The Simulation of Lisa and Data Analysis

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for the LISA_APC group

Outline

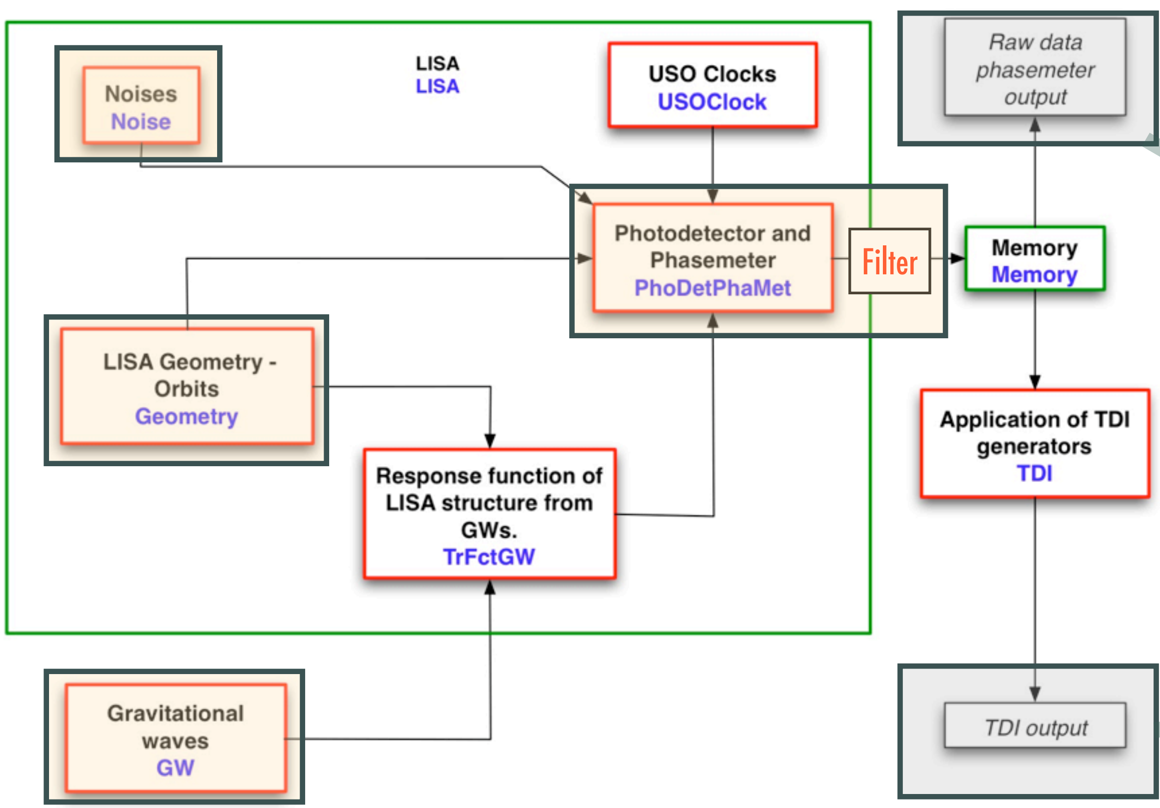
- The simulation of LISA : LISACode
  - Motivations
  - LISACode
  - The sensitivity curve in different situations
- Data Analysis and the Lisa Mock Data Challenge
  - The strategy
  - The Analysis of Training and Challenge 1.1.1a
  - The EMRIs and Time-Frequency analysis

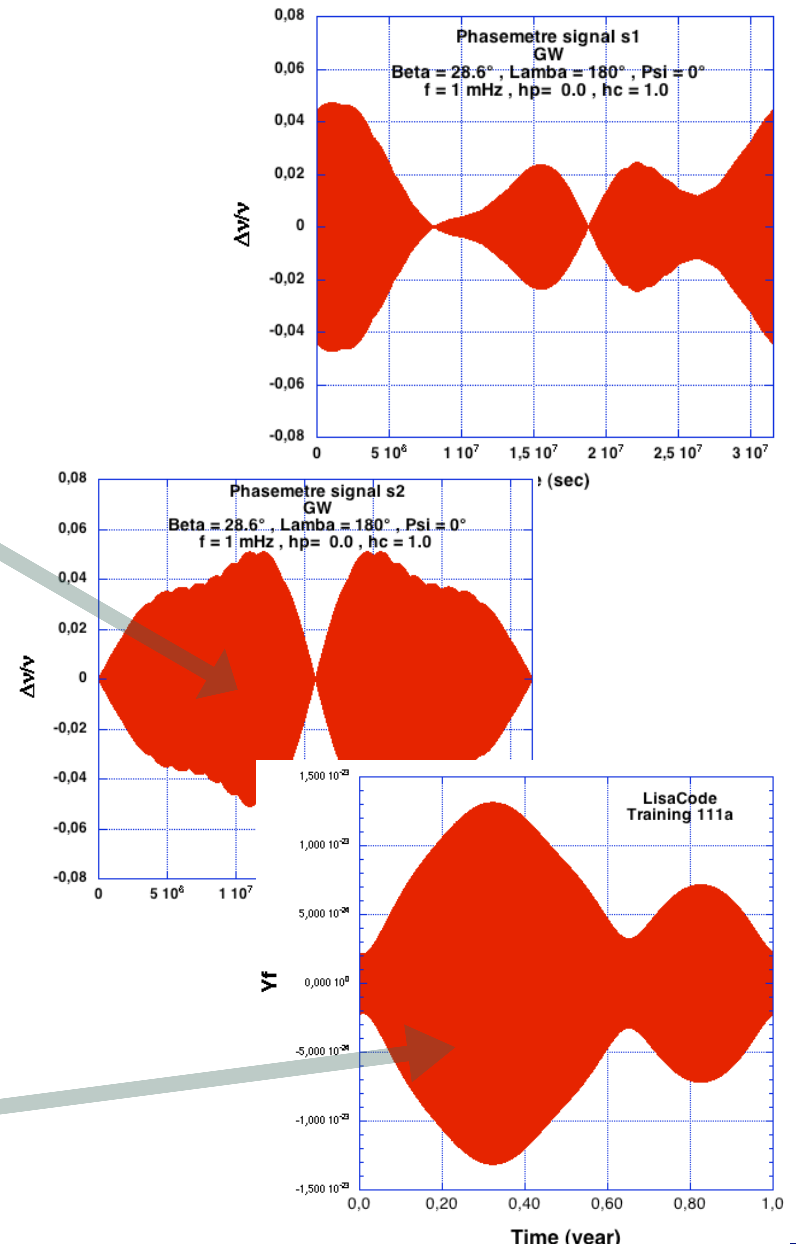
LISACode : the motivation

- Simulation and detector development
- European Effort (ESA/DAST)
- Comparison between different codes
- Data Analysis

LISACode : Basic Principles and structure of the code

- Inputs : Gravitational Waves (and noise !).
- Outputs : Time sequences : phasemeters and TDI



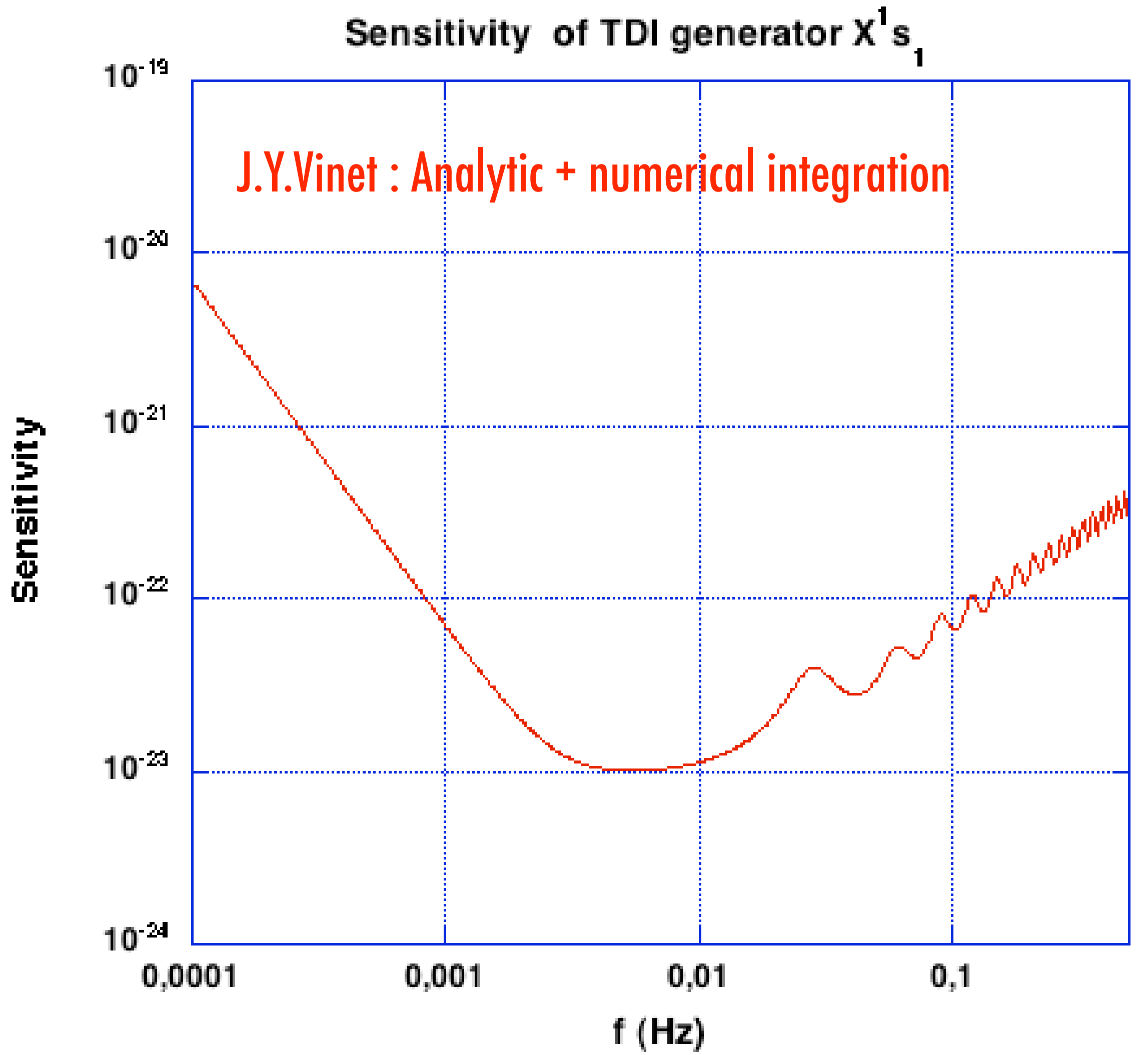


The LISA sensitivity curves : X_1

Lisa is fixed : no flexing or Sagnac

TDI first generation... of course.

