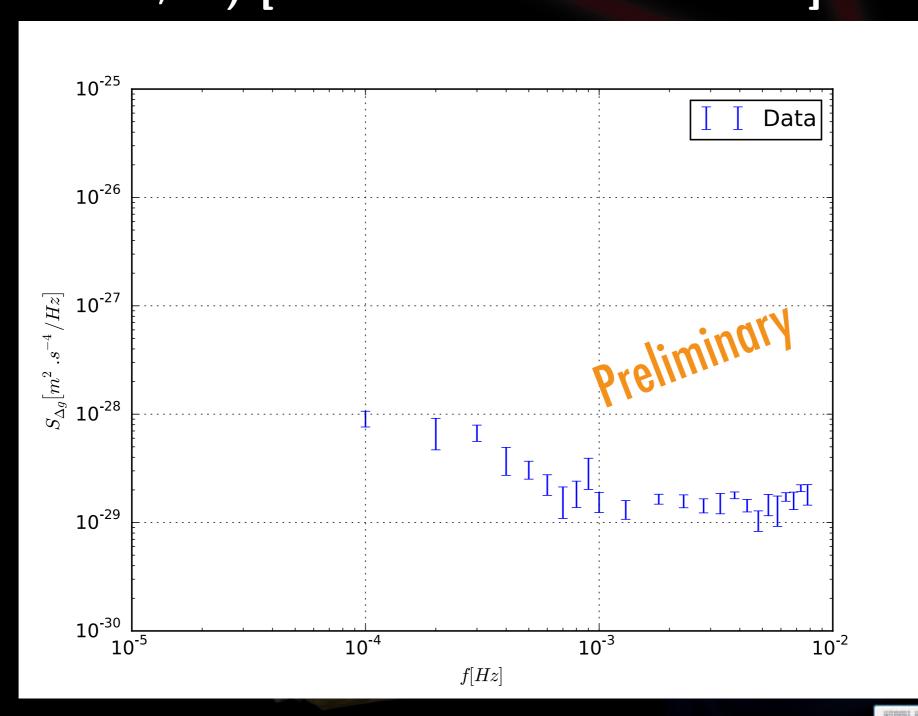
Best average results from LISAPathfinder adapted to LISA (no actuation, ...) [talk from Martin Hewitson]







LISAPathfinder results Best average results from LISAPathfinder adapted to LISA (no actuation, ...) [talk from Martin Hewitson]

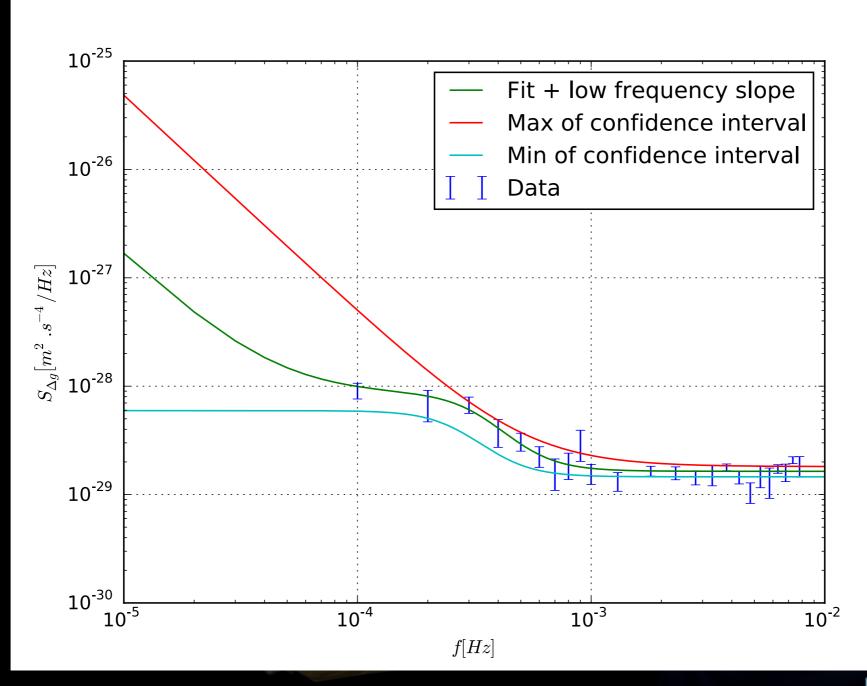


DIDEROT

Stochastic background detection with LISAPathfinder results - A. Petiteau - eLISA Cosmo - DESY - 20th October 2016



- Best average results from LISAPathfinder
 - + confidence interval (large uncertainty at low frequency)

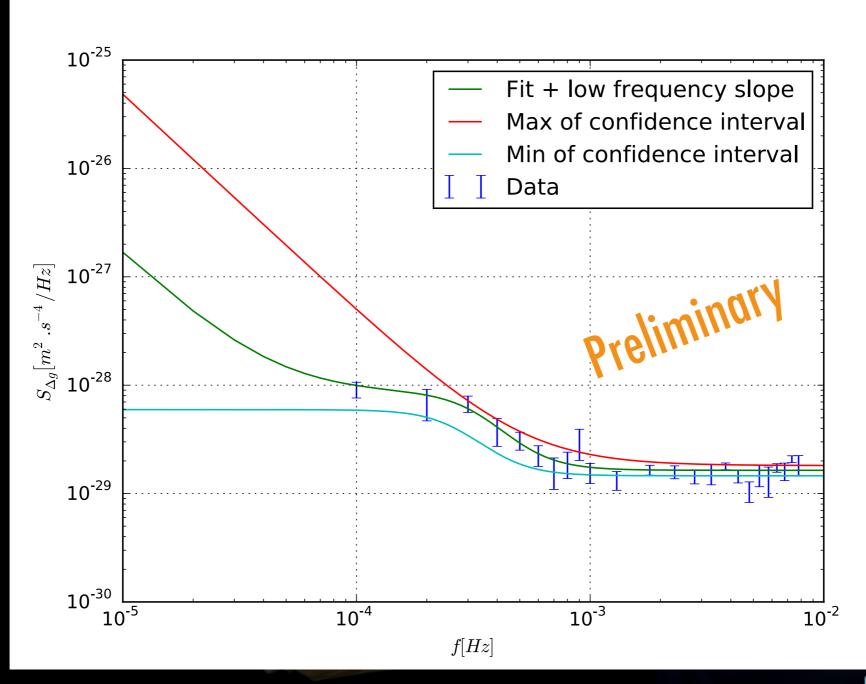


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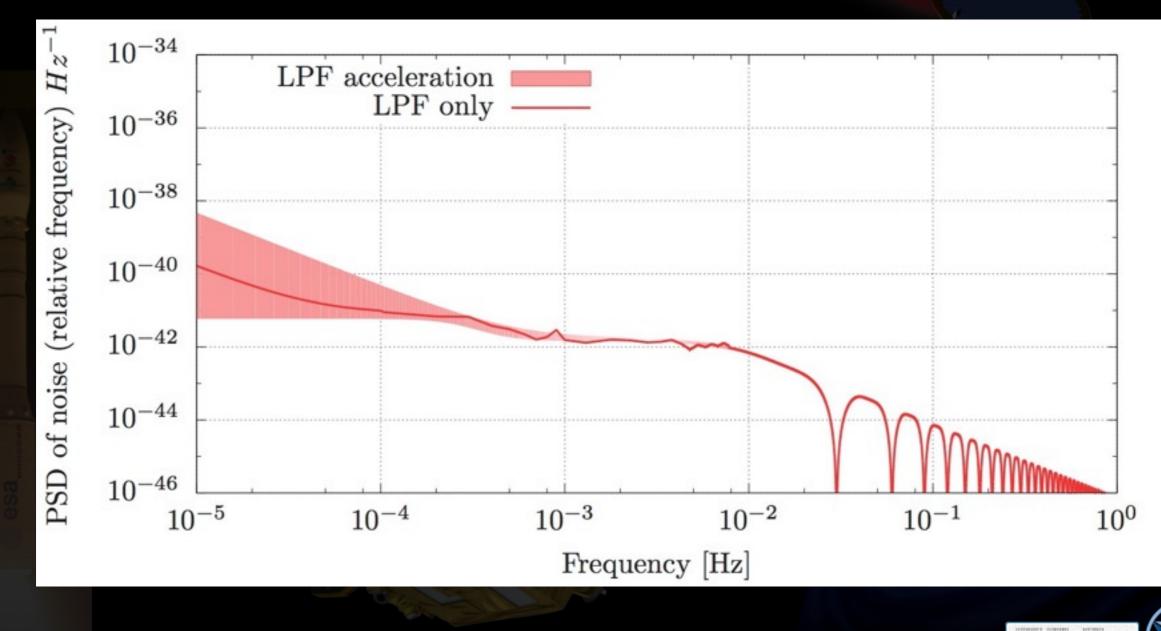


