DE LA RECHERCHE À L'INDUSTRIE

PARAMETER ESTIMATION FOR GALACTIC BINARIES IN LISA WITH MACHINE LEARNING

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ABOUT ME

- Second year engineer student IMT Atlantique
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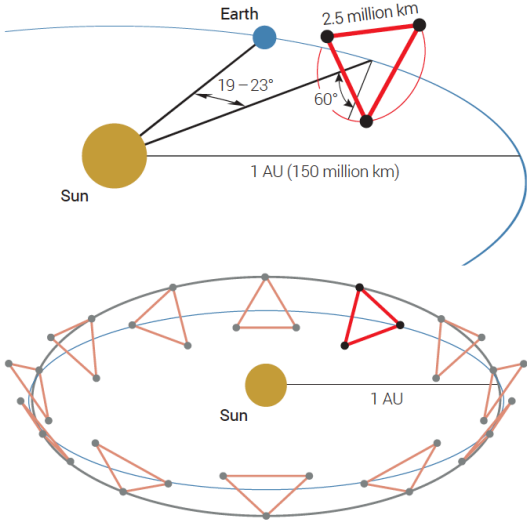
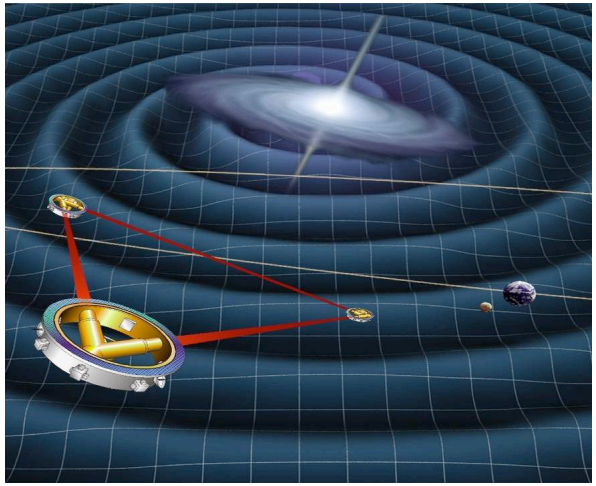
1. Presentation of LISA

LISA (Laser Interferometer Space Antenna)

- Spatial project ESA-NASA.
- LISA is a future space based gravitational wave observatory , to be launched around 2034.
- Allows the detection of gravitational waves undetectable by terrestrial interferometers such as LIGO ,VIRGO.

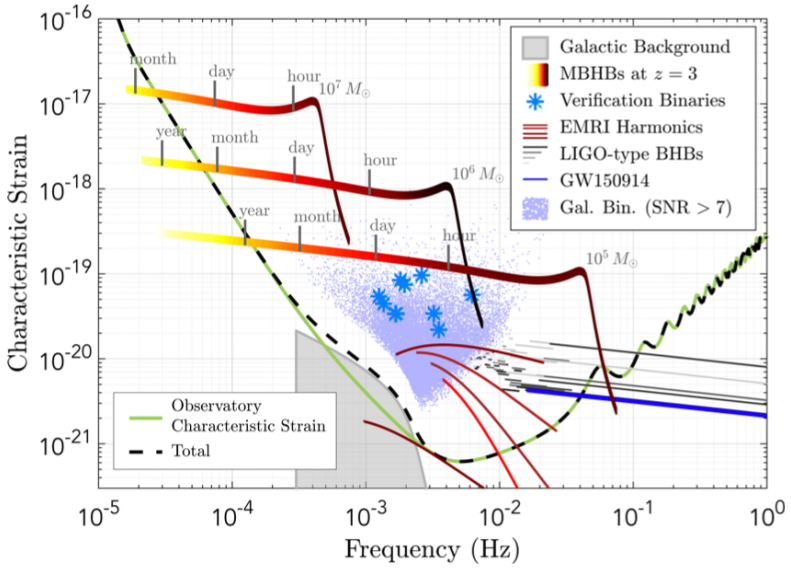




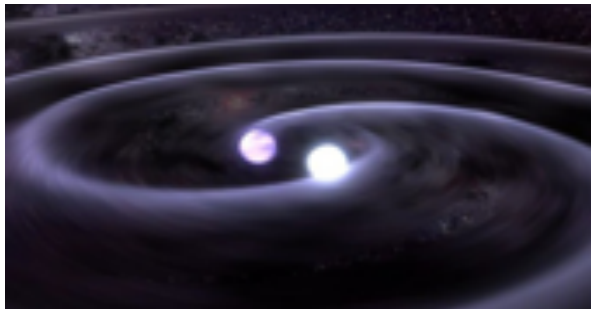
Depiction of the LISA Orbit.