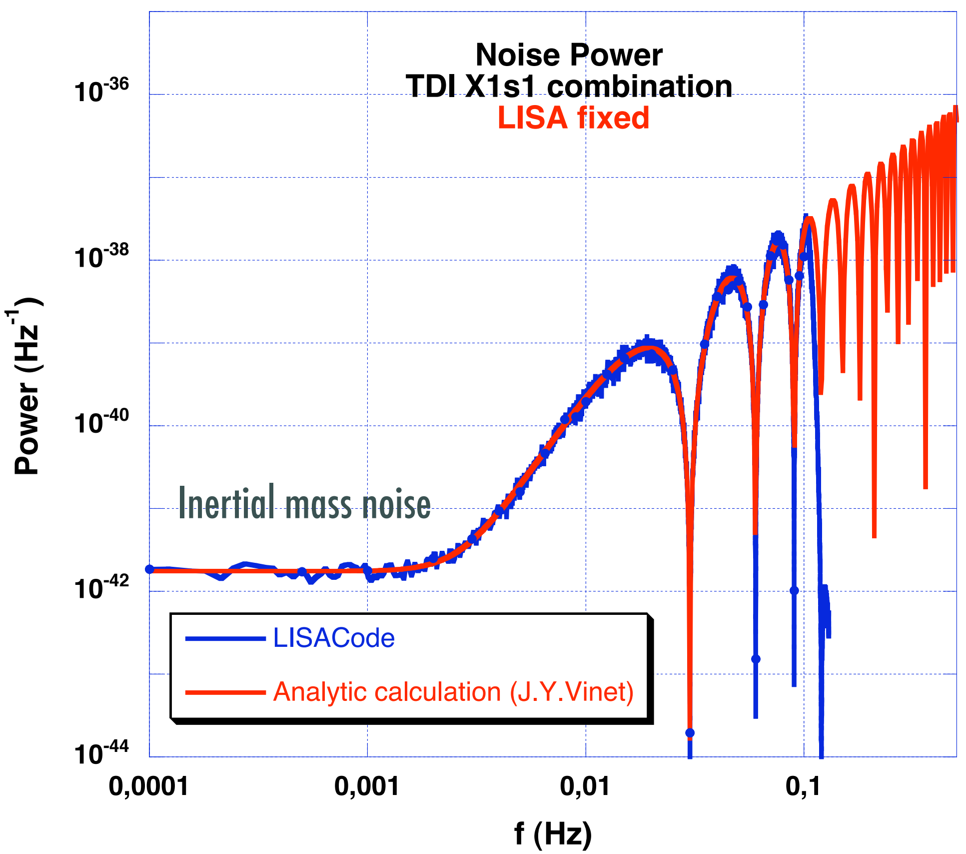
Isotropic distribution of sources

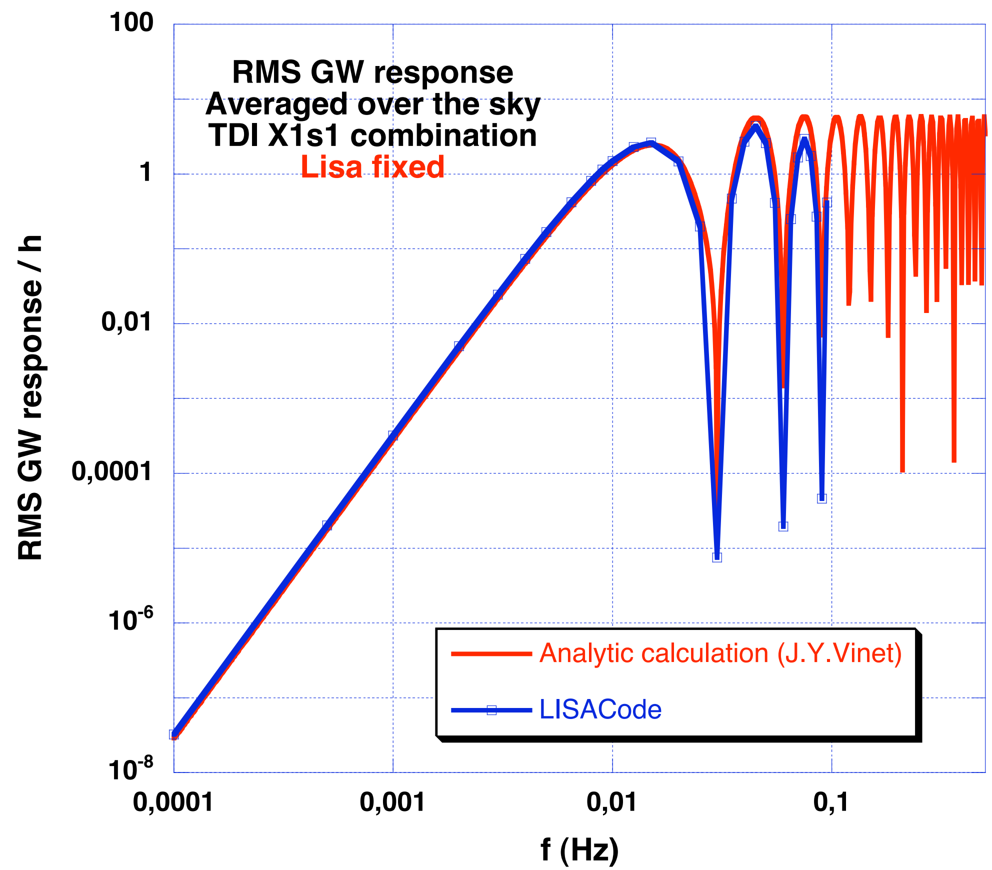


The LISA sensitivity curves : X_1

Standard noises (Pre-Phase A report) :
inertial mass, optics and laser.