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Stochastic background detection with LISAPathfinder results - A. Petiteau - eLISA Cosmo - DESY - 20th October 2016



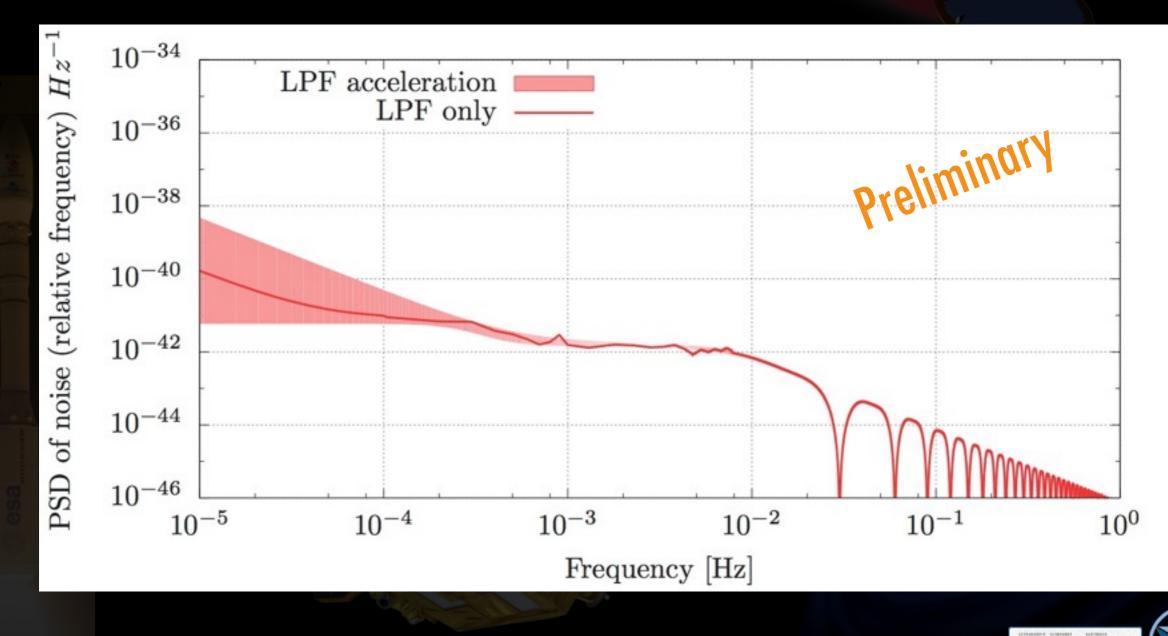
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DIDEROT



- Best average results from LISAPathfinder
 - + confidence interval (large uncertainty at low frequency)



DIDEROT



LISA high frequency noise

• Several versions ...

Configuration	Units	LISA2011M	LISA2011	LxA5MxNxP2D40	LxA5MxNxP2D40	LxA2MxNxP2D30
Model		YB2011M	YB2011	GOAT	AEI2015 [4]	AEI2015 [4]
Armlength	$\times 10^9$ m	5	5	5	5	2
Telescope diameter	cm	38	38	40	40	30
Shot noise	pm/√Hz	7.7	7.7	7.49	6.38	4.54
Relative Intensity Noise	pm/√Hz	1	1		3.03	2.16
Electrical noise	pm/√Hz	1	1		3.03	2.16
Optical path noise	pm/√Hz	7	7		1.00	1.00
Metrology noise	pm/√Hz	5.2	5.2		1.02	1.02
Pilot tone noise	pm/√Hz	0	0		2.57	2.57
$\sqrt{S_{OMS,m}}$	pm/√Hz			5.15		
Margin		1/0.65	1	1	1	1
$\sqrt{\mathbf{S_{IMS,m}}}$	pm/√Hz	18.0	11.7	7.49	8.20	6.19

[4] Barkes et al. 2015

Work in progress to improve the "high frequency" noise budget within the Simulation Working Group





6

LISA high frequency noise

• Several versions ...

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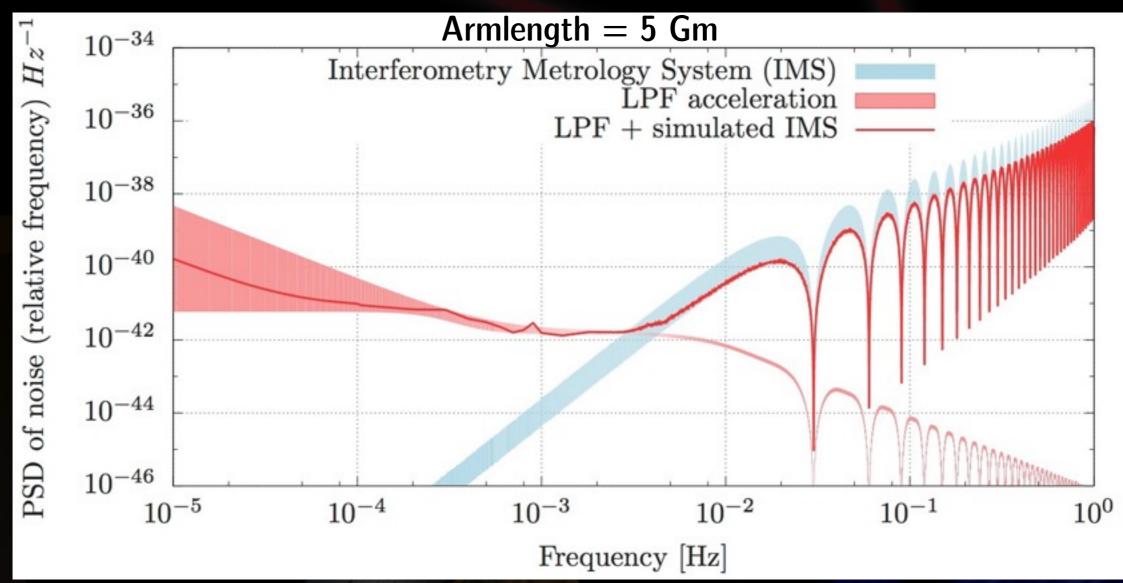
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LISA high frequency noise

Several versions ...



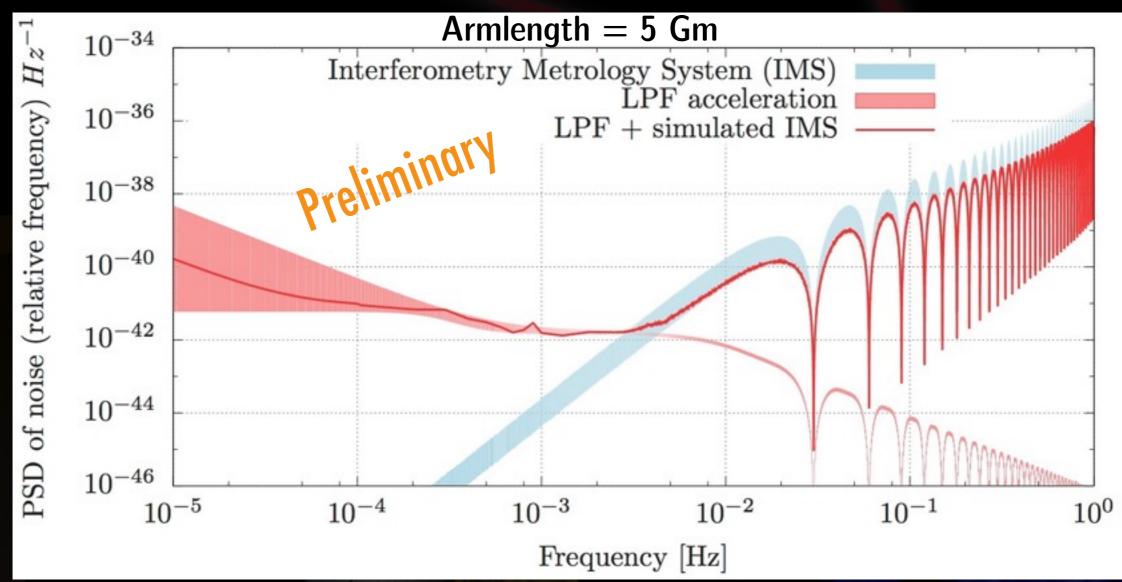
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Stochastic background detection with LISAPathfinder results - A. Petiteau - eLISA Cosmo - DESY - 20th October 2016



LISA high frequency noise

Several versions ...



