Tomographic reconstruction method and application to MLDC data challenges 2.1

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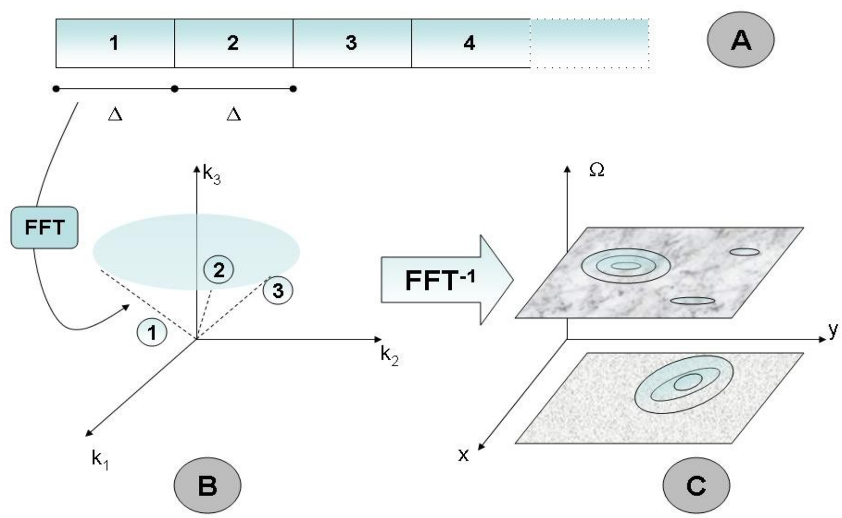
Sky map construction

Details of the method have been reported in the following papers:

1. S. D. Mohanty, R. K. Nayak, Phys. Rev. D, **73** 083006 (2006).
2. R. K. Nayak, S. D. Mohanty, K. Hayama, Proc. 6th LISA symposium (2006).



The figure below shows a schematic of the basic steps involved. Actual details are available in reference 1 above.

A. The time series of a TDI variable (duration 1 year) is split into Δ sec long segments (overlapping is optional).
B. The FFT of each segment is arranged on a cone in a three dimensional space. This is the space of wave vectors corresponding to a particular choice of coordinates for representing the spatio-temporal *signal density* function.
C. A three dimensional inverse FFT is applied[1] to yield **sky-maps**: **x** and **y** are position coordinates on the sky and **Ω** is the source frequency. The quantity plotted as a function of position is, loosely speaking, the magnitude of the density function of monochromatic (in the barycenter frame) sources.
D. Not shown in the figure above are steps that account for the rotating antenna pattern of LISA. There are several possible approaches here and one method has

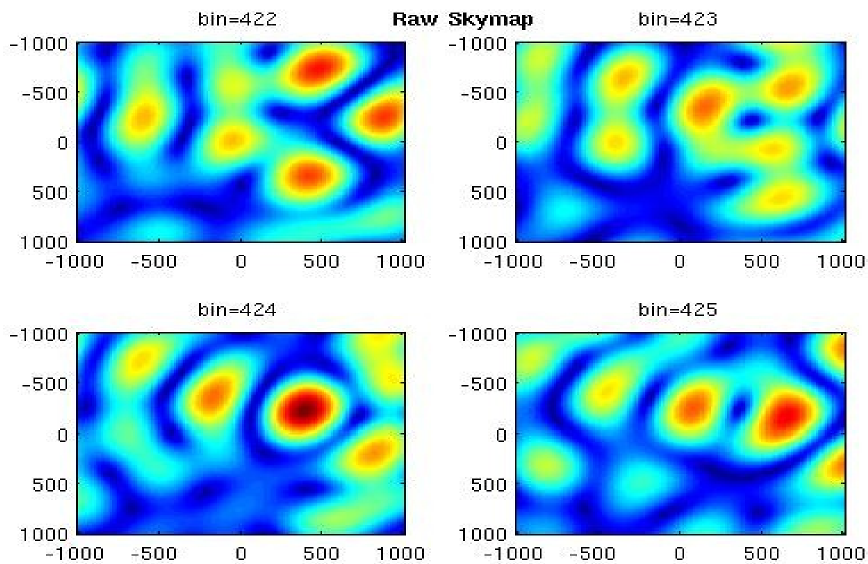
[1] More precisely: This step actually involves a sequence of a 3D FFT followed by a 1D FFT. However, the two can be combined into a single operation. Thus, computing the sky-maps for a given x,y and Ω actually involves computing a particular integral over the azimuthal angle in (k_1,k_2,k_3) space.