Isotropic distribution of sources





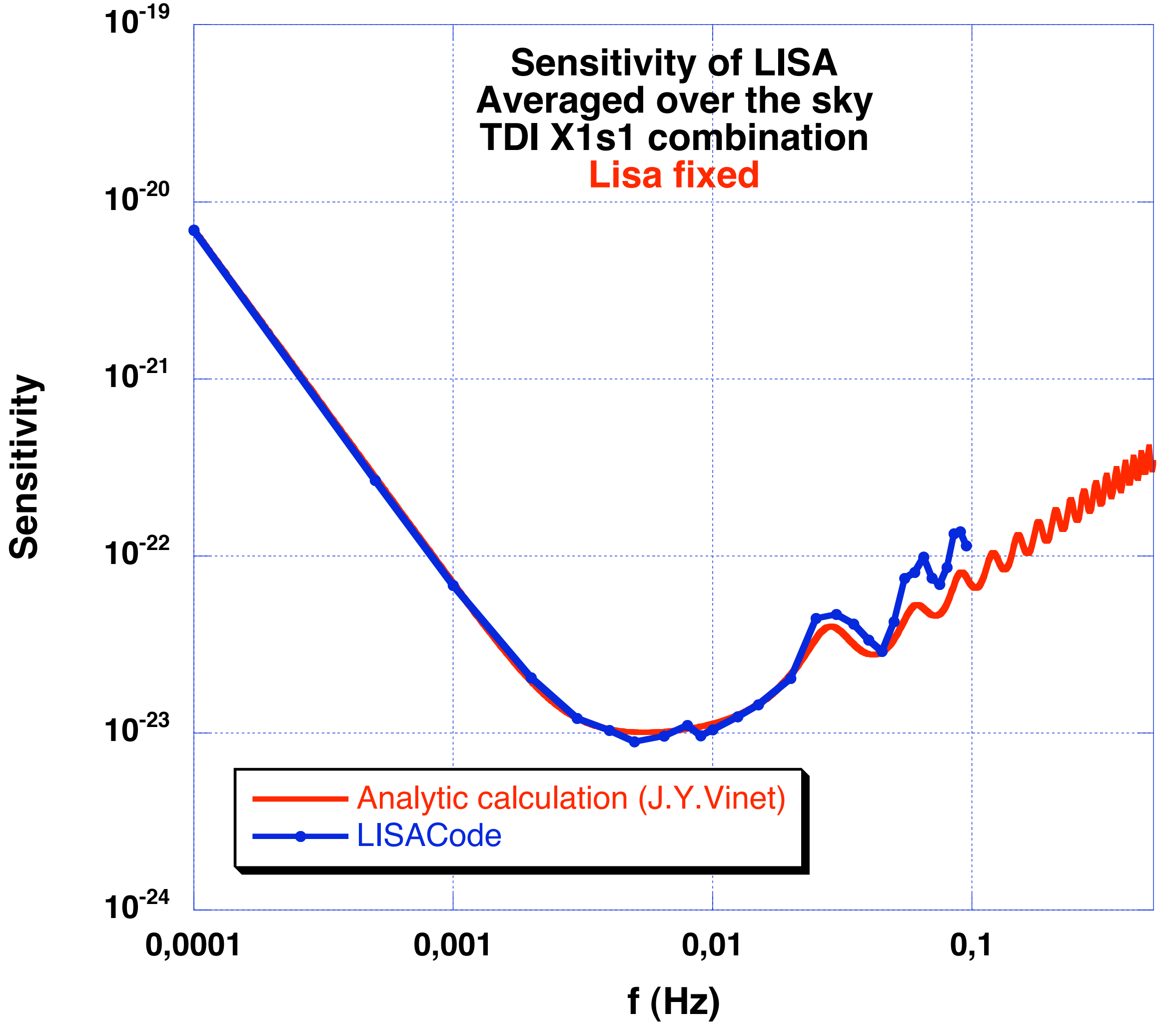
The LISA sensitivity curves : X_1

Sensitivity

$$h = 5\sqrt{\frac{Noise}{Yr * Resp_{GW}}}$$

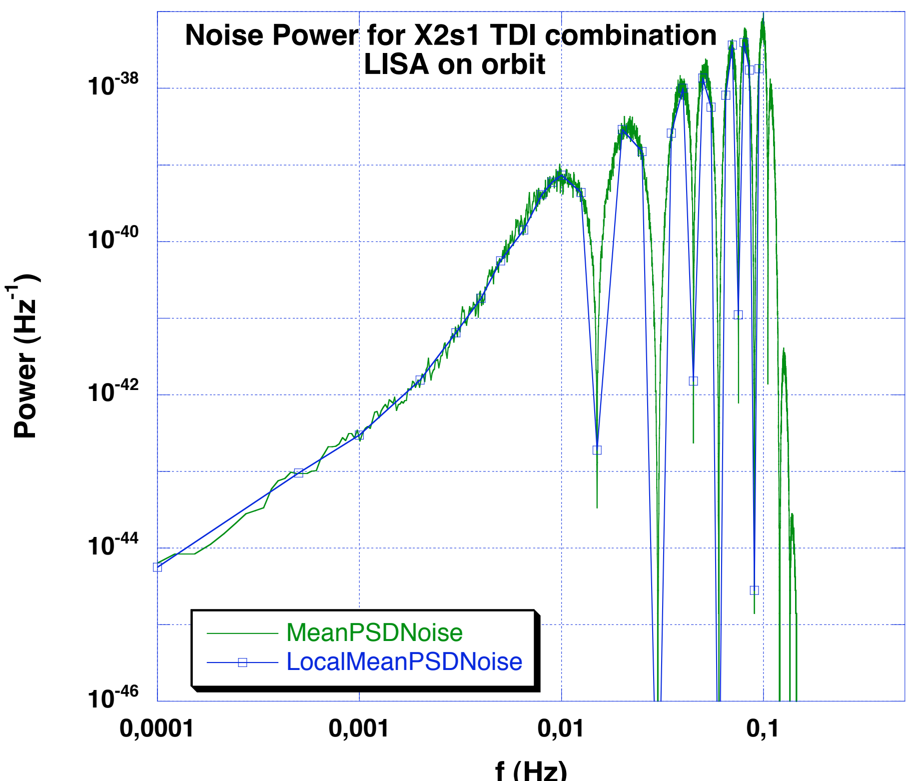
⇩

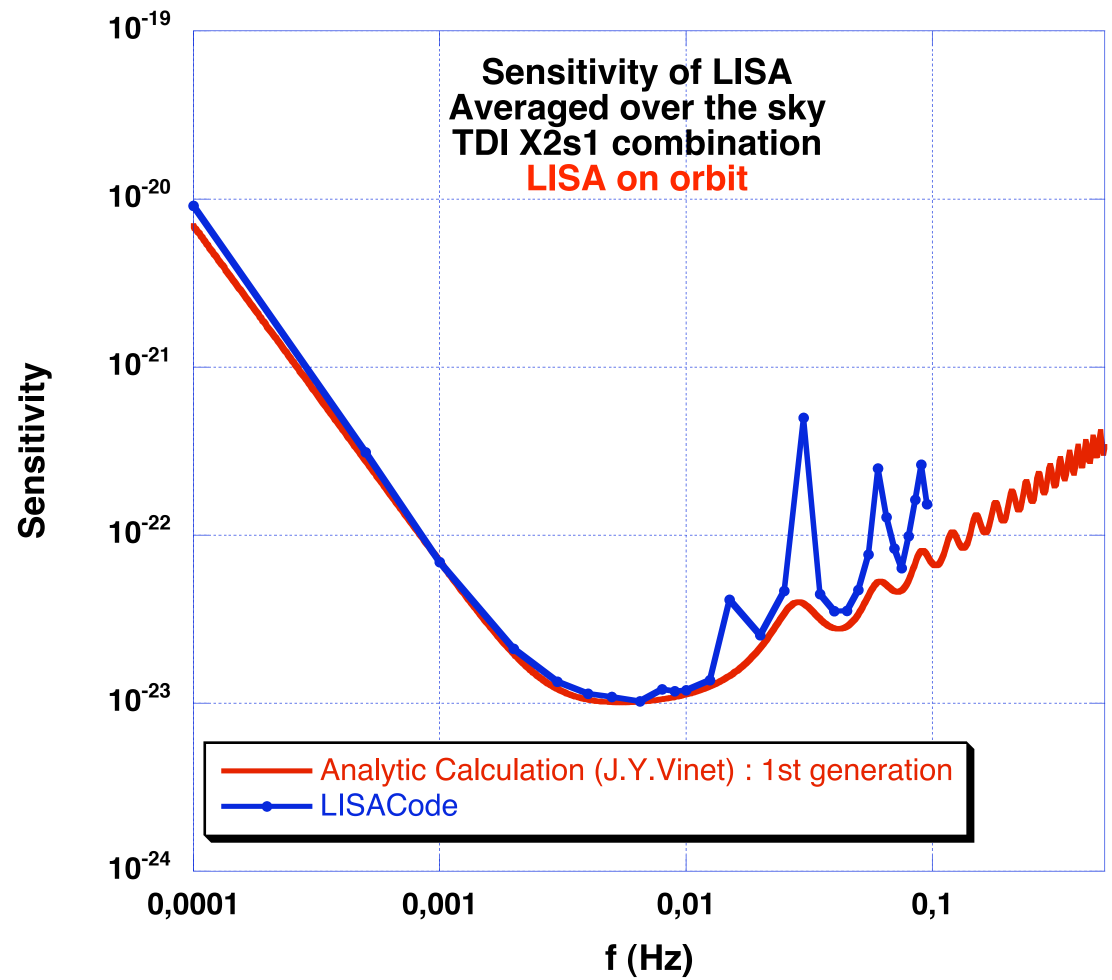
Validation of LISACode



The LISA sensitivity curves : X_2

- Lisa on realistic orbits : Sagnac + Flexing
- TDI 2nd generation

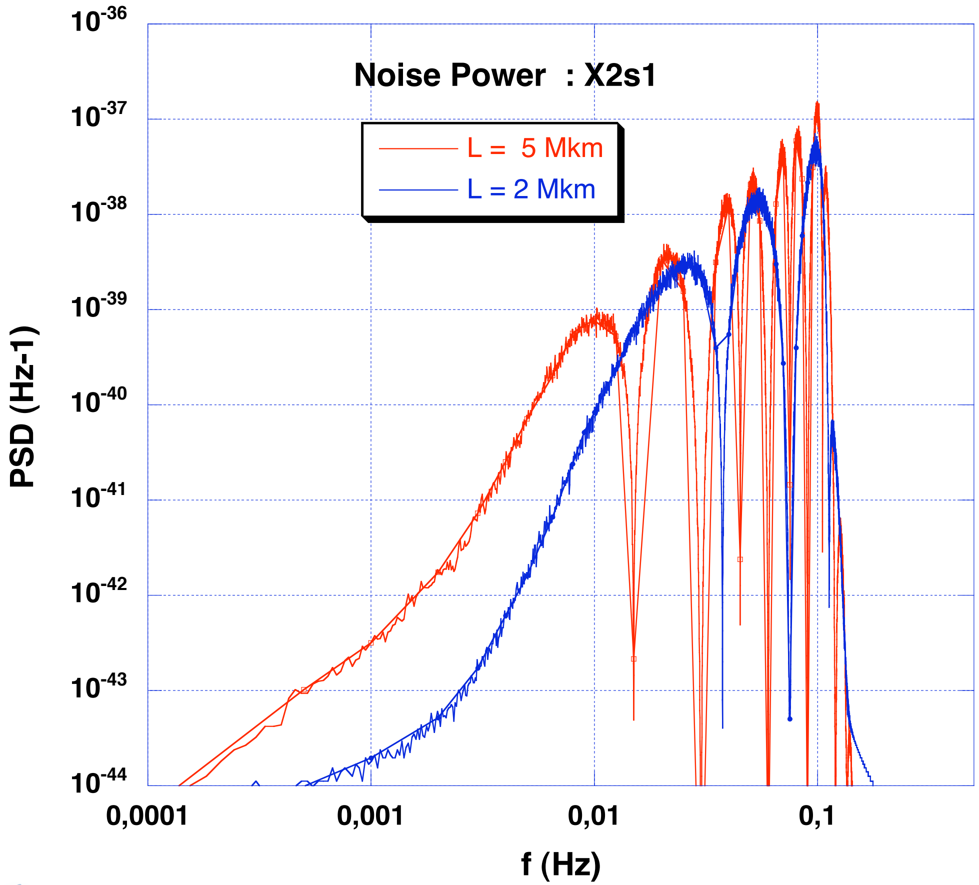


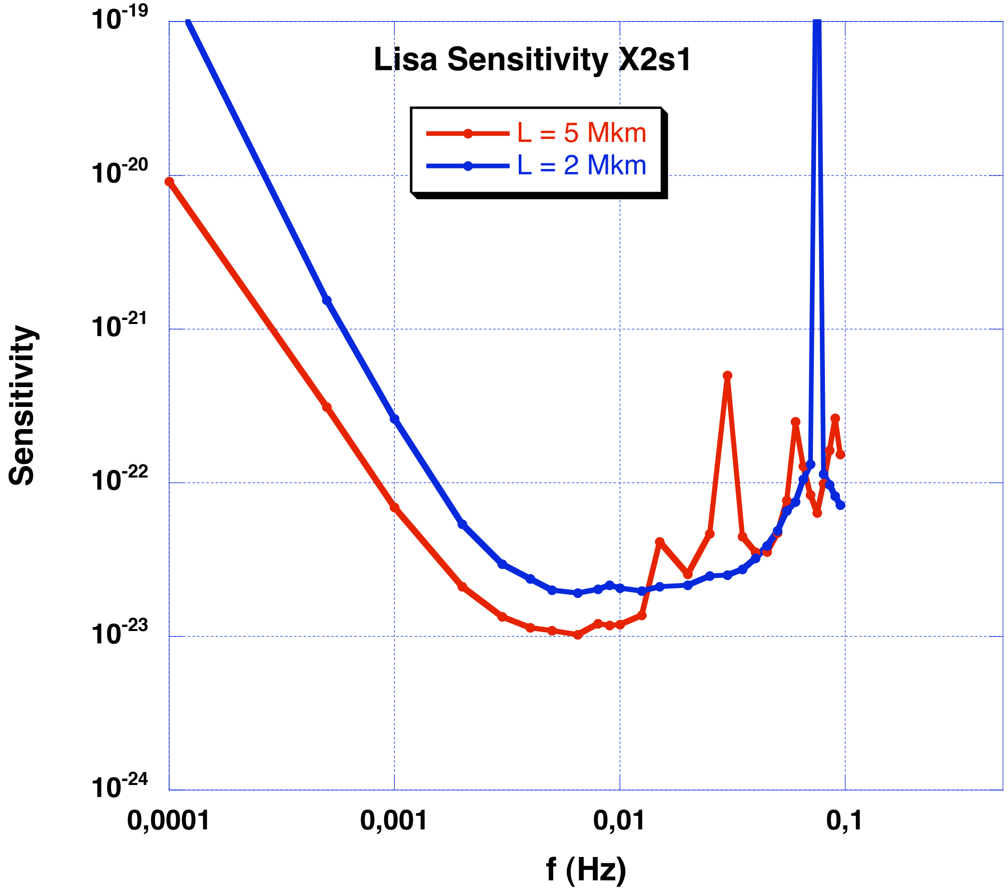


Modifying the Armlengths L

- Analysis of table 4.1 of Pre-Phase A Report

  Only the shot noise varies with L





Status and Evolution of the code

- LISACode is finalised : present version 1.2
  - GW : monochromatic, binaries, input files,
  - Realistic orbits,
  - Noise : Laser, inertial mass, shot noise,
  - Phasemeter : filtering and sampling,
  - TDI : 1st and 2nd generation. Non standard combinations are possible,
  - Inputs by ASCI files for configuration files and GW, output by ASCI files.
- Executes on most platforms : Mac, Unix, Windows
- The future ...
  - XML inputs/outputs
  - Galactic confusion noise (finalised)
  - more inbedded GW types : MBHB, EMRIs,
  - more complex noise functions, phasemeters,...
  - A user friendly interface

The Developers

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E.Plagnol (APC)