Work in progress to improve the "high frequency" noise budget within the Simulation Working Group

Stochastic background detection with LISAPathfinder results - A. Petiteau - eLISA Cosmo - DESY - 20th October 2016

Sensitivity in characteristic strain

8

 10^{-16} Acceleration (LPF IMS 10^{-17} Characteristic strain amplitude 10^{-18} 10^{-19} 10^{-20} 10^{-21} 10^{-22} 10^{-3} 10^{-5} 10^{-2} 10^{-4} 10^{-1} 10^{0} Frequency [Hz]

L = 5 Gm



Sensitivity in characteristic strain

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Sensitivity in characteristic strain

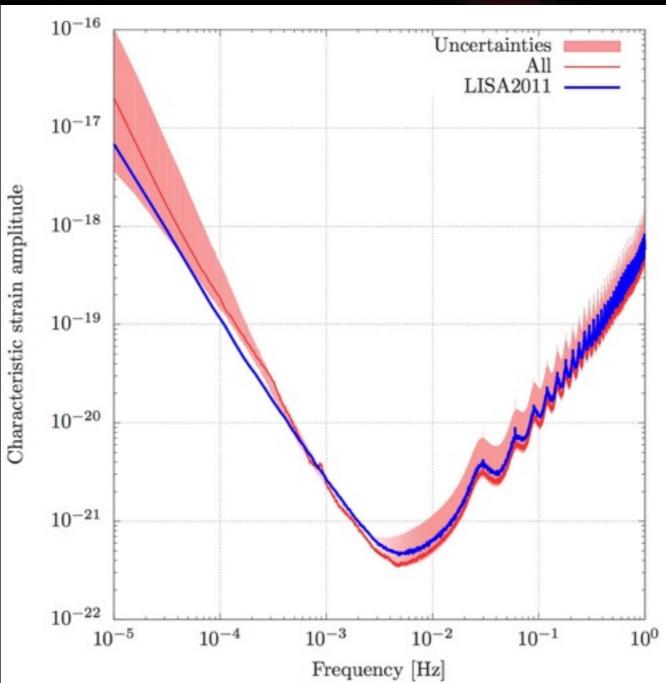
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Stochastic background detection with LISAPathfinder results - A. Petiteau - eLISA Cosmo - DESY - 20th October 2016



L = 5 Gm

Sensitivity in characteristic strain



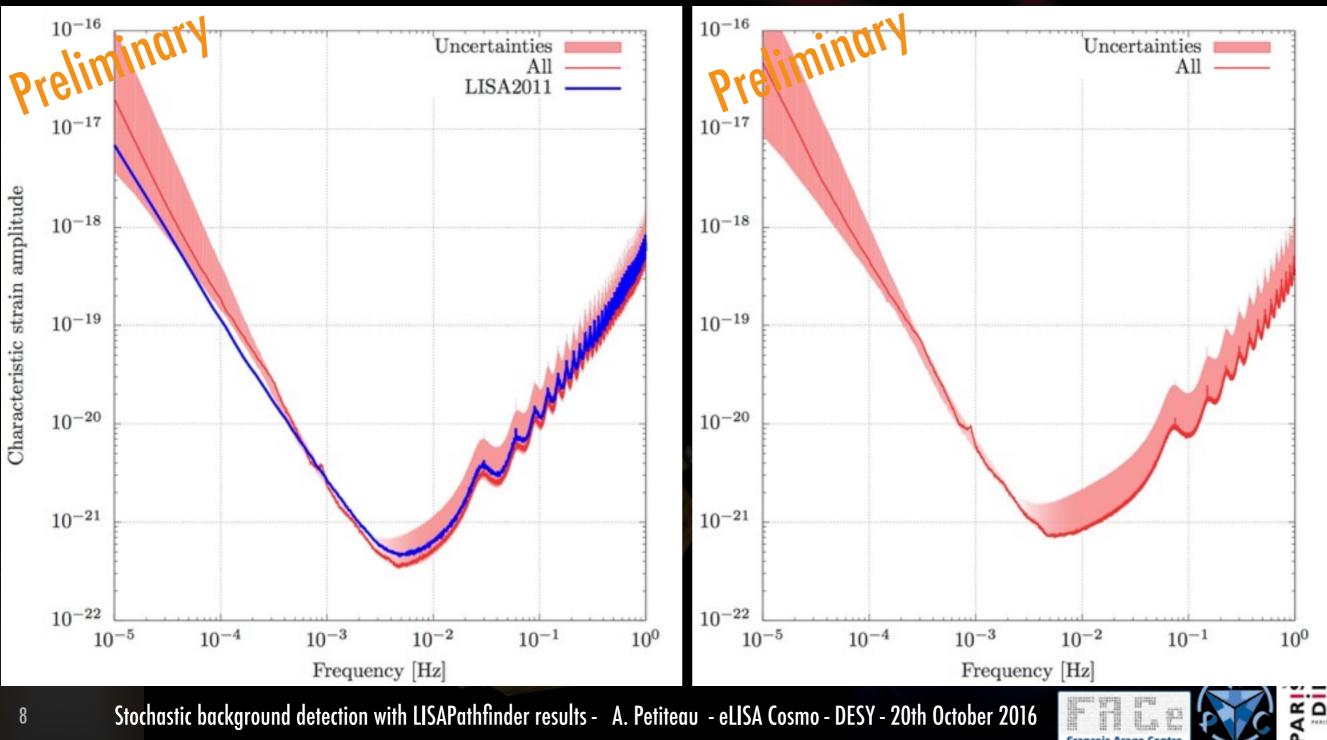
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Sensitivity in characteristic strain