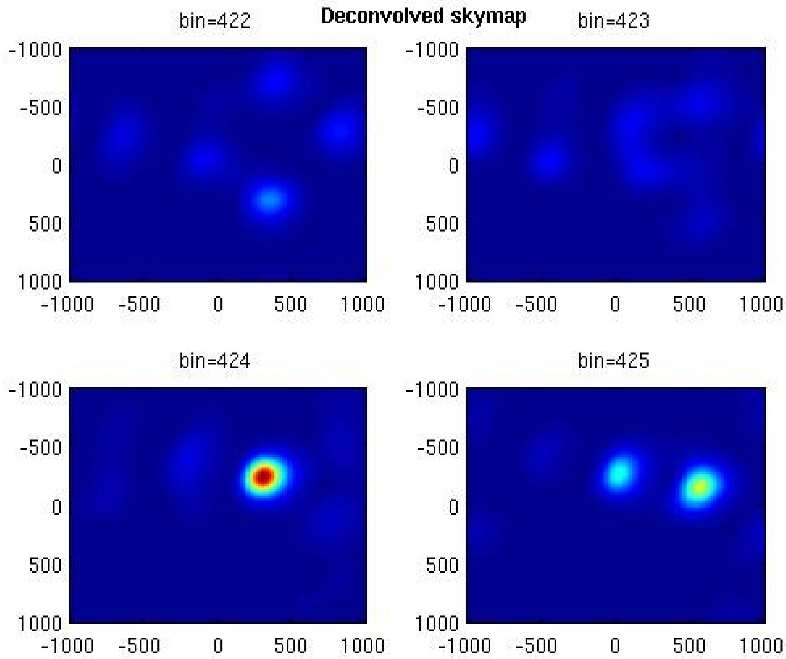
been described in reference 2. **In the present challenge, we do not apply antenna pattern correction.** Therefore, we expect the error in the estimated location and frequency of sources to have a bias that increases with the latitude. The main reason behind not using this step is that it breaks some basic assumptions behind the deconvolution step (see below).

Estimating binary parameters

A monochromatic source (e.g., a Galactic binary) appears in the sky map as a convolution of a delta-function with a point-spread function **P(x,y,Ω).** In the current state of development, we can only reconstruct these three parameters. Error in estimation comes from the ambient noise, comprised of instrumental noise and unresolved binaries, and from the superposition of the side lobes of the psf. In most cases, the effect of the latter is dominant. **A major upgrade of the method has been the addition of a deconvolution step for mitigating the effect of the psf sidelobes.**

We use the Richardson-Lucy deconvolution method on the raw skymaps with a reference PSF. A sample of deconvolved skymaps is shown in the figure below. The raw skymaps have significant artifacts coming from the interference of psf sidelobes associated with sources in neighboring frequency bins (each skymap corresponds to one, 1 year frequency bin). The deconvolved maps clearly show the presence of one source. It is important to note that we are still in the process of developing and understanding the deconvolution step and that **our results should be considered preliminary** in this respect.