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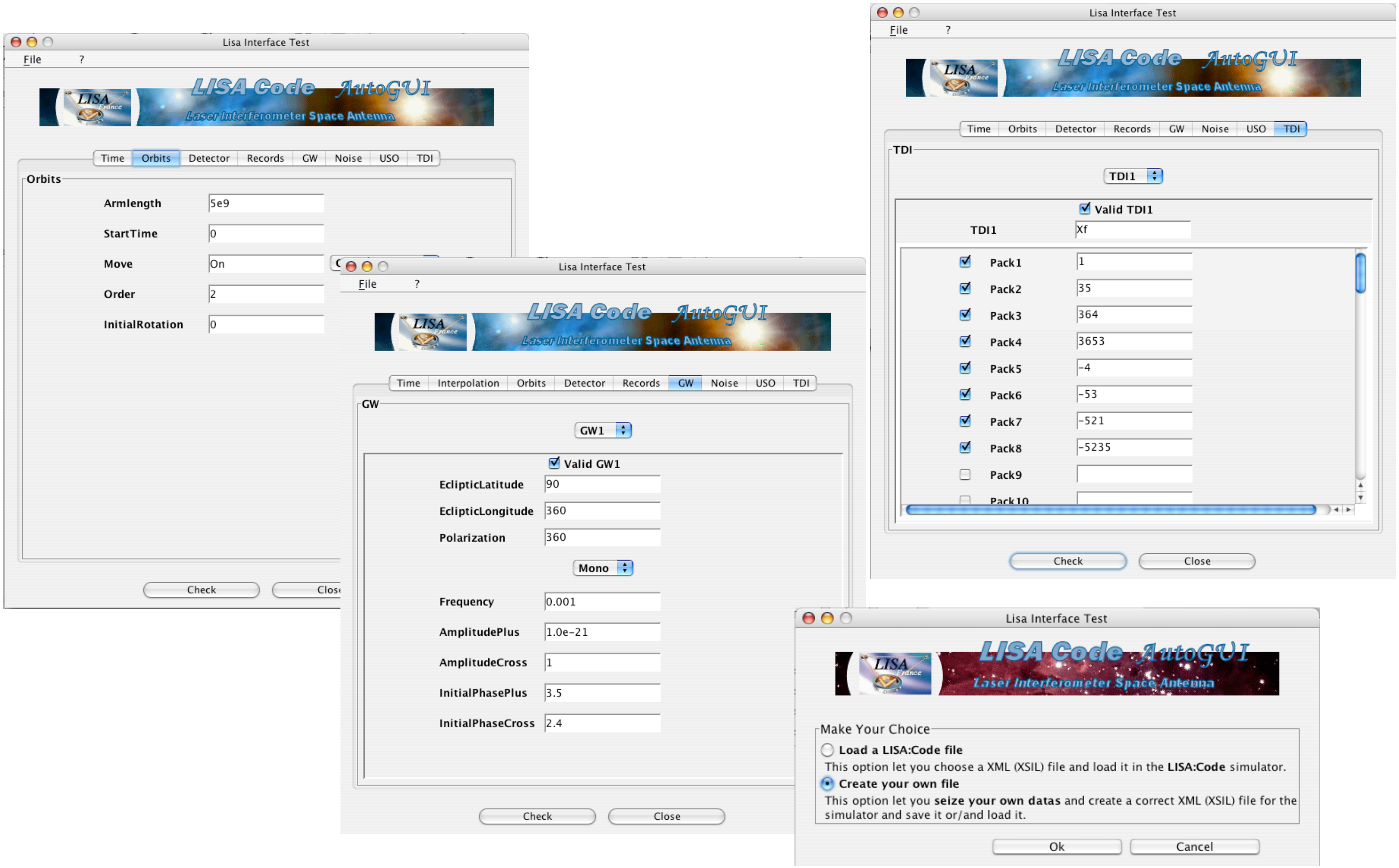
A User Friendly Interface



Data Analysis and the Lisa Mock Data Challenge at APC (Paris)

- One of the aims of LISACode is to analyse data and extract the “physical” parameters of the GW emitter.
- In order to support the LISA project, a “Mock Data Challenge” has been established mid 2006.
- A number of “Training” (known parameters) and challenges (unknown parameters) of increasing complexity have been issued.
- We have started with the simplest:

Training and Challenge 111a

Monochromatic GW : 1 year samples of TDI X_f, Y_f and Z_f

7 Parameters : frequency, amplitude and β, λ, ι, ψ and ϕ

Monochromatic GW : The parameters

7 Parameters

frequency, Amplitude and β, λ, ι, ψ and φ

$A_+ = A\,(1+\cos^2(\iota))\,\cos(2\pi f\,t+\phi)$

$A_x = 2\,A\,\cos(\iota)\,\cos(2\pi f\,t+\phi)$

ψ is the “polarisation angle”

β and λ define the directions of the source in the Barycentric Ecliptic Plane Reference System.

The Strategy

A direct X2 search is NOT practical

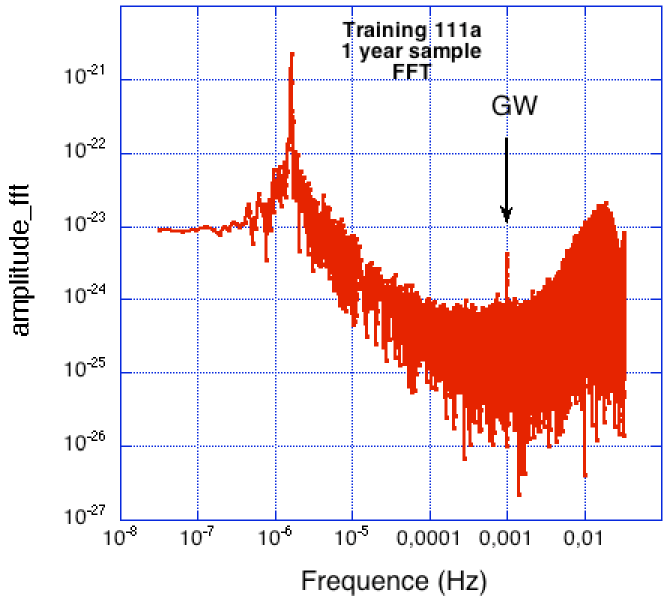
1. Determine (approximately) the frequency f (FFT)
2. Divide the total time sample into N subsets
3. Determine β, λ and ψ (X^2)
4. Re-determine the 7 parameters by minimisation (X^2) with respect to the Fourrier components

