Tomographic method for LISA binaries: application to MLDC data

K. Rajesh Nayak, Soumya D. Mohanty and Kazuhiro Hayama

Center for Gravitational Wave Astronomy

UT-Brownsville

Summary of Tomographic Method

- ☞ Motion of LISA around the Sun allows the relation between detector response and Radon transform. (S. D. Mohanty and R. K. Nayak, Phys. Rev. D 74, 044007 (2006)).

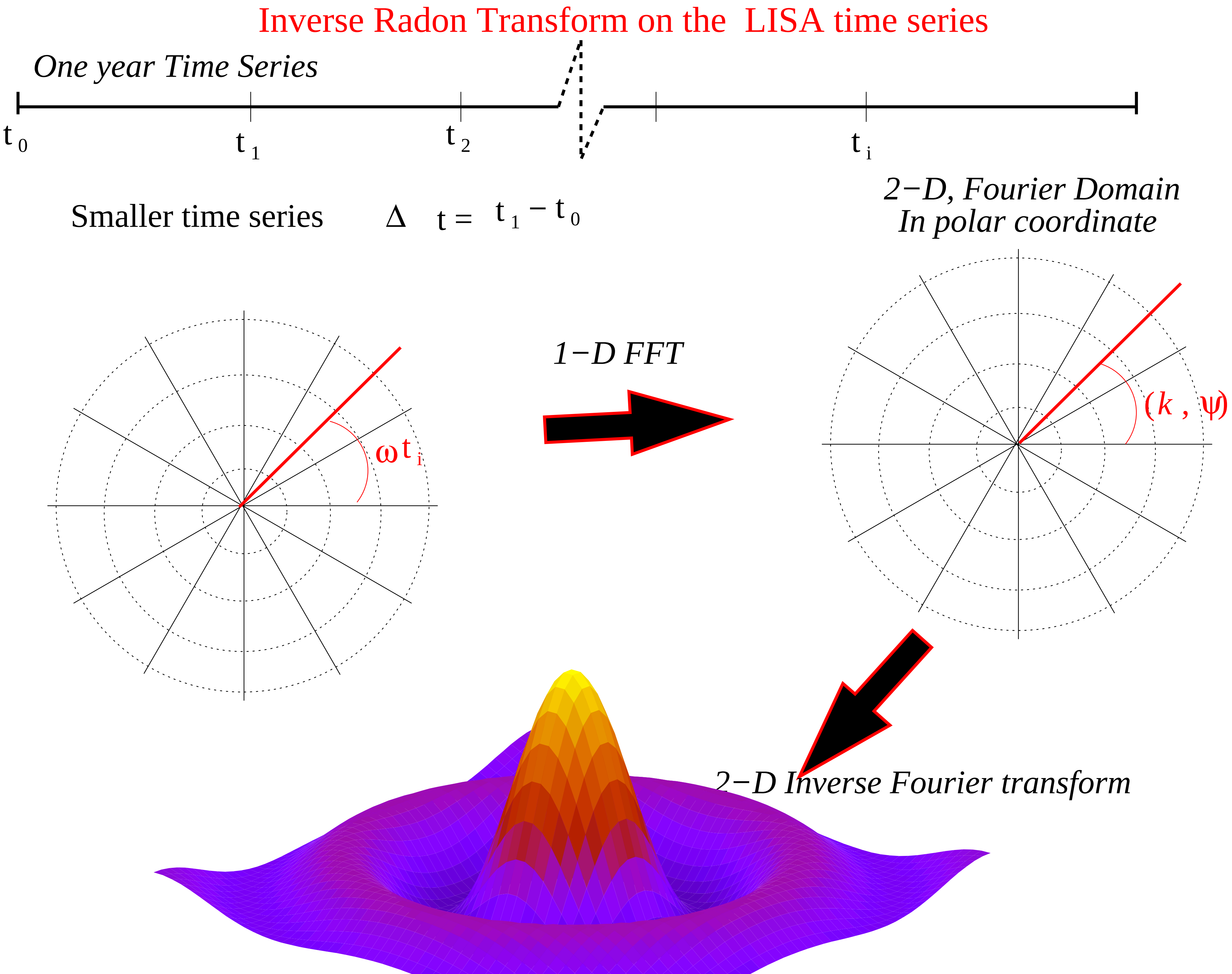
- ☞ The Inverse Radon transform on the LISA time series gives the sky map of gravitational wave sources at any given frequency.