2. LISA's missions

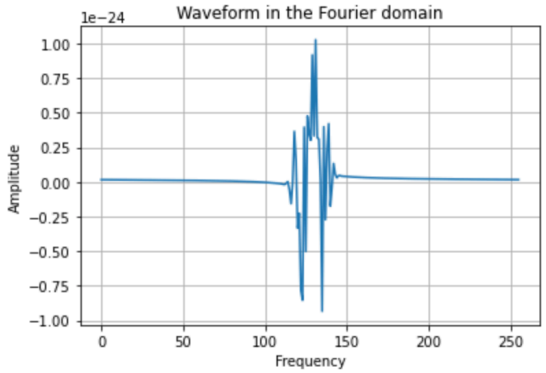
- Identify the formation and evolution of galactic binary systems (stars , etc).
- Characterize approximately 25,000 galactic binary systems.
- The characterization of these binary systems amounts to estimating the parameters of the physical models.
- Work in the low frequency domain (from 10^{-3} Hertz to 1 Hertz).



3. Gravitational wave sources in LISA band

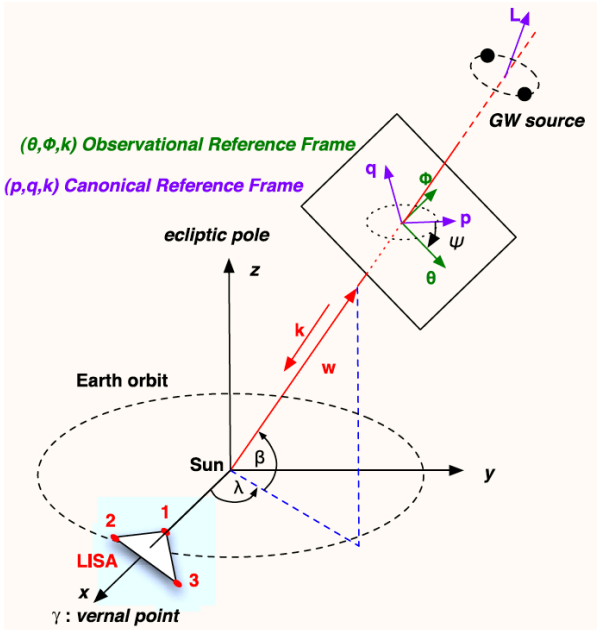


- Galactic binaries
  - Quasi monochromatic
  - Signal to noise ratio
    - Detected sources: 7 - 1000
    - Confusion noise from non-detected sources
  - Event rate
    - 25,000 detected sources
    - More than 10 guaranteed sources (verification binaries)
- Quasi-periodic signal in the time domain
    - So concentrated around a frequency in the Fourier domain.



4 . Description of parameters

- Related to the gravitational wave
  - The amplitude h
    - Detection order greater than or equal to 10^{-22} Strain.
  - Frequency f
    - Frequency between 10^{-3} and 10^{-1} Hz.
- Sources and observer (LISA)
  - The declination β
  - Ecliptic longitude λ



CHAPTER 2: EXISTING ESTIMATION METHODS

1 . Matched filtering

Fit the best model to the data by exploring a large parameters space.

- Template bank: check all sets of parameters (too heavy).
- Maximized likelihood (Generic algorithm, etc)
- Work in Fourier domain