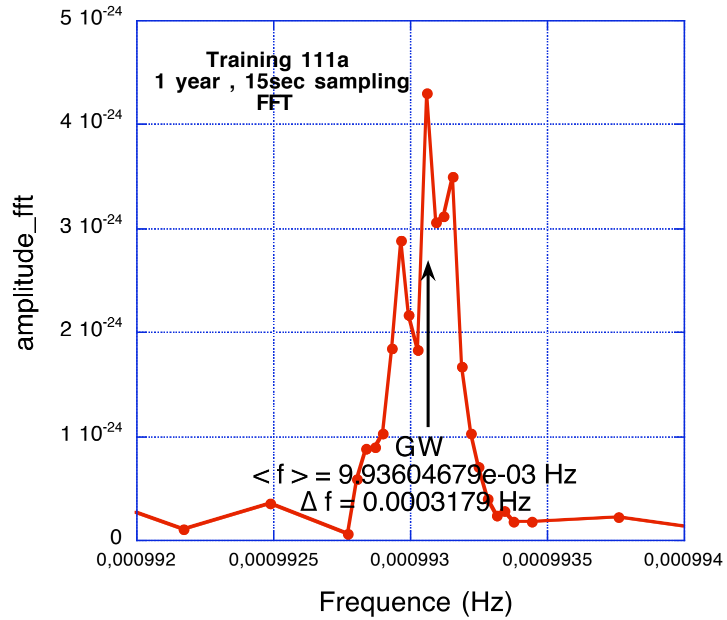
The present problem

Defining the "errors" on the data and on the parameters

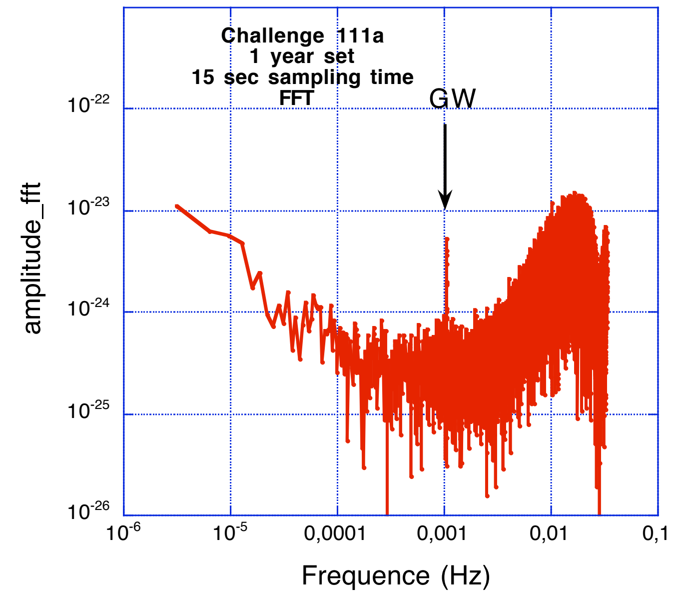
The frequency

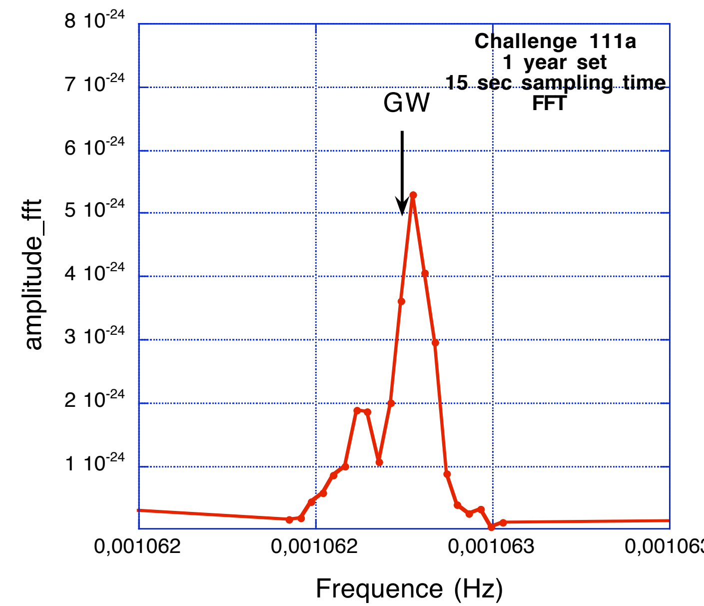
Training 111a





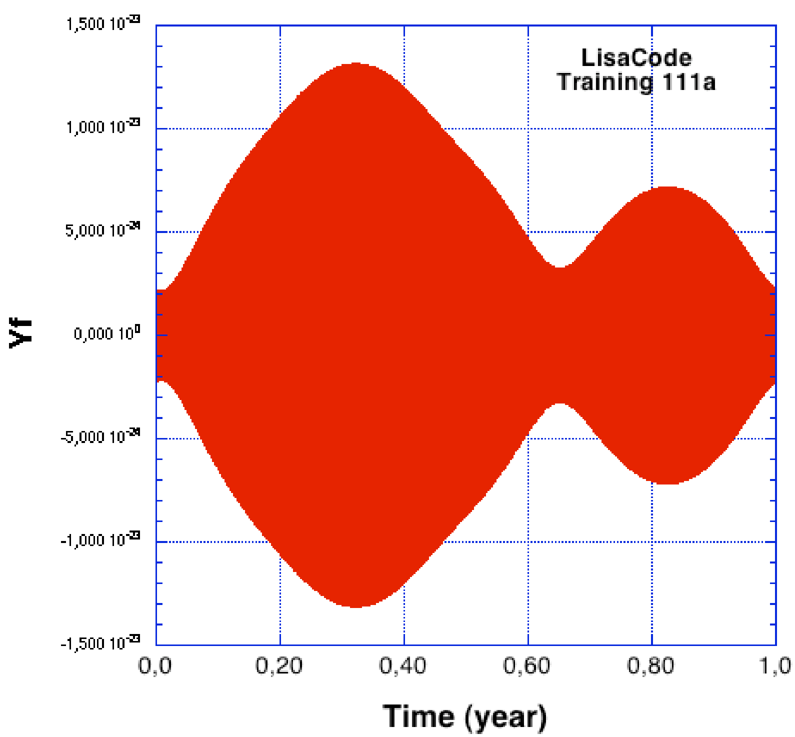
Challenge 111a

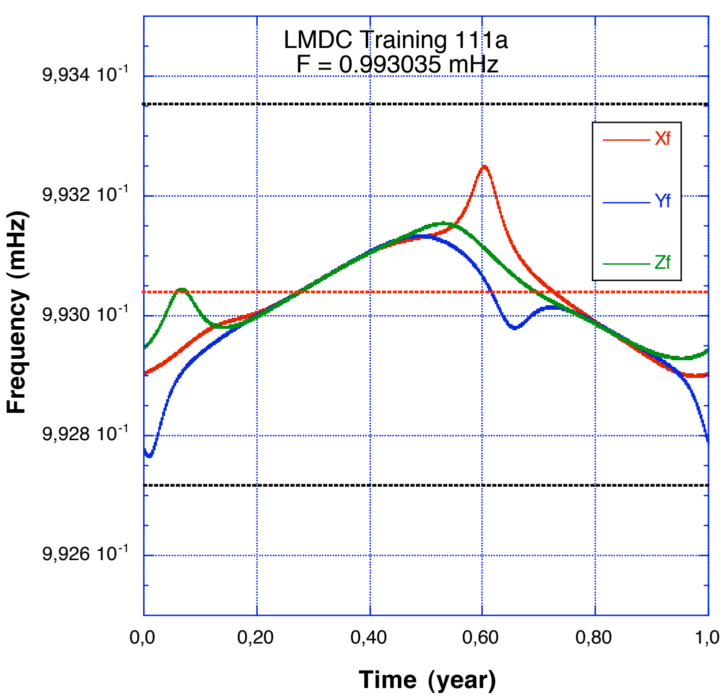




The “spread” of the frequency

- The “spread” of the frequency is due to:
  - The modulation of the amplitude,
  - The Doppler effect due to the motion of Lisa.

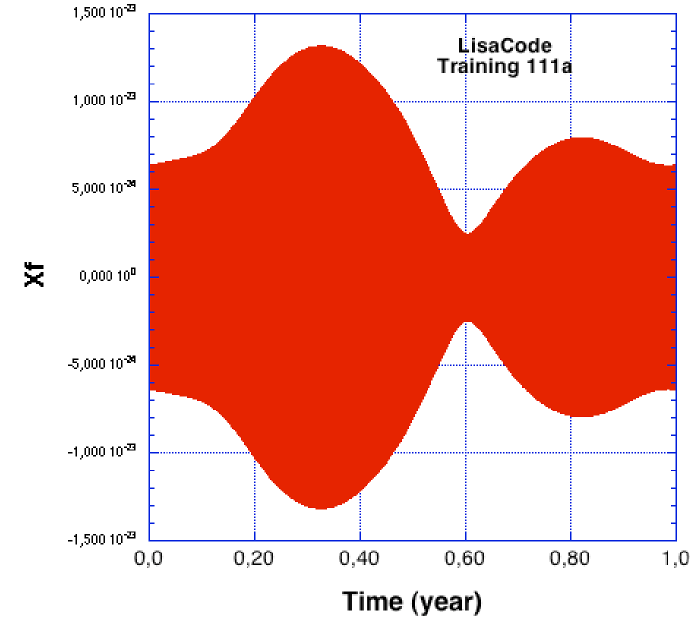




β, λ :The modulation formula

3 assumptions:

- low frequencies $2\pi fL \ll 1$
- The variations of the envelopes are << f
- $h_\times(t) = \rho\, h_+(t-\tau)$ or $\rho_\times h_\times(t) = \rho_+ h_+(t-\tau)$



$$\left.\frac{\tilde{\delta\nu}}{\nu_{opt}}\right|_{AB}(f) = i e^{2i\pi f\left(\hat{w}.\vec{r}_{AB} - \frac{L}{2}\right)} \frac{\pi f L}{1+\hat{w}.\hat{n}} \tilde{h}(f)\left(\xi_{AB,+} + \rho e^{-2i\pi f\tau}\xi_{AB,\times}\right)$$

TDI Michelson :

$$\begin{cases} \xi_{+i} = \left(\widehat{\beta}.\widehat{n_i}\right)^2 - \left(\widehat{\lambda}.\widehat{n_i}\right)^2 \\ \xi_{\times i} = 2\left(\widehat{\beta}.\widehat{n_i}\right)\left(\widehat{\lambda}.\widehat{n_i}\right) \end{cases}$$

$$\tilde{X}(f) = 8(\pi f L)^2 e^{-3i\pi f L} e^{2i\pi f \hat{w}.\vec{r}_{AB}} \tilde{h}(f)\left[\xi_{+3} - \xi_{+2} + \rho e^{2i\pi f\tau}\left(\xi_{\times 3} - \xi_{\times 2}\right)\right]$$