- ☞ The resulting sky map is convolution of GW source distribution with the point spread function or PSF.

- ☞ Known PSF, we can search for isolated bright point source.

  - ✍ Not a Template based method!

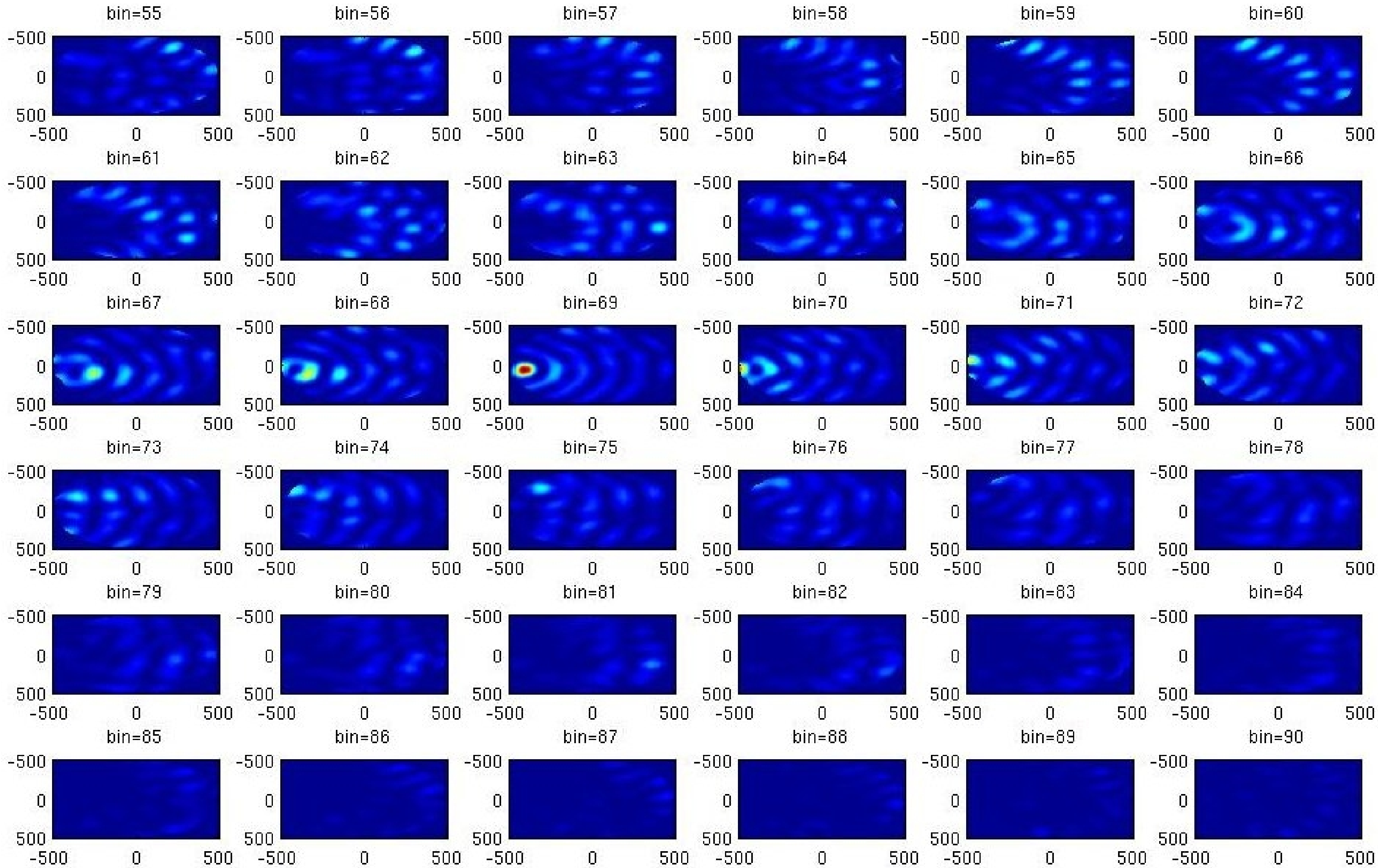
- ☞ Here we use visual inspection for identifying the point sources!