L = 5 Gm

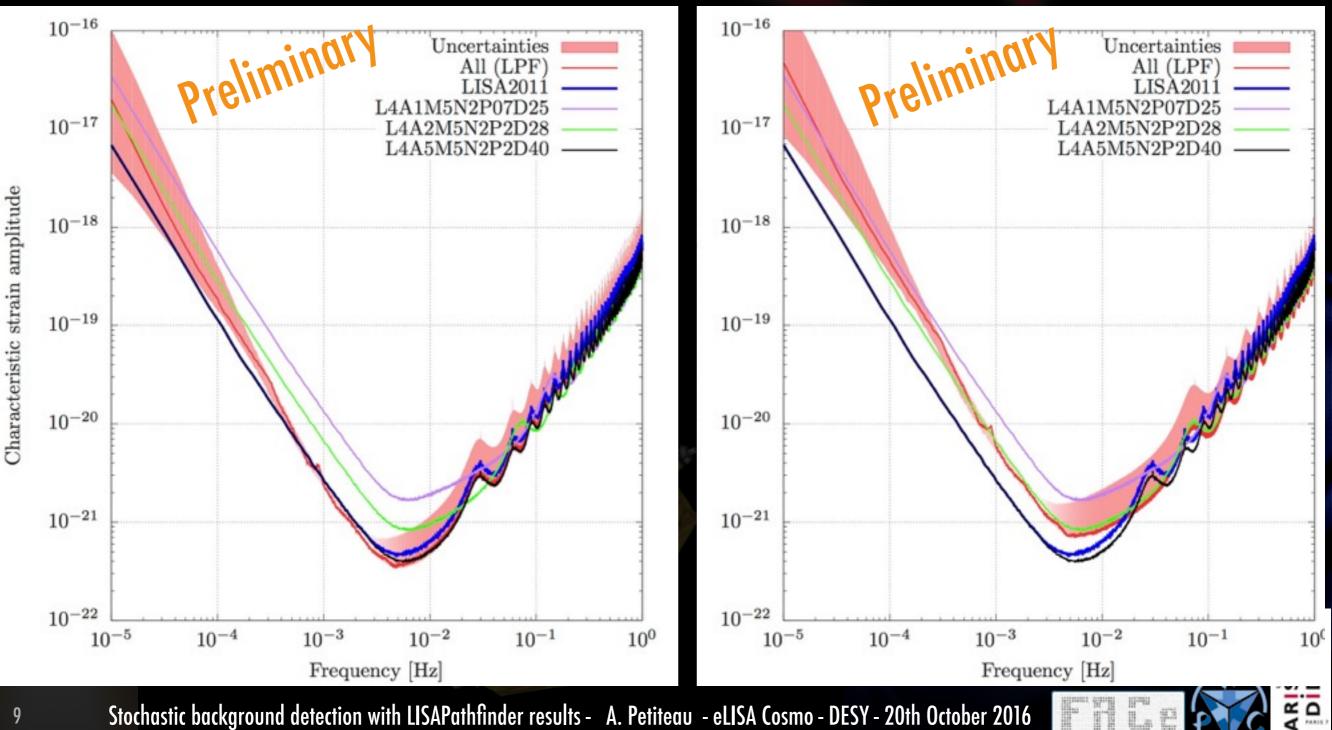
L = 2 Gm



Comparison with GOAT configuration

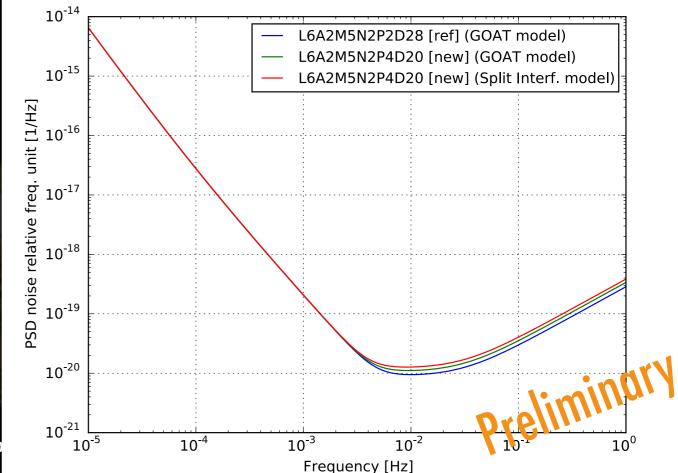
L = 5 Gm

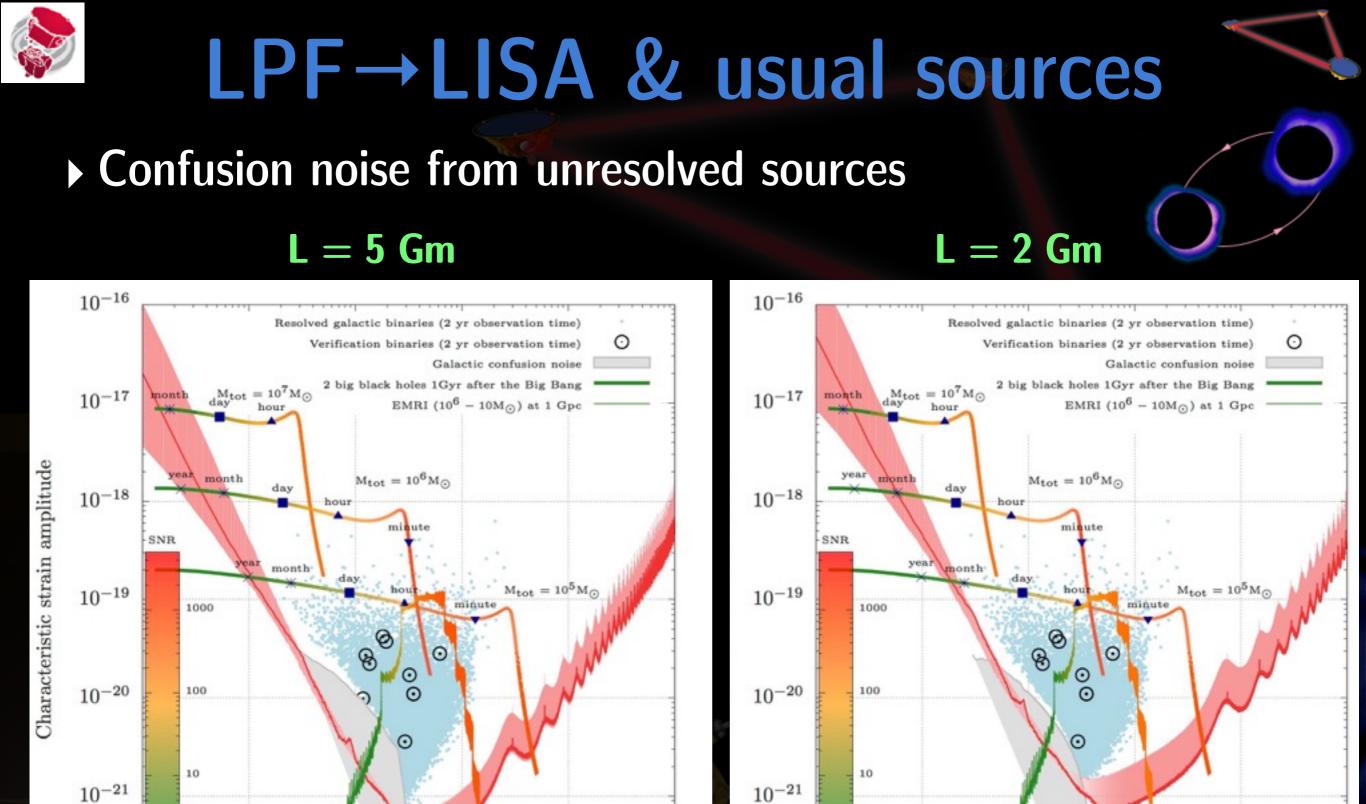
L = 2 Gm



- Configurations in discussion for the response to ESA call (reasonable starting point ?):
 - Telescope: 20 cm, 25 cm, 30 cm, ... ?
 - Laser power: 2 W, 3 W, 4 W, ... ?
 - Armlength: 2 Gm, 3Gm, ... ?

 Maximize the « science » but be sure you can build each item for reasonable cost ...





 10^{-22}

 10^{-5}

 10^{-4}

relimit

 10^{-3}

Frequency [Hz]

 10^{-2}

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Pretimi

 10^{-2}

 10^{-3}

Frequency [Hz]