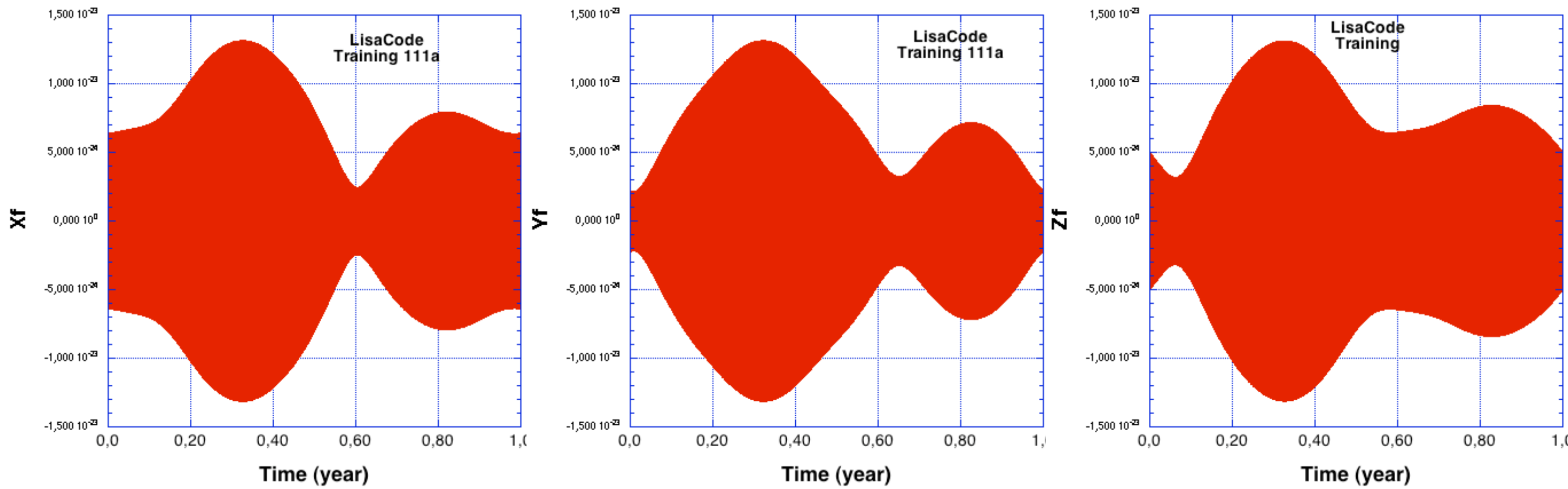
$$\left|\tilde{X}\right| = 64(\pi f L)^4 \left|\tilde{h}\right| \left[(\xi_{+3} - \xi_{+2})^2 + \rho^2(\xi_{\times 3} - \xi_{\times 2})^2 + 2\left(\xi_{+3} - \xi_{+2}\right)\left(\xi_{\times 3} - \xi_{\times 2}\right)\rho\cos\left(2\pi f\tau\right)\right]$$

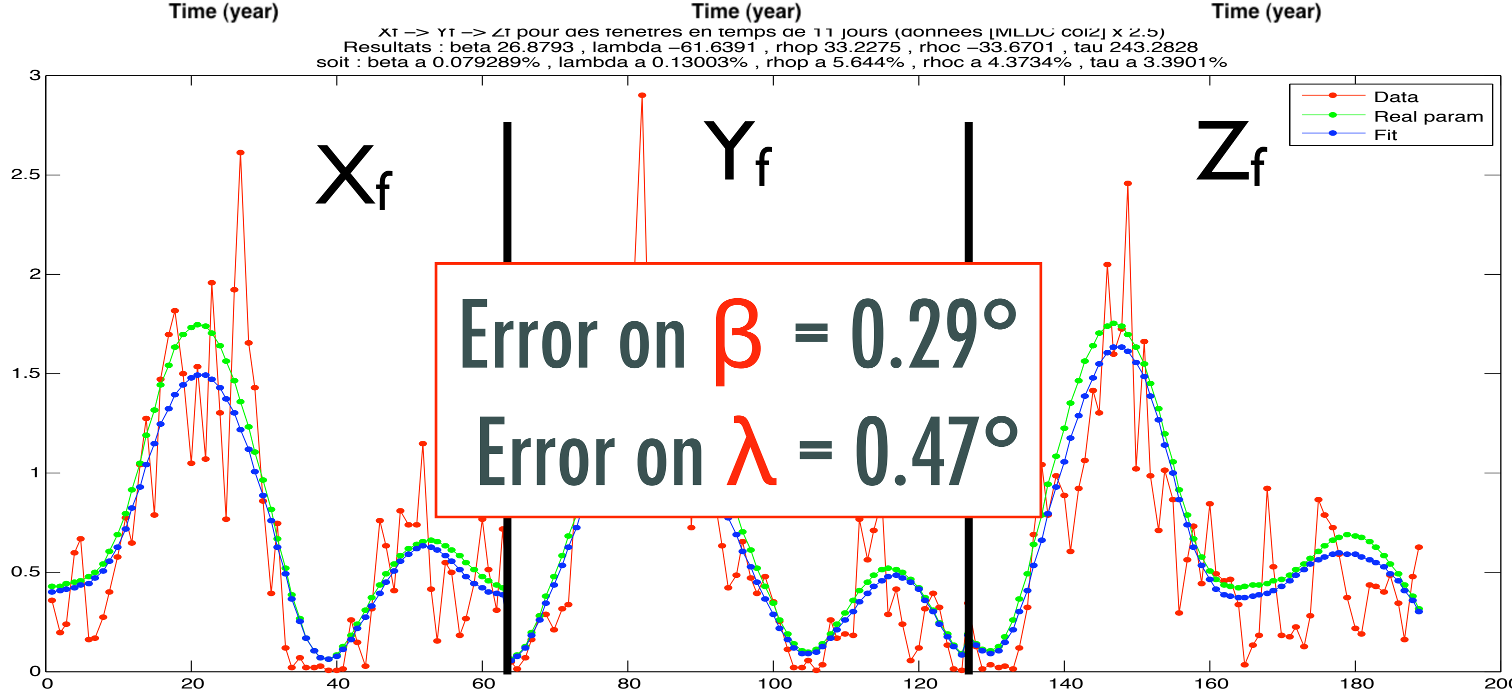
$$\left|\tilde{X}\right| = 64(\pi f L)^4 \left|\tilde{h}\right| \left[\rho_+^2(\xi_{+3} - \xi_{+2})^2 + \rho_\times^2(\xi_{\times 3} - \xi_{\times 2})^2 + 2\left(\xi_{+3} - \xi_{+2}\right)\left(\xi_{\times 3} - \xi_{\times 2}\right)\rho_+\rho_\times\cos\left(2\pi f\tau\right)\right]$$

Training 111a

N subsets and determination of β, λ and ψ with the 3 TDI observables

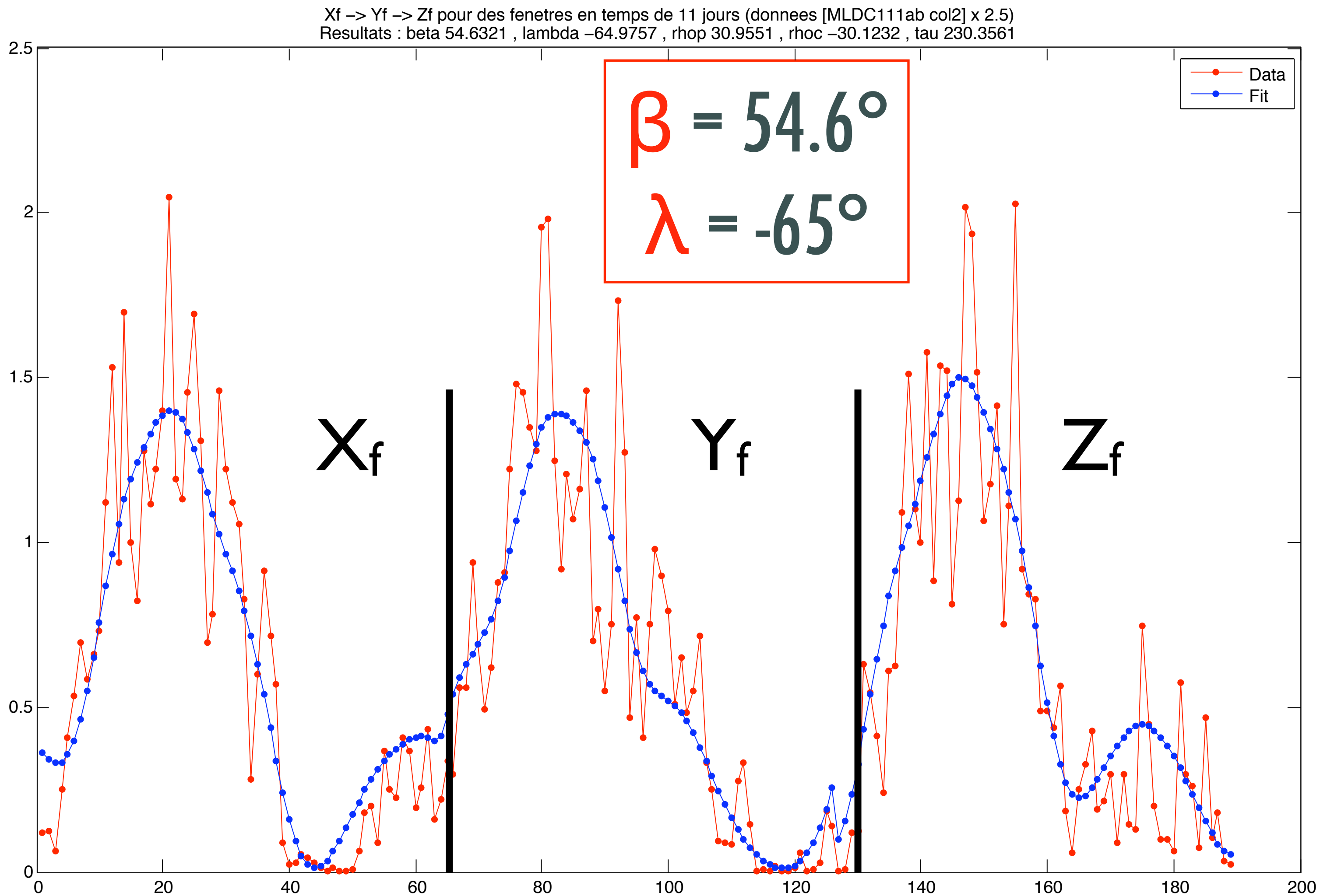
The minima are related “mostly” to the source direction (β, λ)