Inverse Radon Transform on the LISA time series
One year Time Series
t 0
t 1
t 2
t i
Smaller time series
Δ t = t 1 − t 0
2−D, Fourier Domain
In polar coordinate
1−D FFT
ω t i
(k , ψ)
2−D Inverse Fourier transform

Visual Identification

As an example, for MLDC data set 1.1.4, sky maps are plotted:



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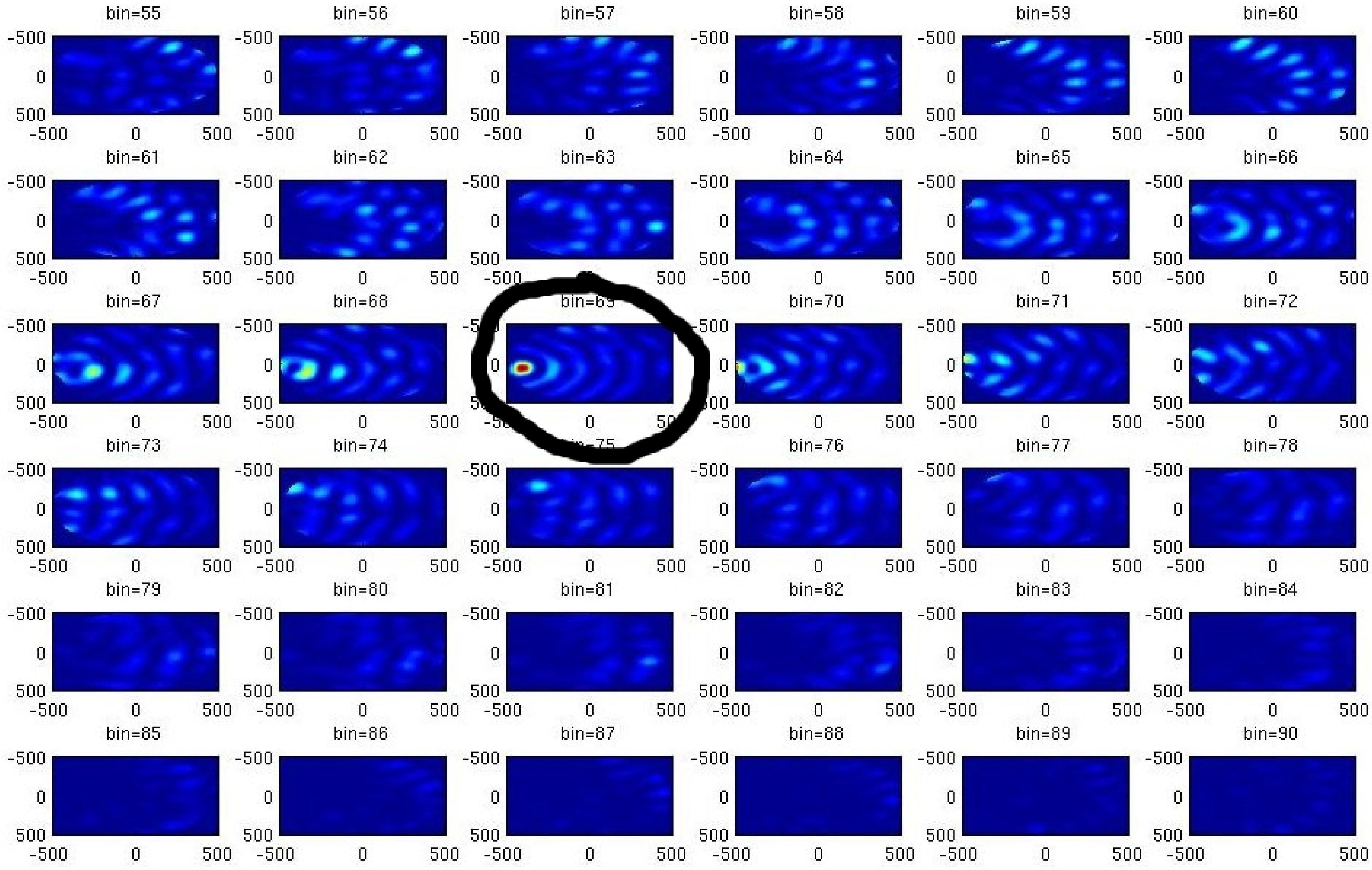