11

 10^{-22}

 10^{-5}

 10^{-4}

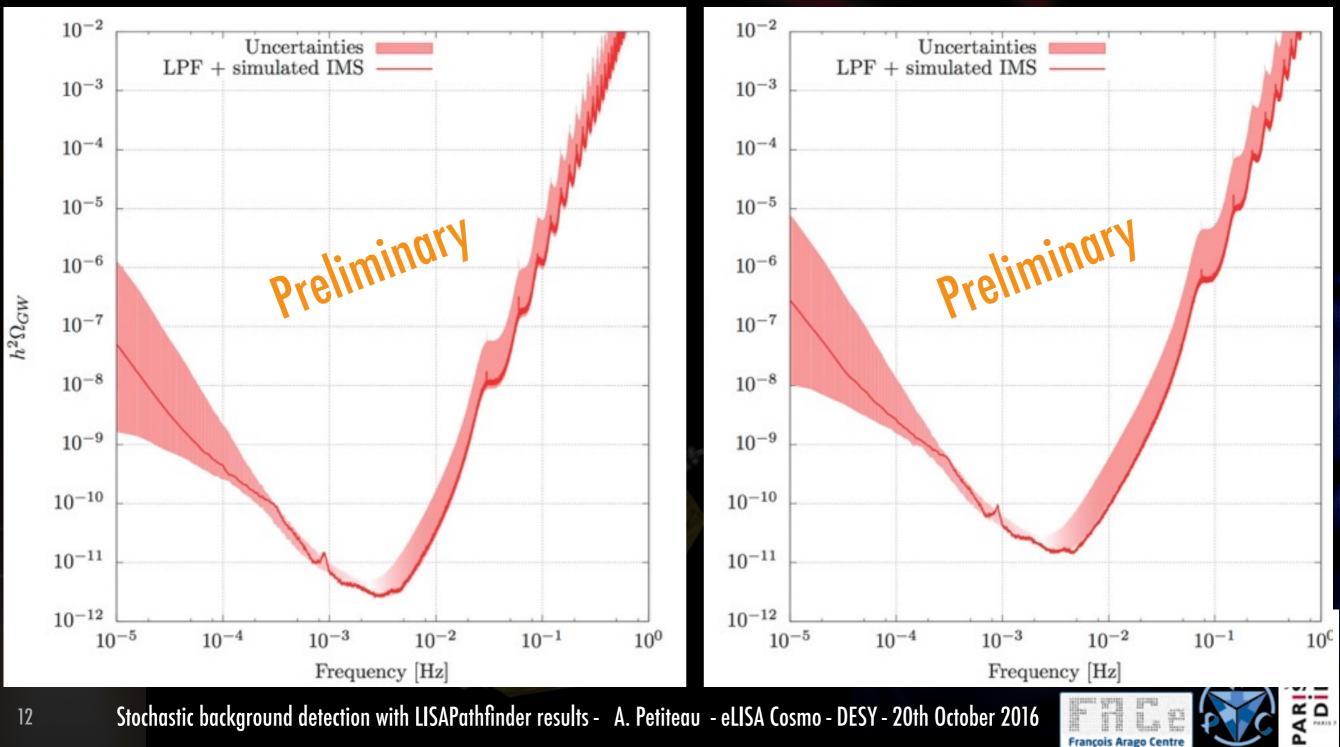


LPF→LISA: Sensitivity

Sensitivity in energy density LPF-LISA

L = 5 Gm







 $h^2 \Omega_{GW}$

13

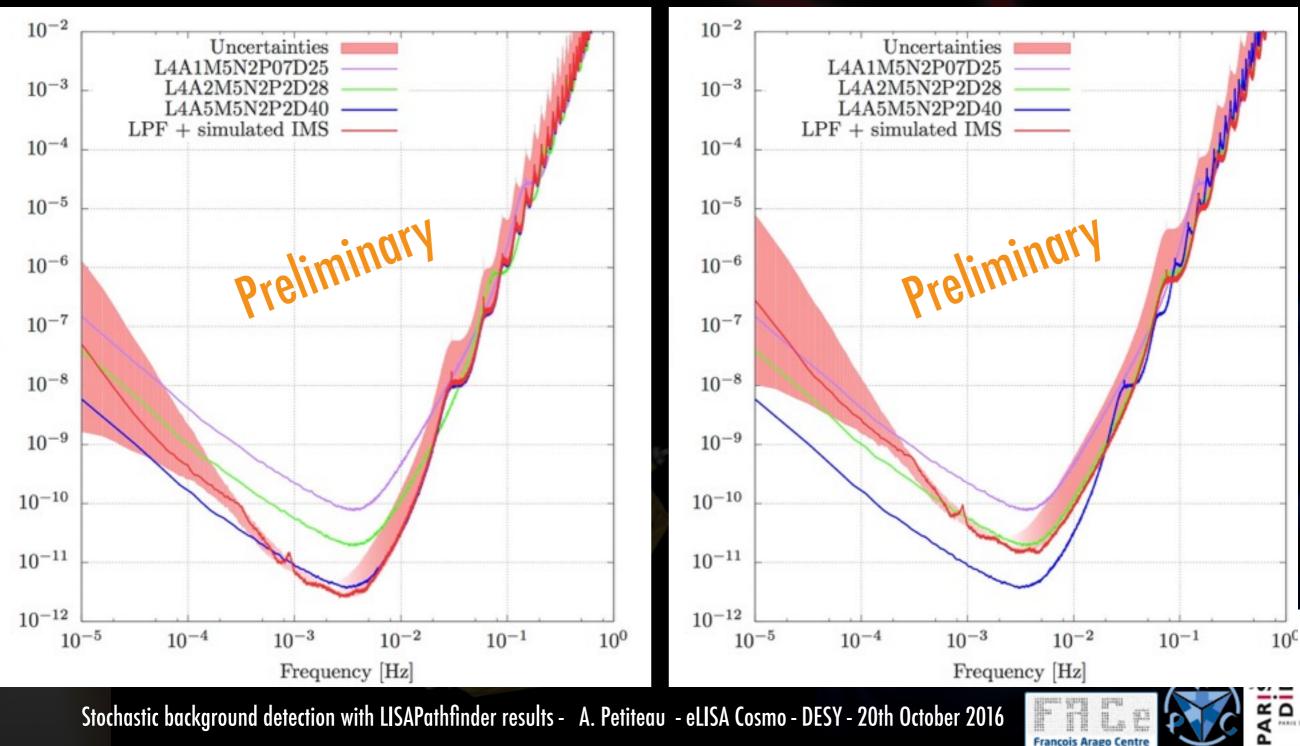
LPF→LISA: Sensitivity

Sensitivity in energy density LPF-LISA vs GOAT

L = 5 Gm

L = 2 Gm

François Arago Centr

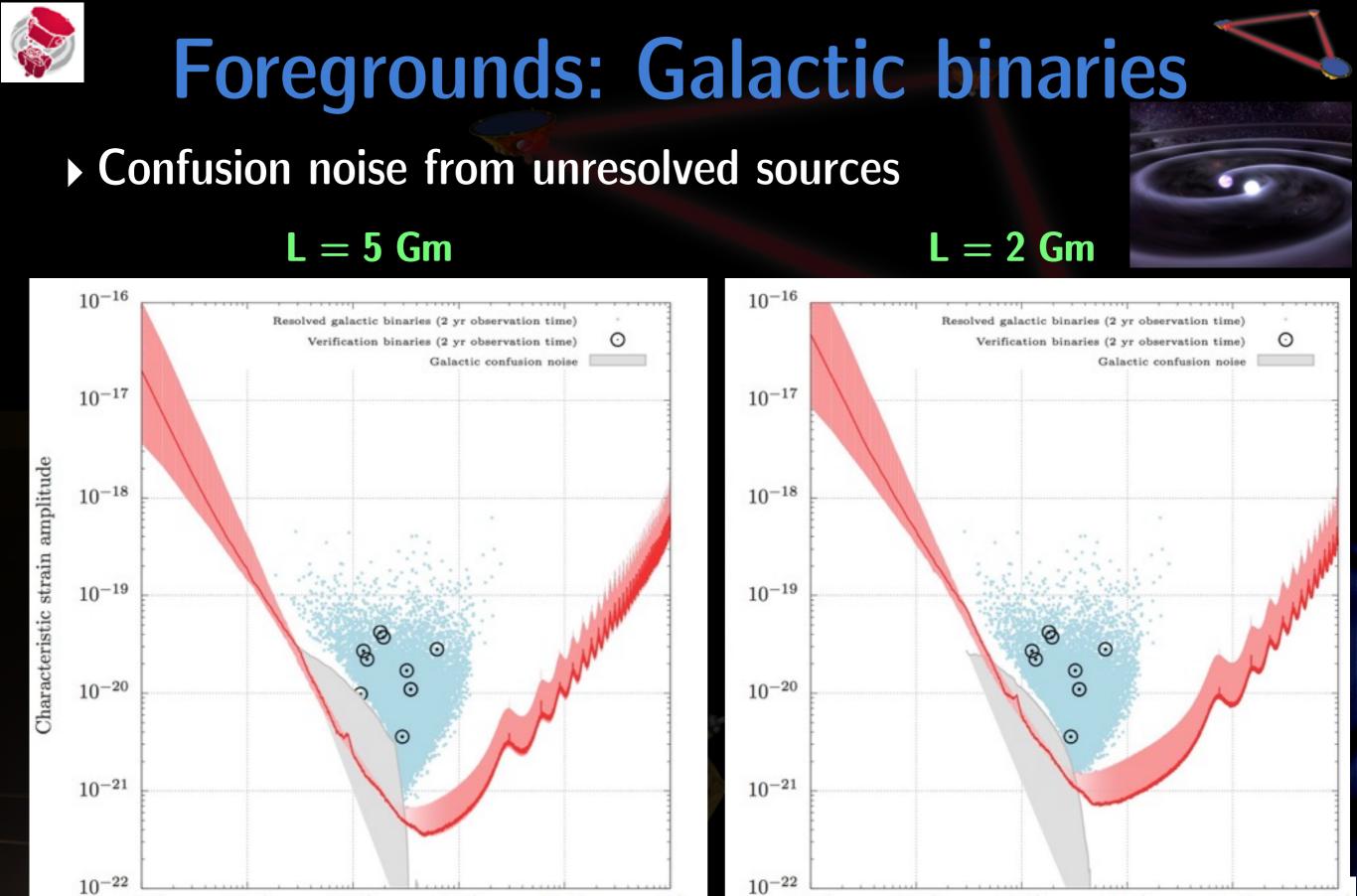




Foregrounds: Galactic binaries

- ▶ 60 millions of galactic binaries in the Galaxy:
 - white dwarfs, neutron stars and stellar mass black holes
- About 1000 to 20 000 sources can be detected depending on the LISA configuration.
- The sum of all the unresolved ones for a confusion noise
 Can be partially « removed » because of the particular spatial distribution of the sources (Adams & Cornish 2014)





 10^{0}

 10^{-5}

 10^{-4}

 10^{-3}

Frequency [Hz]

 10^{-2}

 10^{-1}

100

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 10^{-1}

 10^{-2}

 10^{-3}

Frequency [Hz]

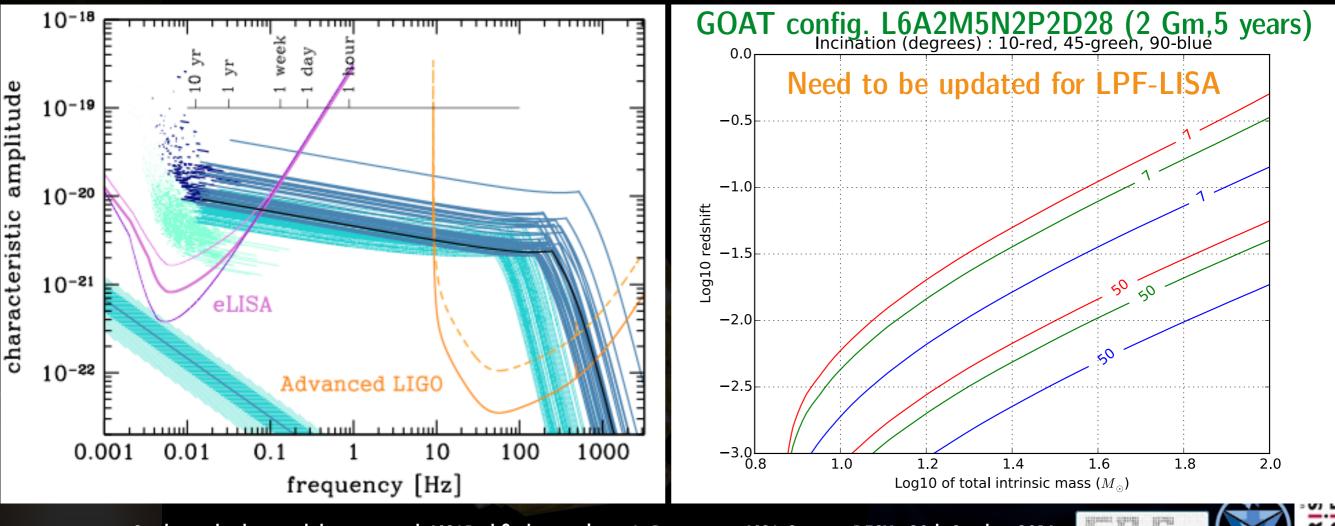
 10^{-4}

15

 10^{-5}

Foregrounds: Black Hole Binaries

- Black hole binaries of few tens solar masses (as GW150914)
 [Sesana 2016]
- The sum of the unresolved sources could form an isotropic foreground for stochastic background