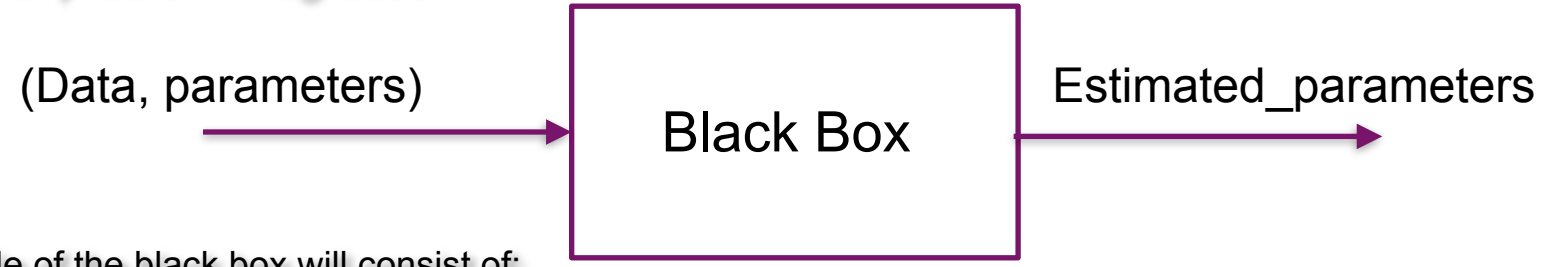
2. MC-MC Approach

Classical maximum likelihood approach

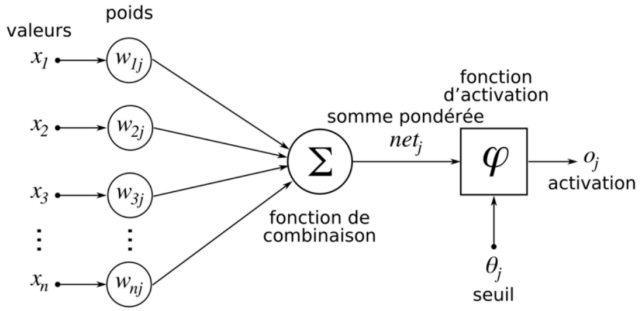
- Method to sample probability distributions.
- Several algorithms for sampling.
- Problems with these methods
  - Long computing time
  - Slow convergence.

1. Neural Networks

- Type of problem : regressor



- The role of the black box will consist of:
  - Estimate the direct correspondance between measurements and parameters .
  - Black box ?
    - Neural Networks
- Several types of neural networks but the type of data leads us to choose :
  - Multi-Layers Perceptron
  - Convolutional neural networks

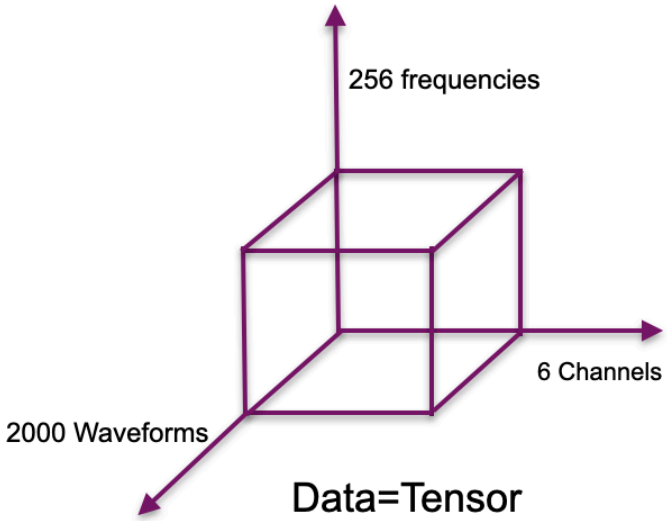


Neural network architecture

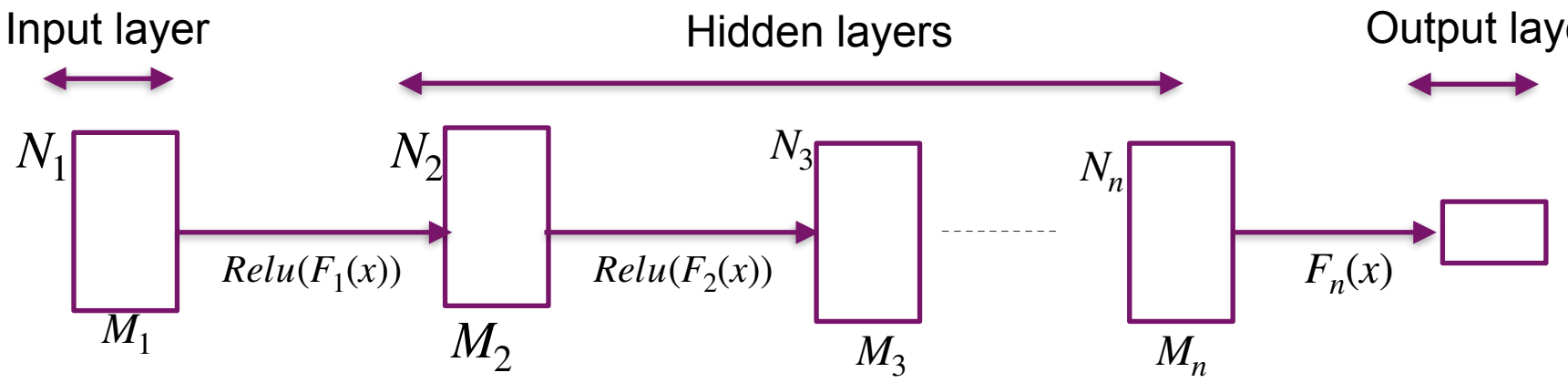
2. Network architecture

- Data for learning and testing: LISAcode
- Data is made up of:
  - A waveform
  - 3 channels (X, Y, Z)
  - 256 frequencies
- Complex type
  - Separation of the real and imaginary part of each waveform.
    - Changing the number of channels from 3 to 6.
    - Generate five different amplitudes for each waveform
    - Increase signal SNR up from 1 to 20 dB