Bright source

Visual Identification

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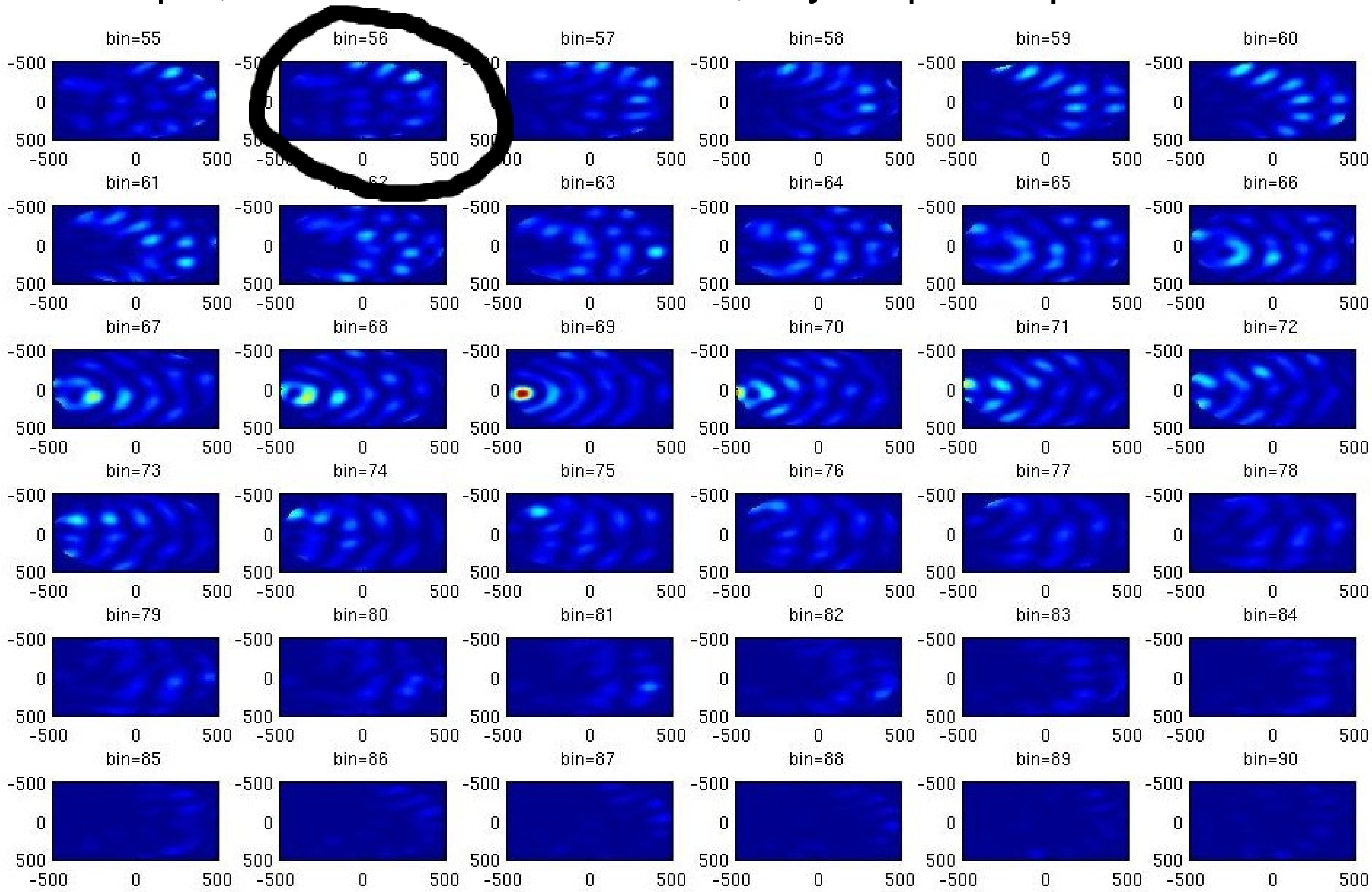

Confusion because of overlapping PSF.