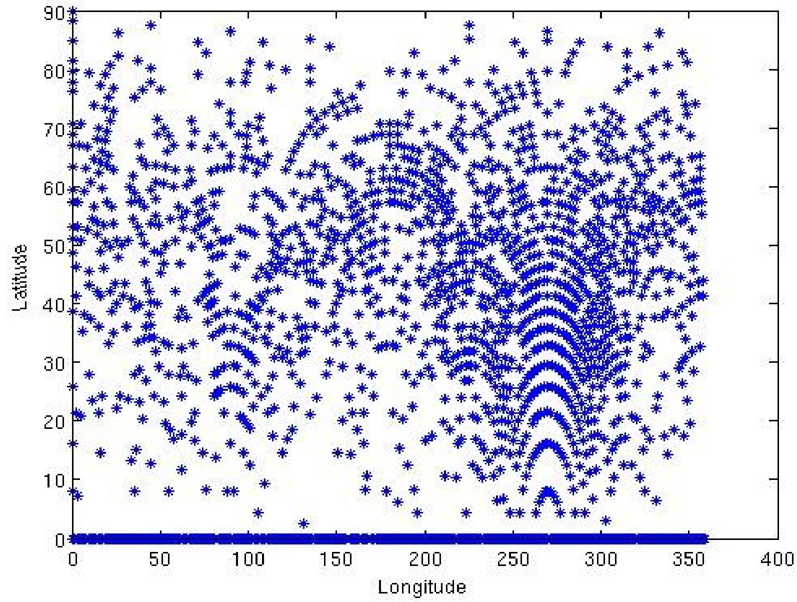


Computational cost

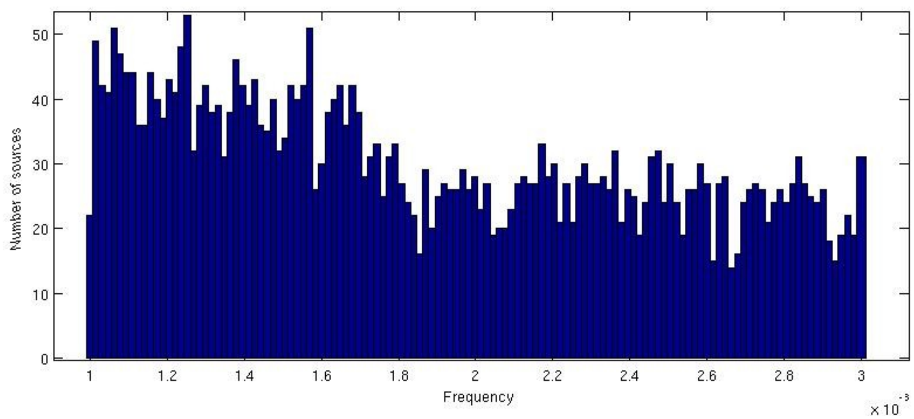
The construction of each sky-map entails a fixed computational cost. For a block of 500 frequency bins a *desktop with a single 2.1 GHz CPU takes about 25 minutes to construct the corresponding 500 skymaps (for the position resolution used here). The computational cost for the deconvolution on a block of skymaps is about 8 minutes.* The total time taken on the same machine for constructing 65,000 skymaps was about 24 hours.

Summary of results

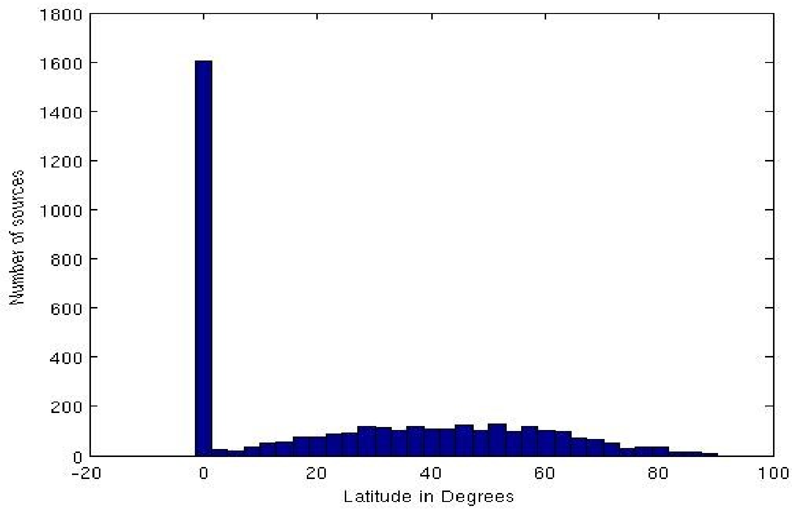
- The method currently can not distinguish between sources in the upper and lower hemispheres. *Hence, the values of Latitude we have given are absolute values.* This limitation can be removed by properly account for LISA's antenna patterns, but as mentioned earlier, this is still an area of research for us and we do not use this correction for the present challenge.
- *Only a one year long time series is used* and hence we have a frequency resolution of about 31 nHz. Given the other modifications we were making to the method, the time in hand was not sufficient to reliably extrapolate the code to more than one year of data.
- We limit ourselves in this challenge to the identification of bright binaries that are clearly discernible in the deconvolved sky maps.
- The tomographic method was used in the frequency band 0.2985 mHz to 3.0015 mHz. i.e about 63000 frequency bins for a one year observation time. **We identified 3862 sources.** The identified source position across all frequencies is shown below:



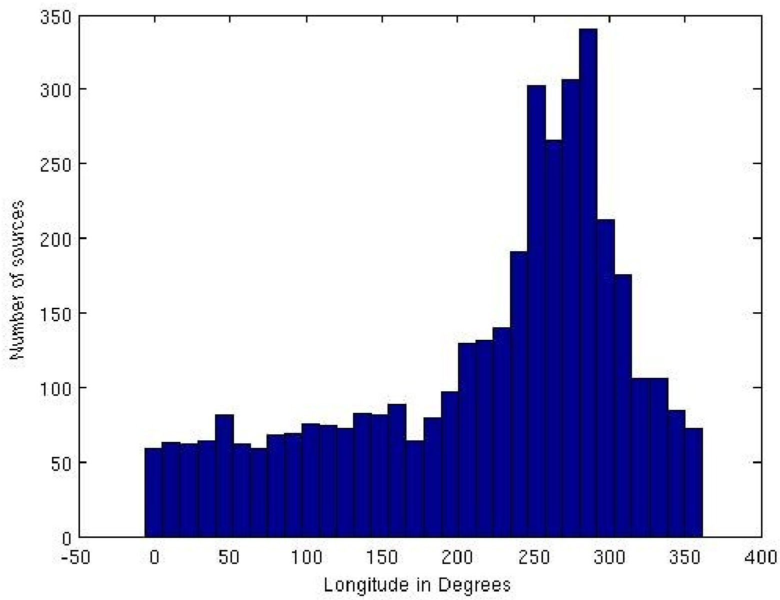
- The number of identified sources in non-overlapping blocks of 500 frequency bins is plotted below:



- The distribution of sources as function of latitude is given below:

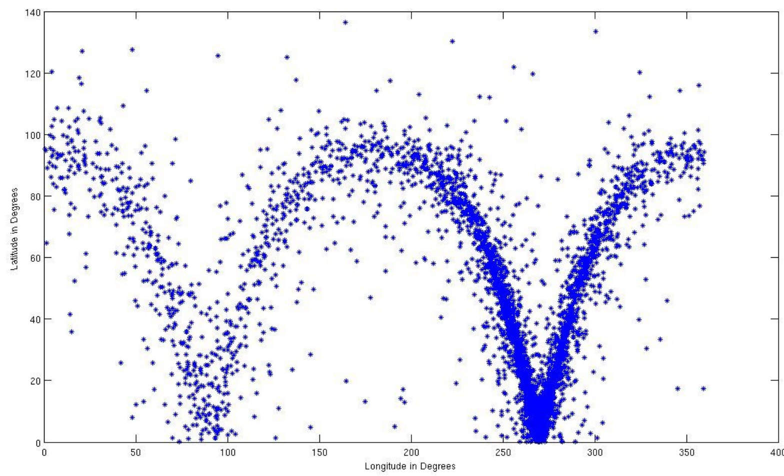


- The distribution of sources as function of longitude is given below:

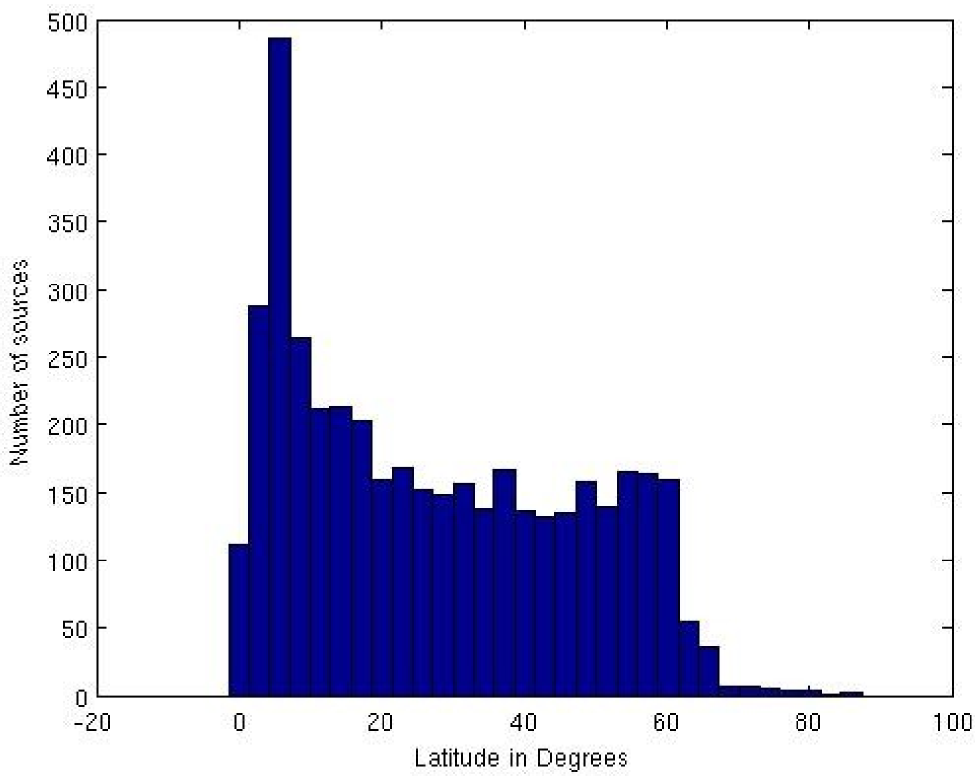


Comparison with training key data set

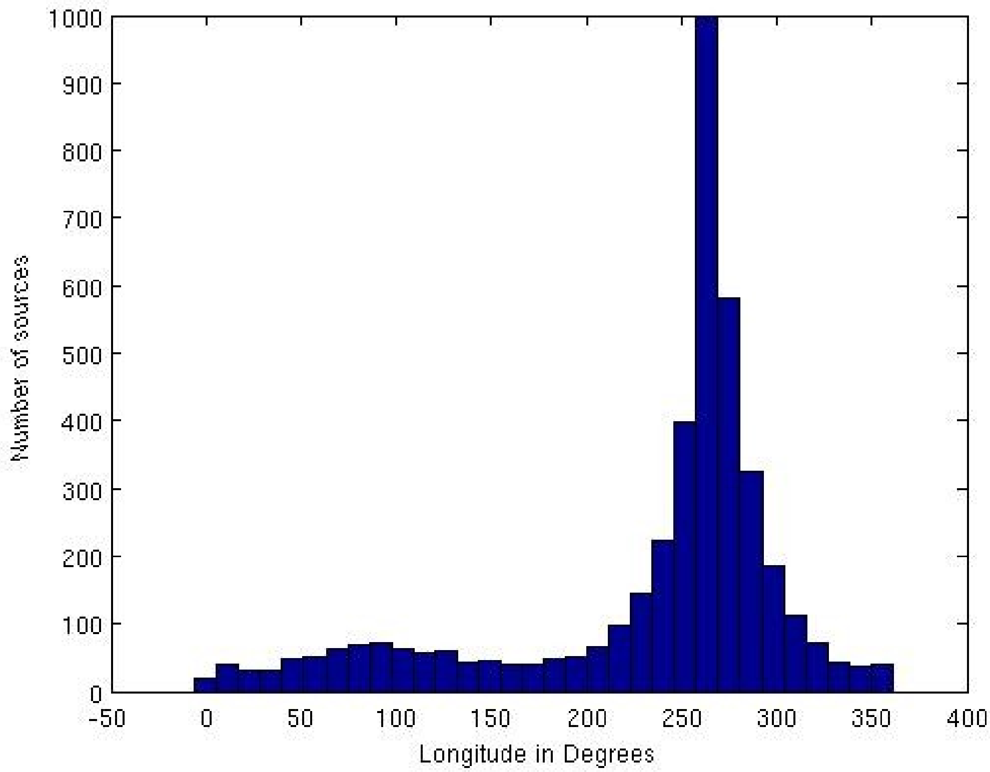
- Plots sky positions of bright 4180 binaries in the frequency band [0.9985 mHz, 3.0015 mHz] from training key set:



- Plots latitude distribution of bright 4180 binaries in the frequency band [0.9985 mHz, 3.0015 mHz] from training key set:



- Plots longitude distribution of bright 4180 binaries in the frequency band [0.9985 mHz, 3.0015 mHz] from training key set:



Number of sources
1000
900
800
700
600
500
400
300
200
100
0
-50
0
50
100
150
200
250
300
350
400
Longitude in Degrees