- Input shape (2000,256,6).
- Estimation in a single band at constant frequency f_0 .
- Estimated parameters
  - Amplitude
  - Beta
  - lambda



CHAPTER 3 :PROPOSED SOLUTION

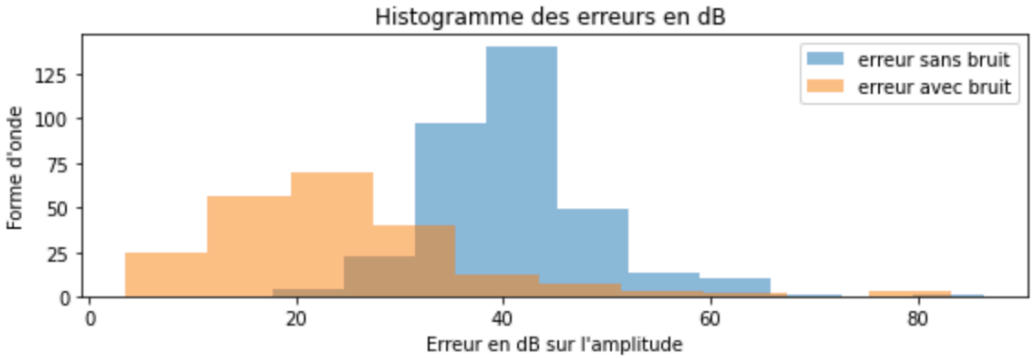


- Weight and bias matrix
  - Shape tensor $W = (M_1, N_1, M_2, N_2), b = (M_1, N_1)$
  - Prediction function $F(x) = \sum_{jt} w_{ikjt} \times x_{mjt} + b$
- Activation function :Relu
- Number of hidden layers : 3
- Optimizer Adam.

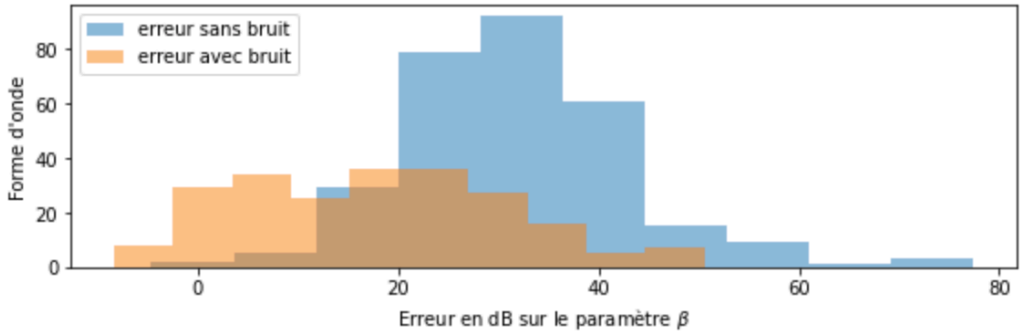
3. Results

- Estimation with noise
- Estimation without noise

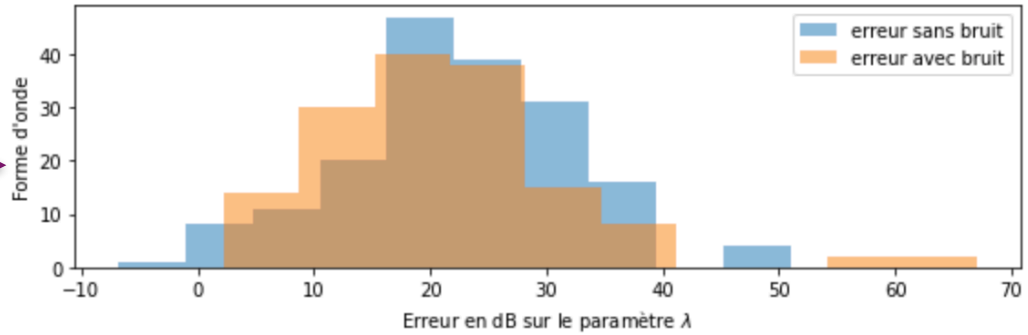
MSE on the Amplitude



MSE on Beta



MSE on Lambda



CONCLUSION

- First study of machine learning for the estimation of binary parameters from LISA data.
- Perspective
  - Comparison with MC-MC and matched filtering methods
  - Go to the estimation of the 8 parameters of interest
  - Process complete data
    - Several million points/samples
    - Invariance by translation
      - CNN