Detectability of Stochastic Background

- How to evaluate if a particular stochastic background can be detected ?
- The standard sensitivity not very well adapted because it does not take into account the integration over frequencies and observation time

One possible estimator: Signal to Noise Ratio (SNR):

$$SNR = \sqrt{T \int_{f_{min}}^{f_{max}} df \frac{(h^2 \Omega_{GW}(f))^2}{(h^2 \Omega_{Sens}(f))^2}}$$

- If $SNR > SNR_{threshold} => detection$
- SNR_{threshold} ?





Power Law Sensitivity (PLS)

- For an isotropic unpolarized Gaussian stationary stochastic background described by a power law : $h^2 \Omega_{GW}(f) = \Omega_{\beta} \left(\frac{f}{f_{ref}}\right)^{\beta}$
- PLS = sensitivity for a given integration time and SNR
- Computed via a scanning of all slopes, finding for each ones
 the amplitude corresponding
 to the SNR
- Ex: LISA2011Margin, 1 year
 See Thrane & Romano 2013 for more details

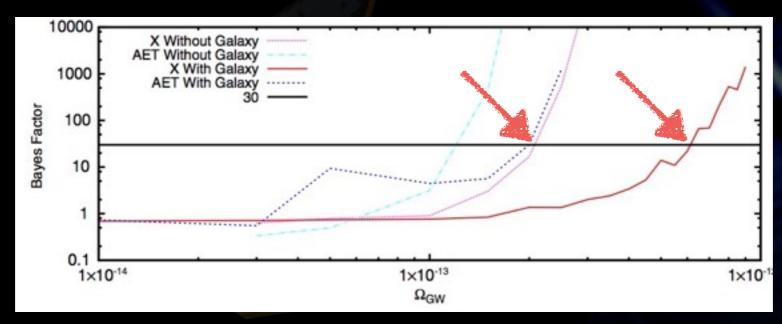
 $fet = \begin{bmatrix} 10^{-8} \\ 10^{-10} \\ 10^{-12} \\ 10^{-14} \\ 10^{-4} \\ 10^{-3} \\ f(Hz) \end{bmatrix} \begin{bmatrix} 10^{-2} \\ 10^{-2} \\ 10^{-2} \\ f(Hz) \end{bmatrix}$

10⁻¹



SNR threshold

- How to calibrate the SNR threshold ?
- Results from Adams & Cornish 2014 [see Neil's talk]:
 - Detection of a stochastic background on simulated data taking into account the galactic confusion noise (Bayes factor>30)
 - Minimal detected amplitude:
 - $\Omega_{GW}>2$ x $10^{\text{-}13}$ with 6 links, LISA2011M and 1 year
 - $\Omega_{GW}>7$ x $10^{\text{-}13}$ with 4 links, LISA2011M and 1 year

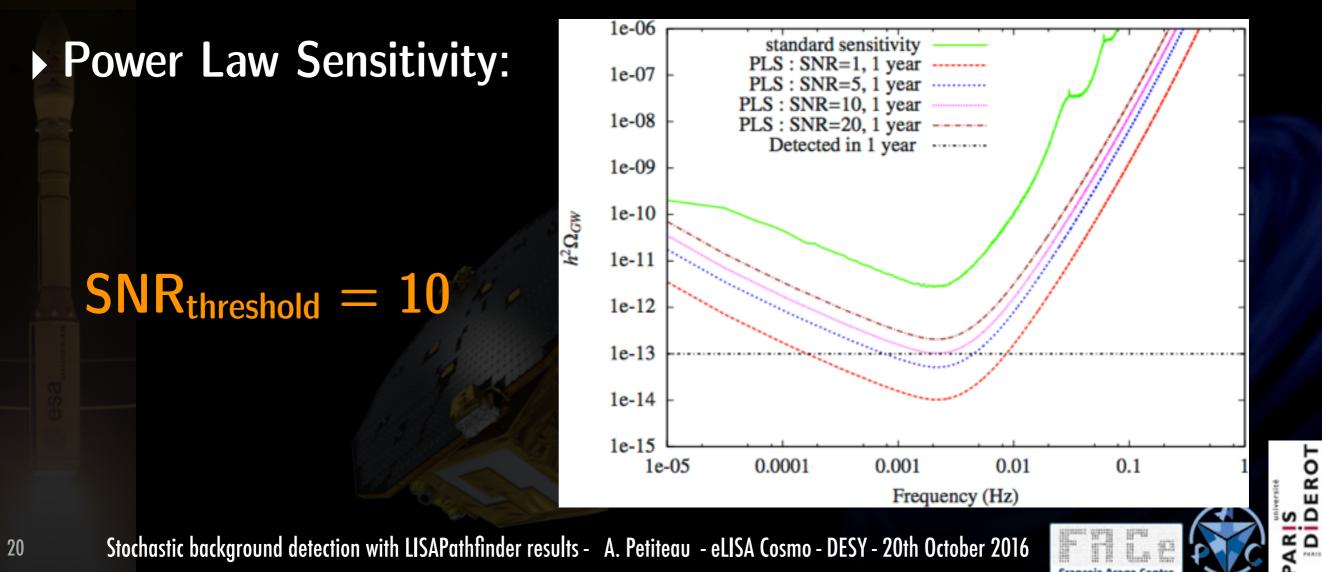






Sensitivity & SNR: 6 links

- Adams & Cornish: with LISA in one year detection of $\Omega_{GW}>2 \ x \ 10^{-13} => h^2 \ \Omega_{GW}>1 \ x \ 10^{-13}$
- Seems to be a safe results because with 3 arms we can "have" spectral shape informations using cross-correlation

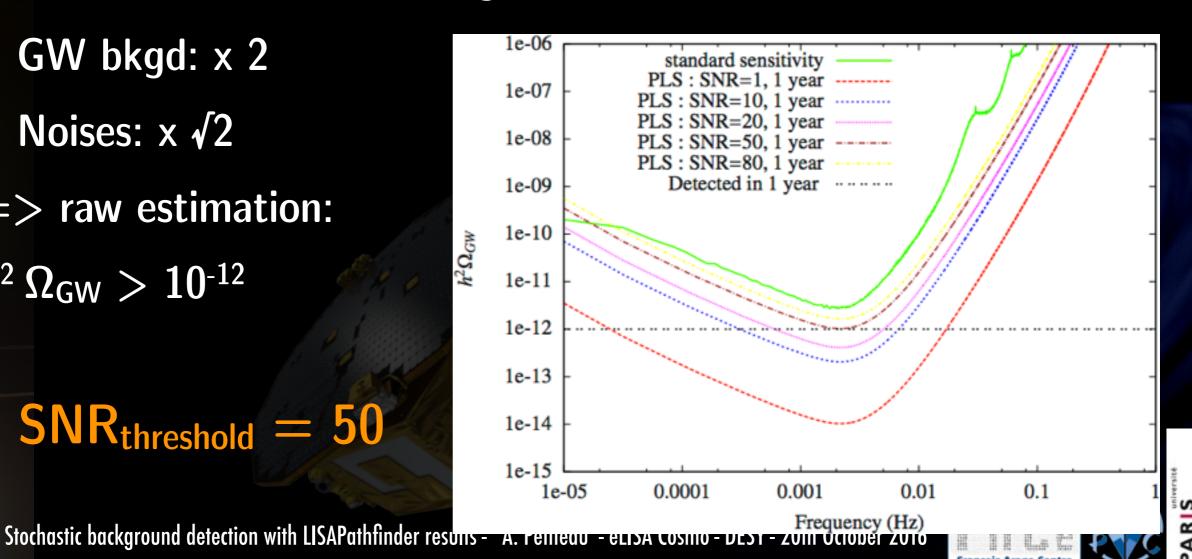




Sensitivity & SNR: 4 links

- Adams & Cornish: with LISA in one year detection of $\Omega_{GW} > 7 \ge 10^{-13} = h^2 \Omega_{GW} > 3.5 \ge 10^{-13}$
- BUT we need some spectral informations !
- Raw estimation: more degrees of freedom in the fit:
 - GW bkgd: x 2
 - Noises: $x \sqrt{2}$
 - => raw estimation: $h^2 \Omega_{
 m GW} > 10^{-12}$