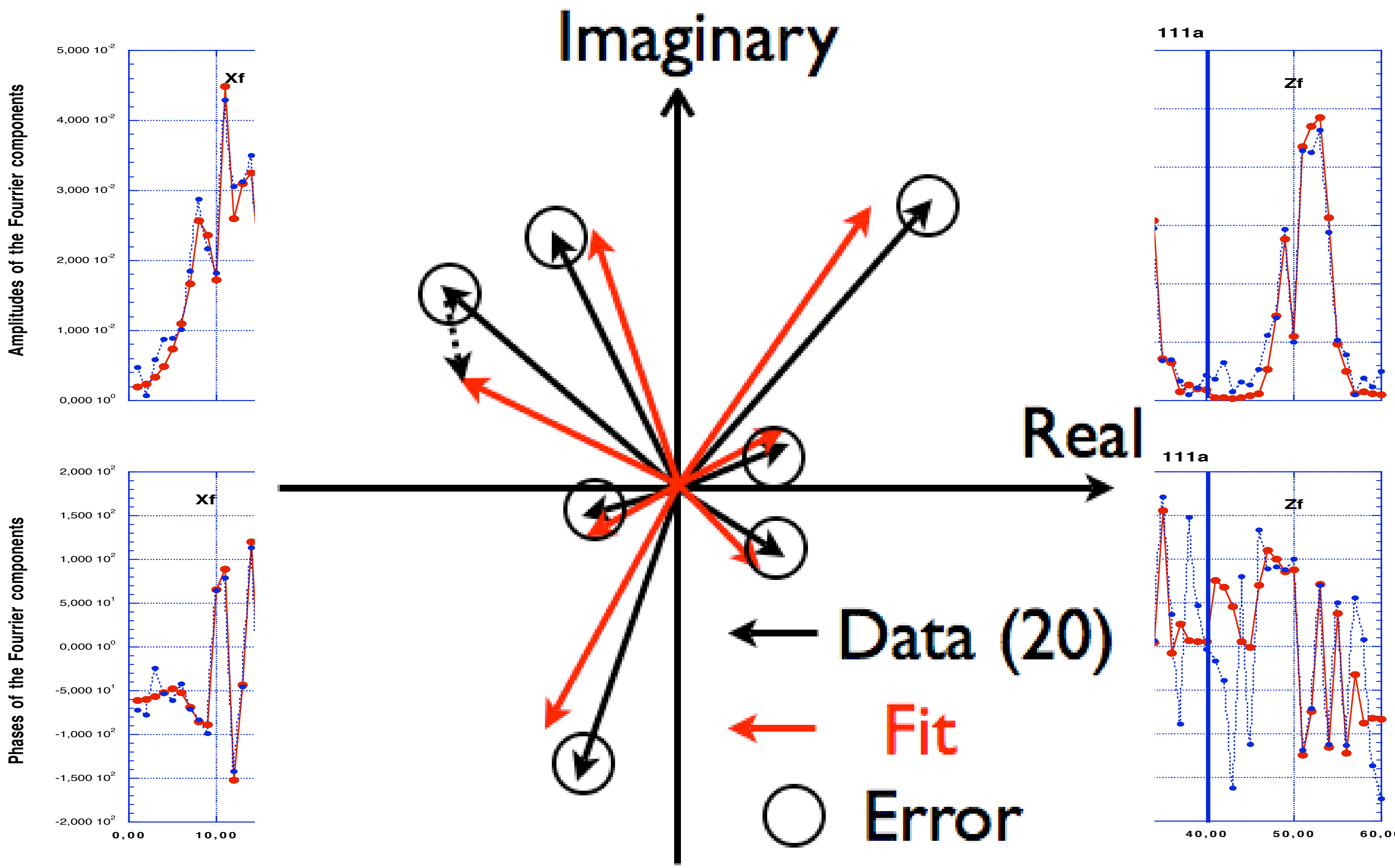
The optimum determination seems to be obtained for 64 (overlapping) samples of 11 days

The blind Challenge 111a



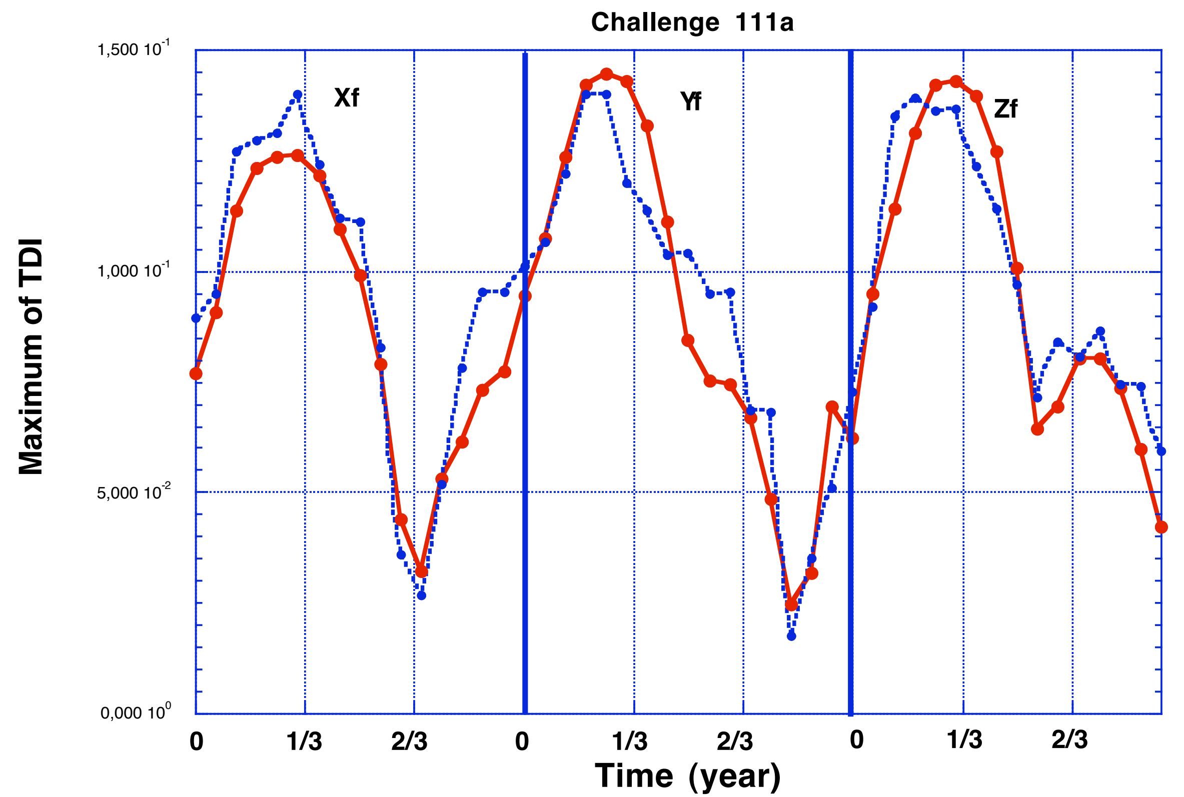
The general fit on the 7 parameters

- From the FFT, 20 frequencies are considered, centred on the "mean" frequency.
- This gives 20 amplitudes and phases or, equivalently, 20 "vectors".
- The X2 is calculated using the "vector difference" between the fit and the data.
- The error on the amplitude is extracted from the "noise" to the left and right of signal.



The final parameters

- f =1.06273044e-3 mHz
- A =0.63 10^{-22}
- β = 54.6°
- λ = 291.°
- ι = 55.0°
- ψ = -113.0°
- φ = -61.0°



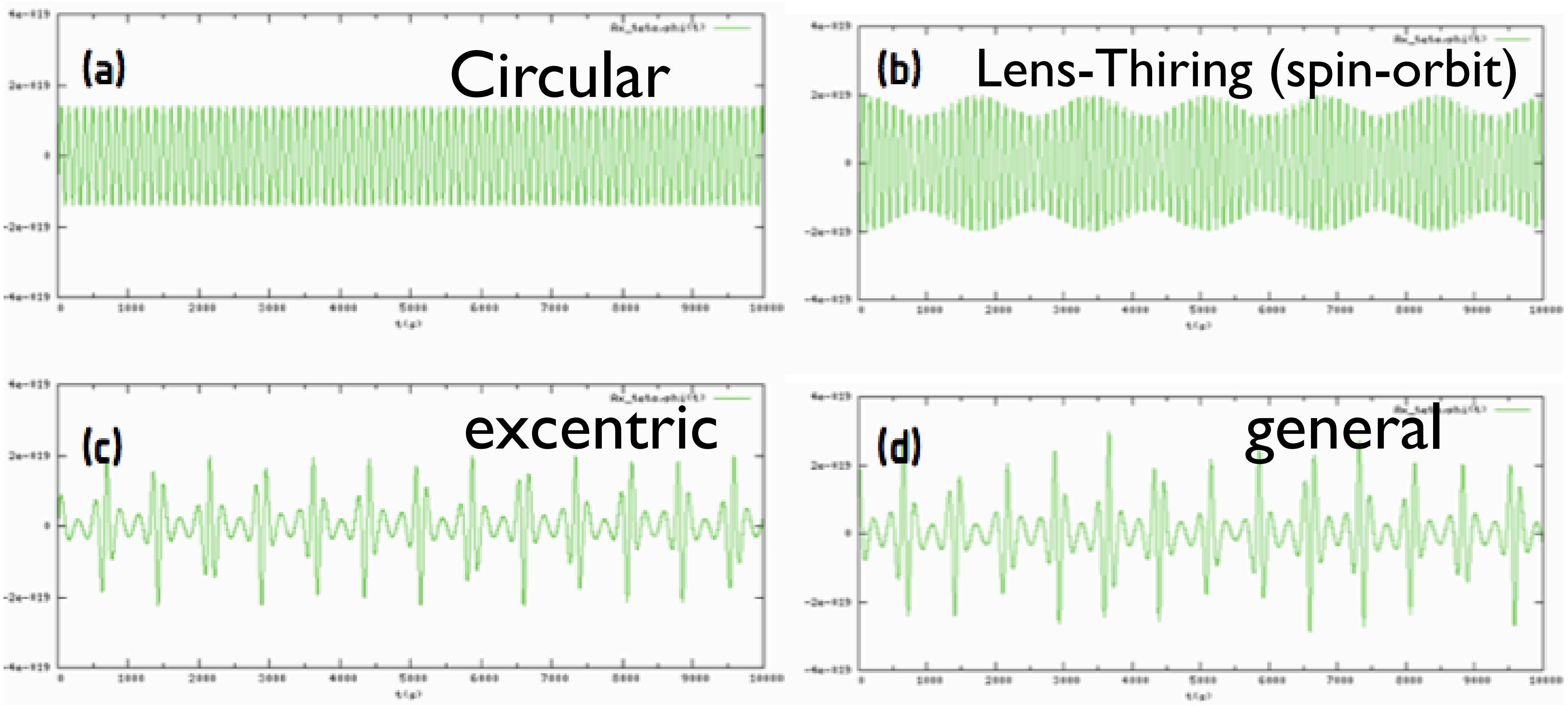
Open problems:
- definition of the errors of the data and of the X2
- determination of the error on the parameters.