Visual Identification

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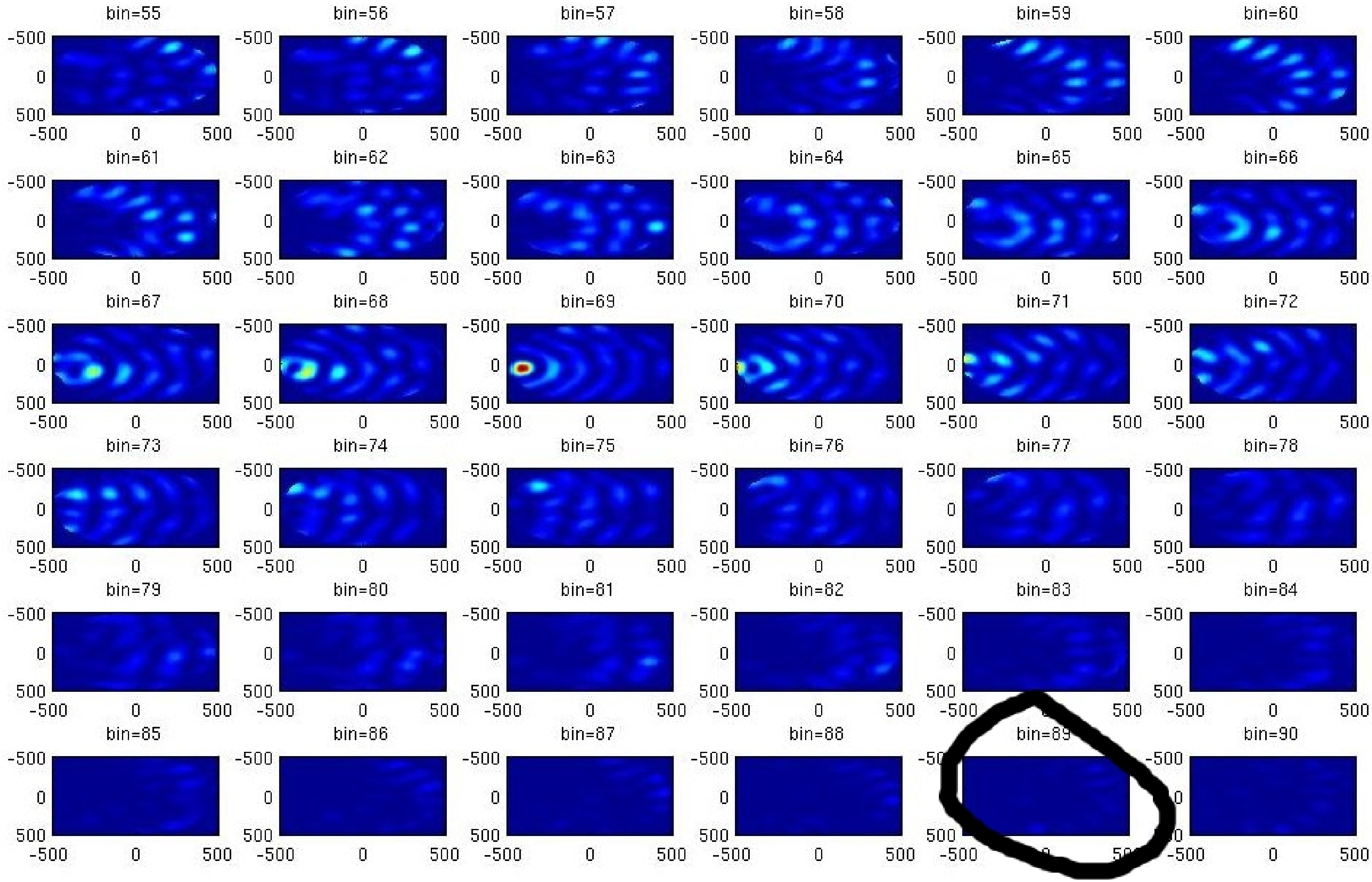