DEROT



 10^{-2}

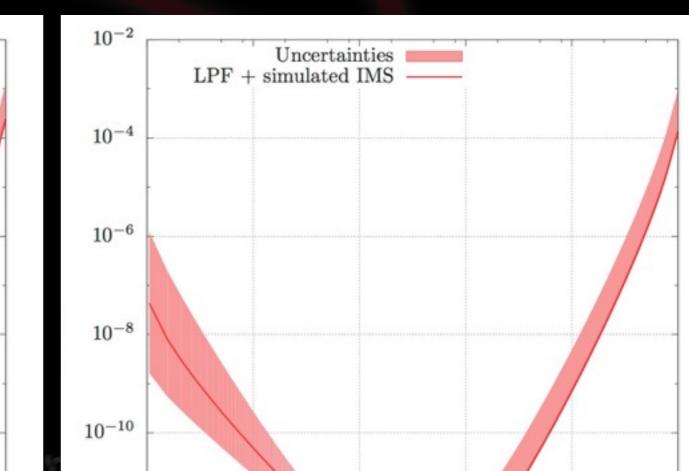
Power Law Sensitivity (PLS)

For LPF→LISA

L = 5 Gm

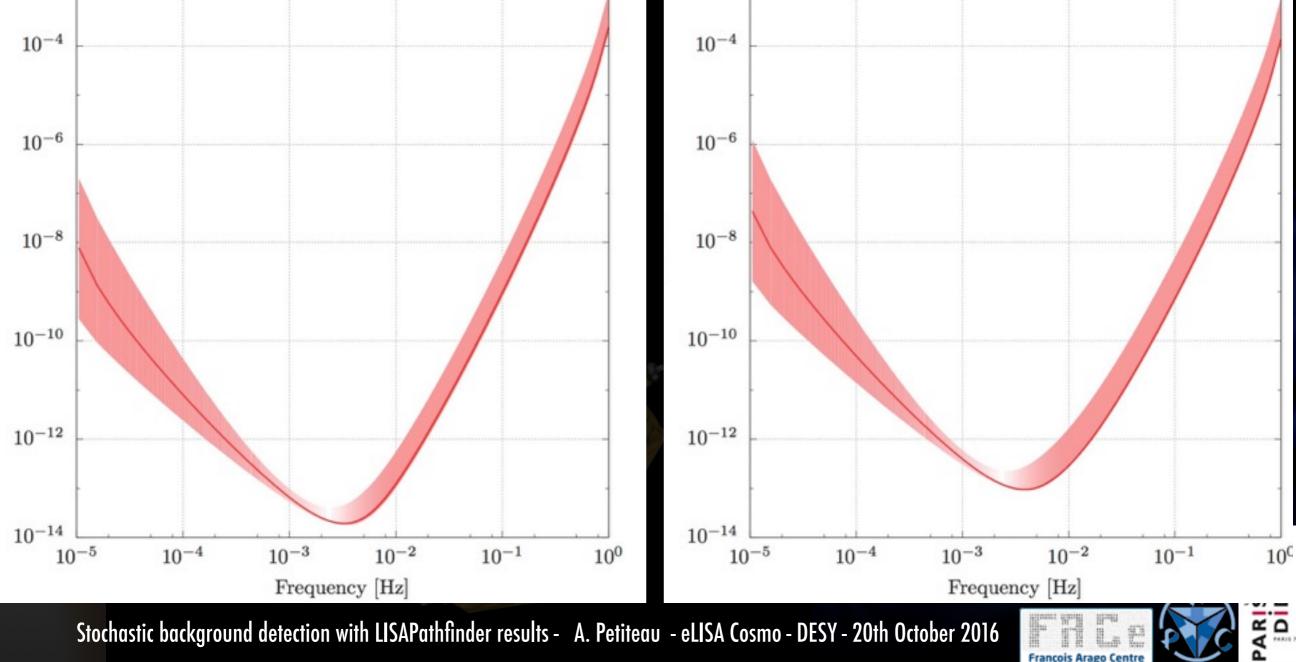
Uncertainties

LPF + simulated IMS



Francois Arago Cer

L = 2 Gm



 $h^2 \Omega_{GW}$

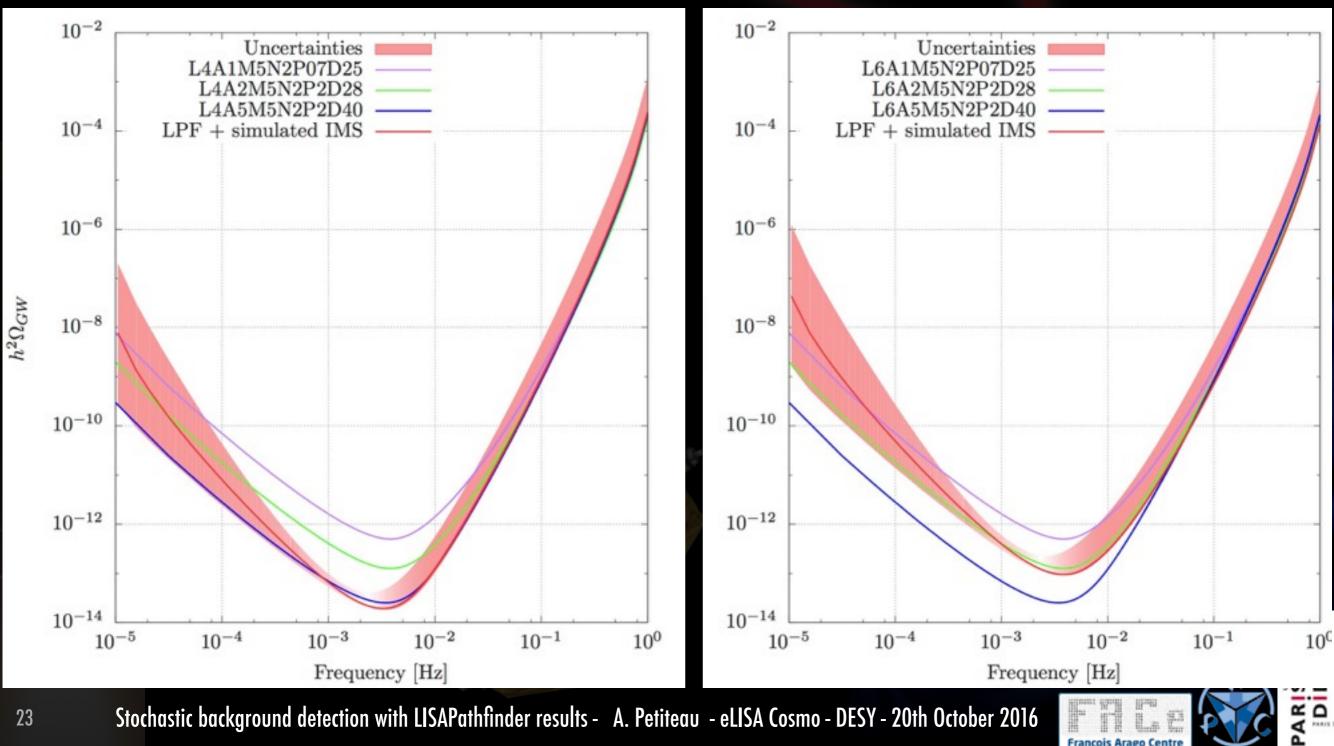




► For LPF→LISA and GOAT configurations

L = 5 Gm

L = 2 Gm



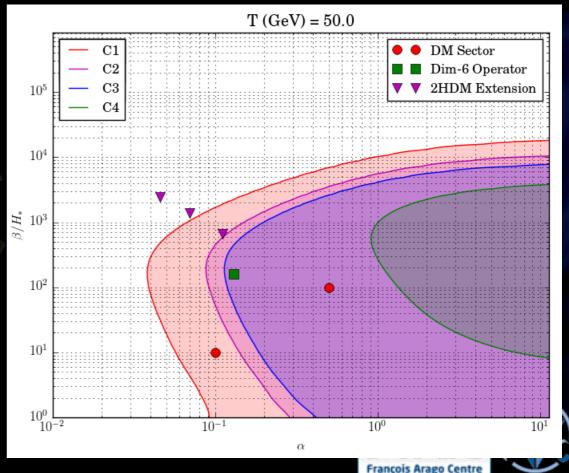


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Estimation of detectability

- Given a stochastic background depending on parameters
 Ω_{GW} (f, p₀, p₁, p₂, ...),
- We compute the SNR for a given configuration & observation time
- The part of the parameter with SNR>SNRthreshold can be detected. T(GeV) = 50.0
- Already used in Caprini et al.
 JCAP 04, 001 (2016)