The difficulties are ahead !

- A monochromatic GW, over 1 year with a high S/N is the simplest problem... and it can be optimised.
- More complicated scenari are included in the LMDC
  - multiple overlapping GW
  - smaller time samples with and without “chirp”
  - EMRIs

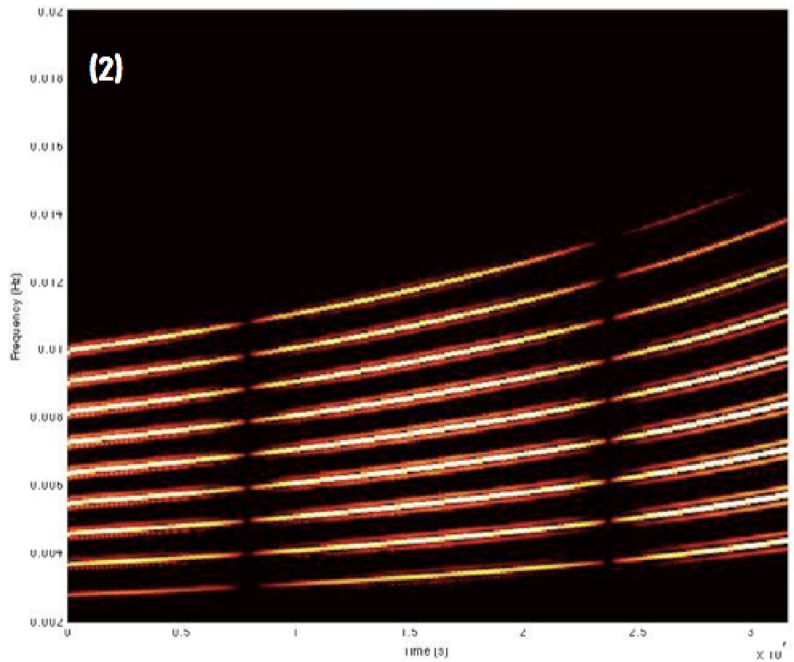
EMRIs produce a wide variety of waveforms

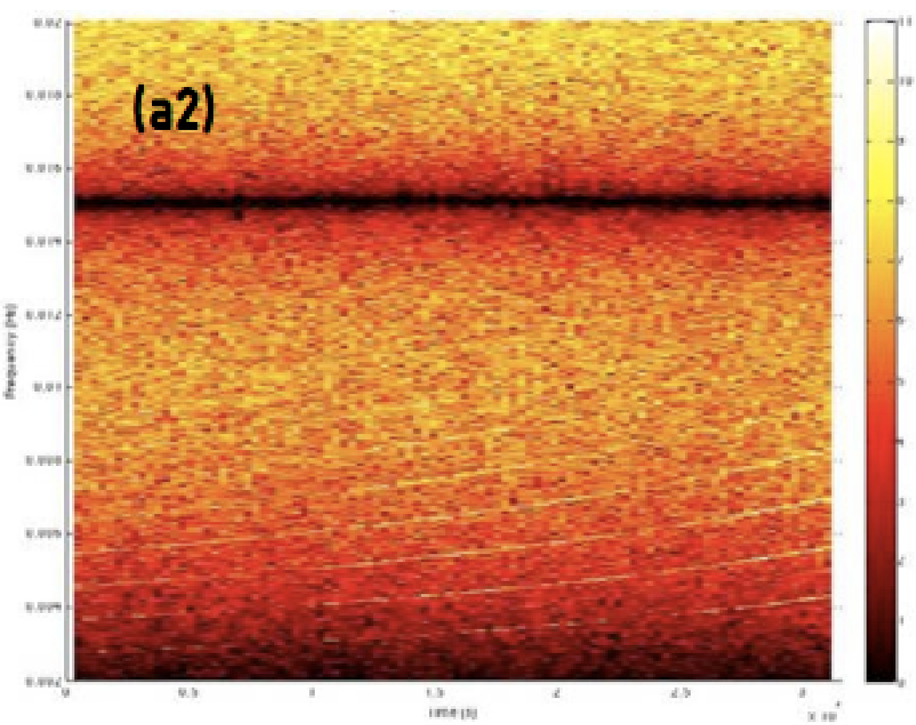
14 -17 parameters

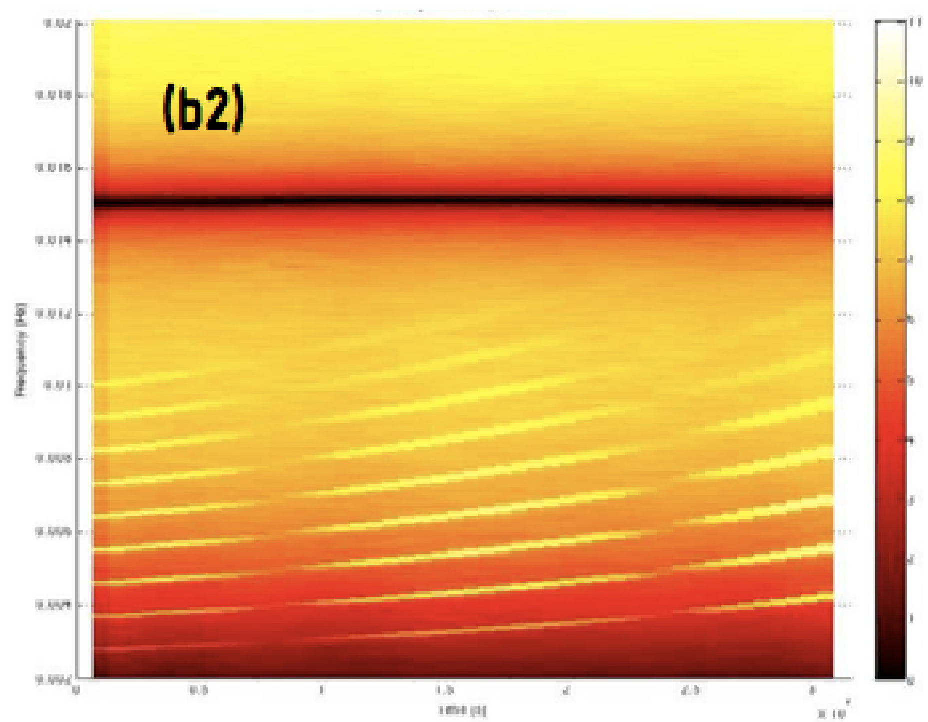


This translates into multiple frequencies and complex time-frequency patterns

Time-Frequency Analysis

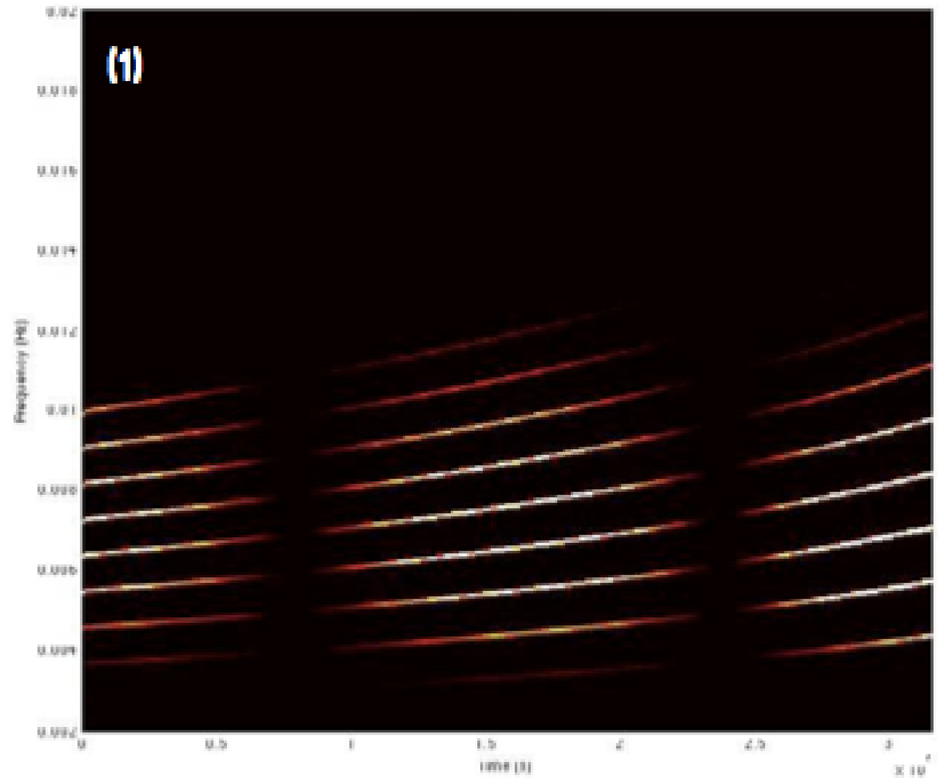






EMRIs

- The simultaneous study of multiple frequencies
- The possible "connection" of different time-frequency lines
- We are looking into "wavelets" type analysis and image processing methods.



Summary

LISACode

- LISACode is a “sophisticated” software simulator of LISA which impacts both the technical development of LISA and the data analysis.
- It is readily available to the public and is permanently upgraded, both in efficiency and versatility.

Data Analysis

- Our data analysis effort is “starting”.
- We believe we are on the right track but many new tools have still to be developed and understood.
- In many instances, the correct estimation of the errors (data and parameters) is an issue.