Source lost because of near by bright source

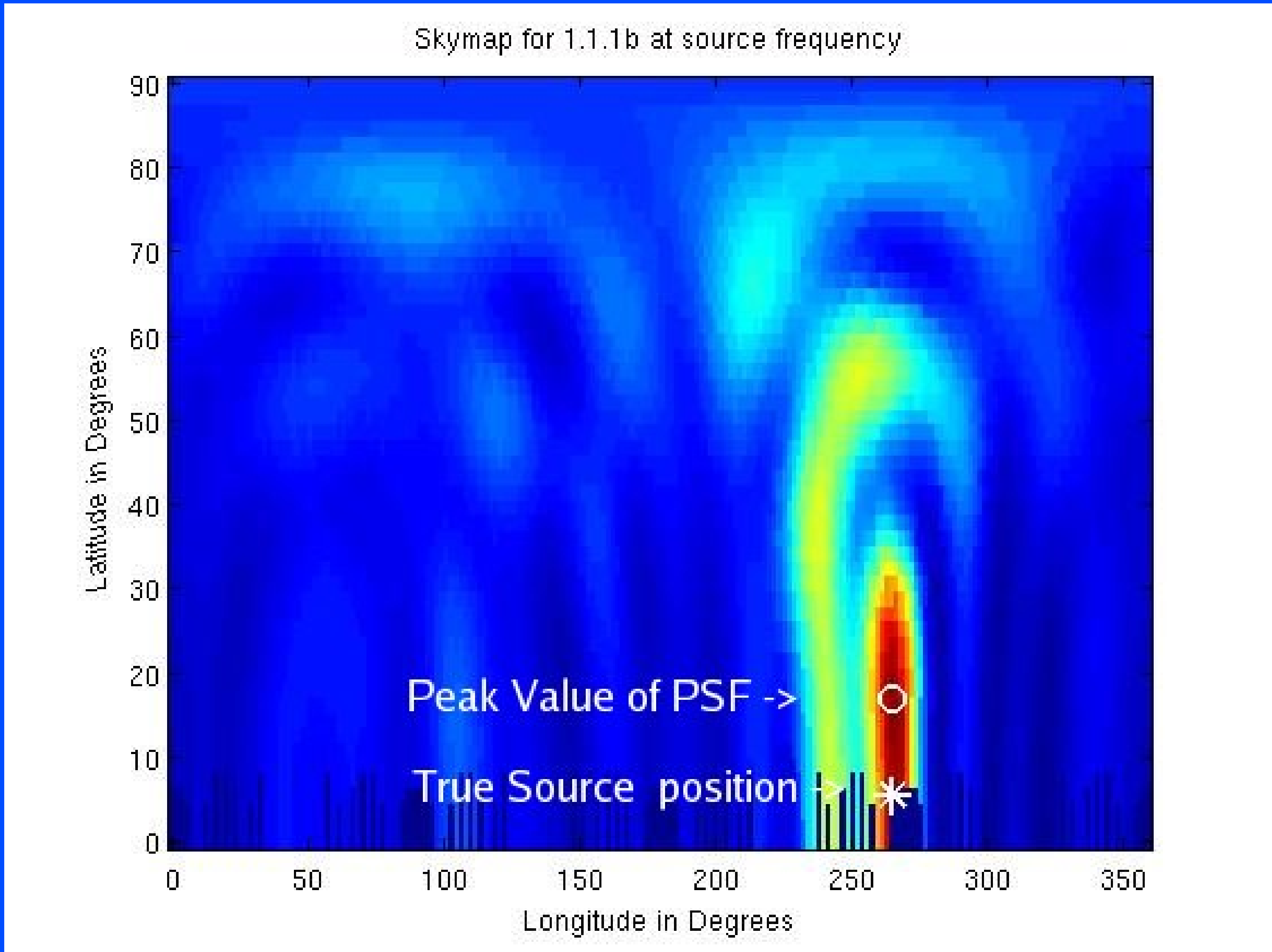
Application to MLDC 1.1.1-1.1.4

Summary:

- ☞ Sky maps are generated for every frequency bin in the band of interest. (1 bin = 1/one_year).
- ☞ The frequency resolution is one bin (i.e $<$31 nHz).
- ☞ error in sky position inversely proportional to the frequency.
- ☞ At present we can get only absolute value of latitude.