ROT

The proto Data Processing Center

- Development started after a CNES phase 0 study
- Tool for the consortium
- DPC: https://elisadpc.in2p3.fr/home/index.php
 - Continuous integration: compilation, quality evaluation, doc., virtual machine for user, ...
 - Hybrid infrastructure (regular cluster + cloud)
 - to absorb fluctuations of computation charge.
 - Database
 - Documentation ? Web-service ?
- The proto-DPC is the framework for eLISA simulations & for future MLDC ...





eLISA CI

Jenkins

CONTINUOUS INTEGRATION HOMEPAGE

This is the toroughp for the 4LSB continuous integration service provided by the APQ-FAEs. From this page you can explore the projects actuarly processed, box at the search of the integration (Landond) and shear the quality of the costs (DarwQual). Some pages trans multiched accesses if you need performing excesses at some services, phases send on error's trainadore attendings, edgeb. For some projects, the access to the source costs's protected for all the page's involved in the quality relation.

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GitLab

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eLISA CI

Jenkins

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For some projects, the access to the sauce code is primited bit guaranteed to all the people lowered in the specific anisot.

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Tools in the LISA DPC

- Several project managed by a continuous integration system:
 - eLISAToolBox:
 - Compute LISA noise budget [LISANoise.py]
 - SNR and plot for a given stochastic background (file)
 [SNRStochBackground.py]
 - Make contour plot for parametrized stochastic background [PlotContour.py]
 - ...
 - Simulator ...
 - Others tools:
 - LISACommon, LISAOrbits, docker for LISA, ...





Next steps

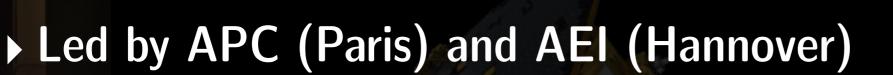
- Stochastic backgrounds:
 - Polarized background ? Anisotropic background ? Non-gaussian background ?
- Simulation: more realistic data ...



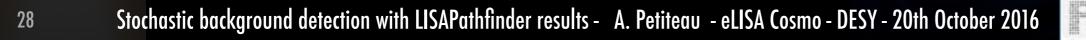


The Simulation Working Group

- About 20 scientists from various European laboratories
- Diversity of expertises:
 - LISAPathfinder
 - LISA instrumentation
 - GW waveform modeling
 - Data analysis
 - Astrophysics



- Start using LISACode as a basis
- ► Very active group. You are welcome to join !









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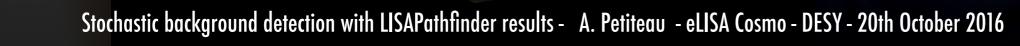
The Simulation Working Group

Goals:

- End-to-end simulation \rightarrow the mission simulator
- "Quick performance" study for various configurations → final design (required for phase A)
- Accompany the hardware developments (industries & labs.)
- Tool(s) for performance controls

First requirements:

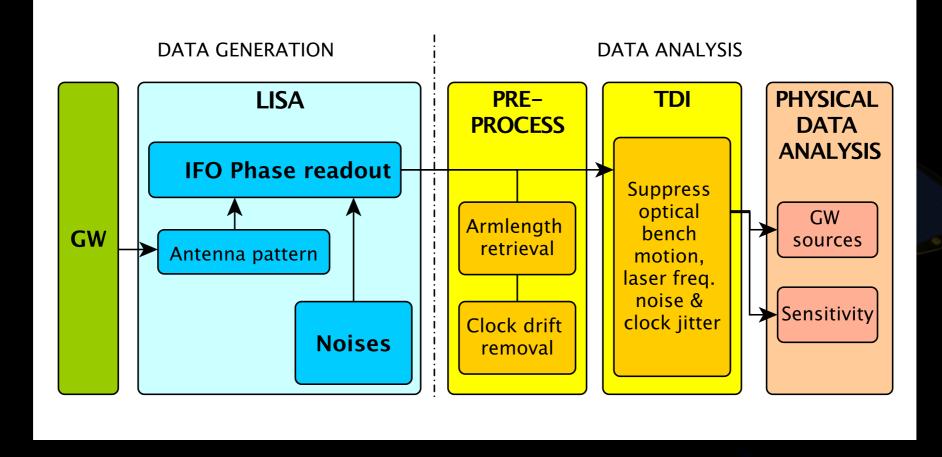
- Close modeling of the instrument subsystems
- Waveform generation for various GW sources
- Noise generation using various types of representation
- Data pre-processing (distinct from simulation)
- Modularity
- Computation speed (> 10-100 times faster than reality)
- Open-source





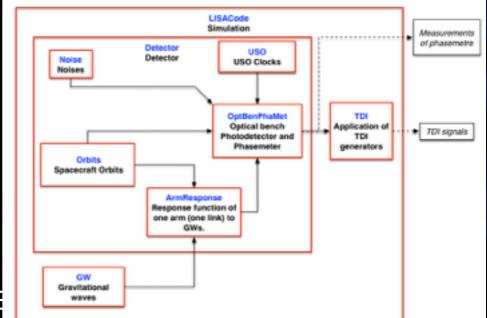


LISA Simulation



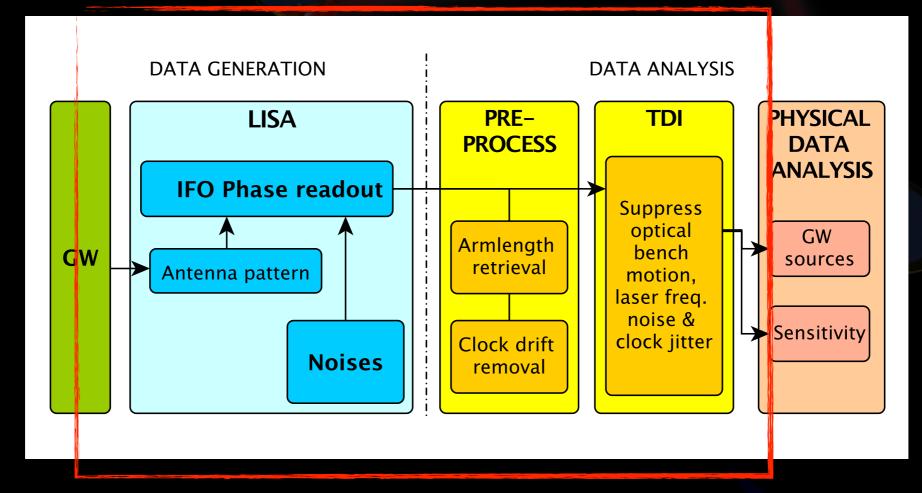
LISACode is the starting point of the end to end simulator

- 2 complementary simulators:
 - TDISim (check TDI)
 - LISADyn (3D dynamic)
 - Stochastic background detection with LISAPathfinder results A. Petiteau eLISA Cosmo DE



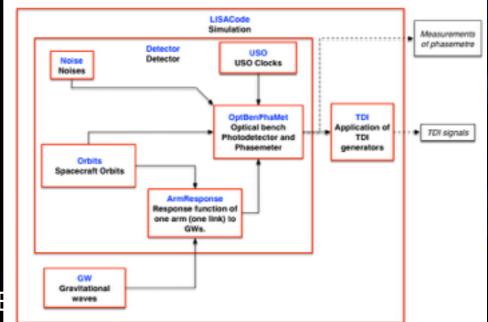


LISA Simulation



LISACode is the starting point of the end to end simulator

- 2 complementary simulators:
 - TDISim (check TDI)
 - LISADyn (3D dynamic)





Next steps

- Stochastic backgrounds:
 - Polarized background ? Anisotropic background ? Non-gaussian background ?
- Simulation: more realistic data ...
 - Instrument simulation: work in progress ...
 - Simulation of stochastic background: current implementation similar to the MLDC one: 192 sources of GW noise distributed on sky. Implement new type of stochastic background ?
 - Better modeling of foregrounds:
 - Improved/updated Galactic binaries confusion noise
 - « Confusion noise » from few tens solar masses binaries





Next steps

> Data analysis:

- Restart MLDCs making use of the LISA DPC framework:
 - More realistic sources all together + simplified noises
 - More realistic instrument modeling + simplified sources
- Implement (or re-implement or just collect) data analysis pipelines for stochastic background
- Make the exercices of applying them on simulated data
 => Improve or understanding of background detectability
 => Provide easy-to-use tools for estimating the detectability of any stochastic background





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Thank you