MLDC 1.1.1a-c

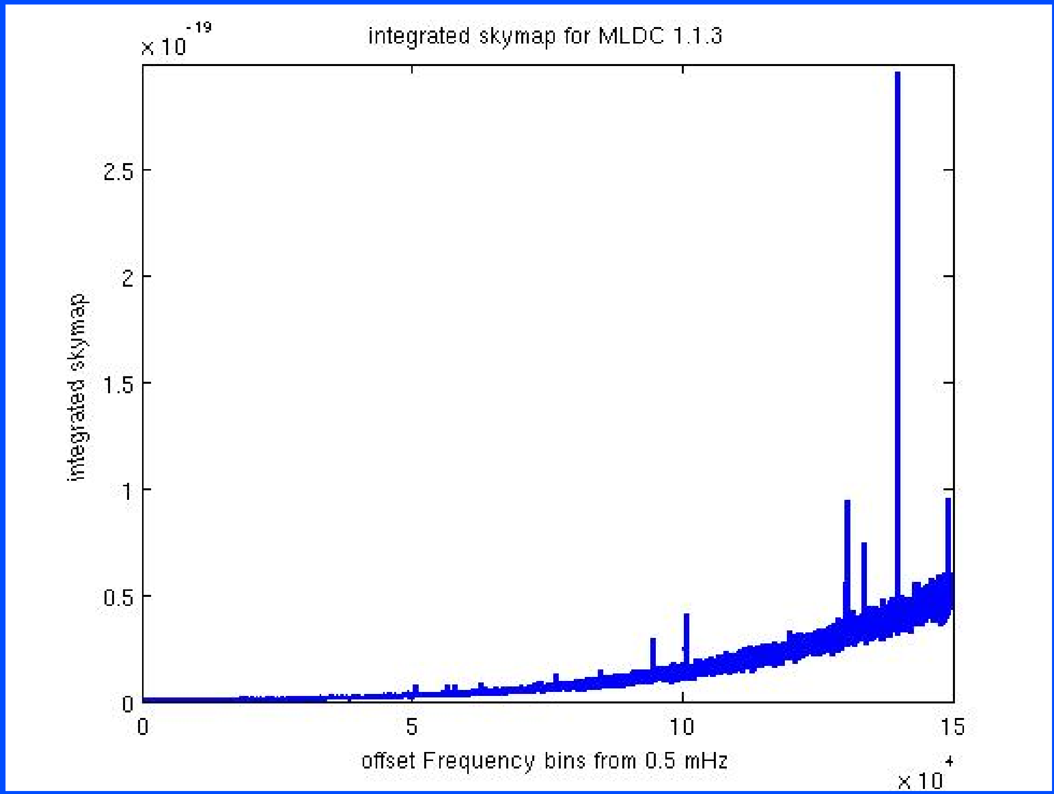
The sky map at source frequency is :



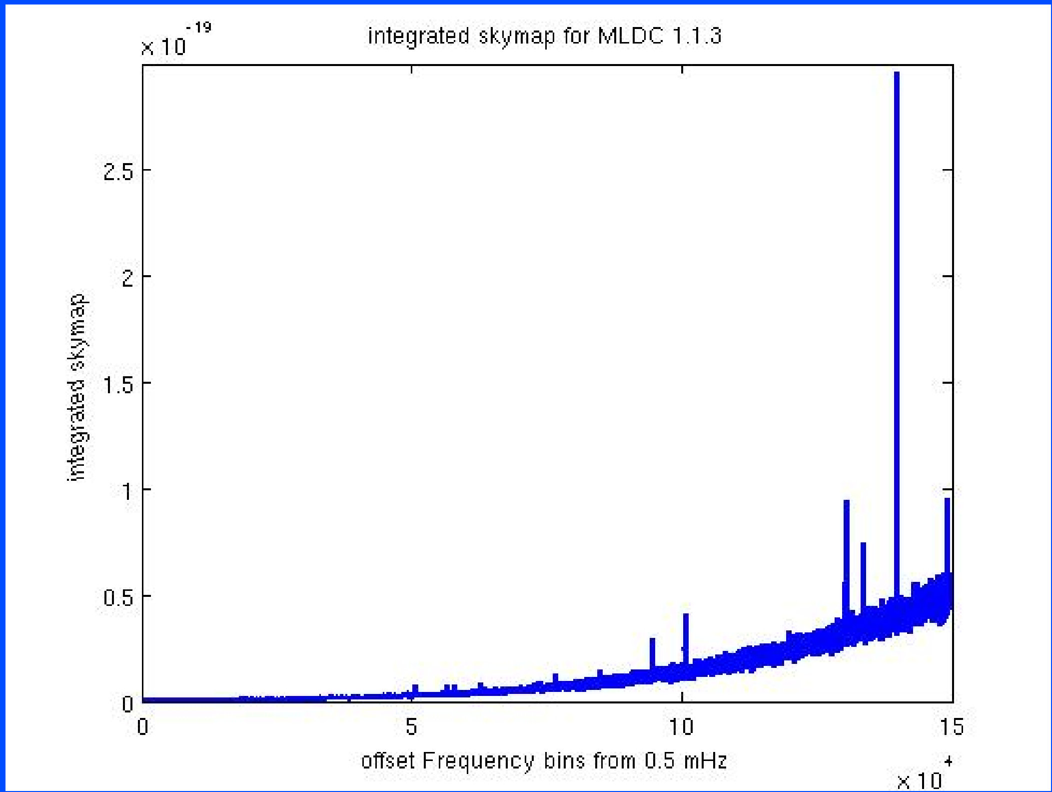
MLDC 1.1.2 and 1.1.3

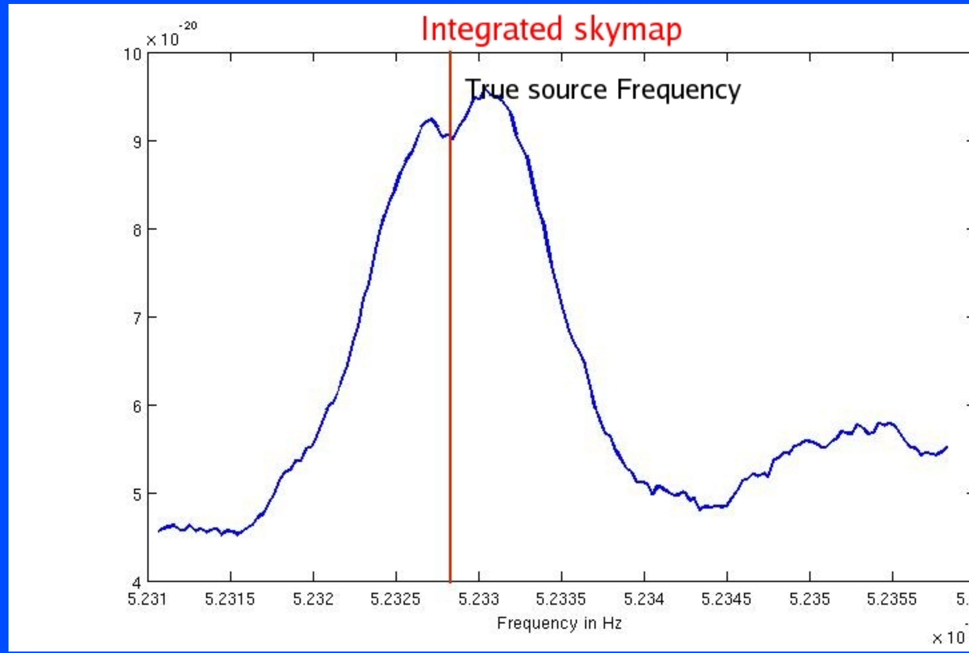
- ☞ For source Identification: first, sky maps are constructed from frequency 0.5 mHz to 8 mHz. That is about 250000 sky maps!
- ☞ This is computationally expensive, because of larger number of bins involved. It took 15 Hrs on a standard 2.1 GHz Pentium desktop for a coarser sky resolution.
- ☞ Integrated sky maps are plotted as a function of frequency.

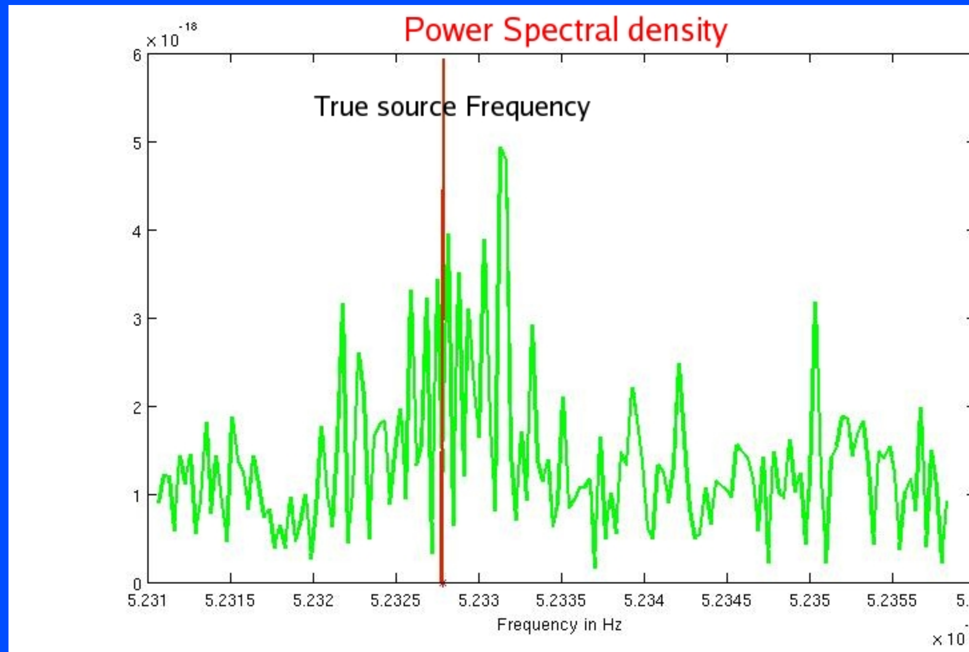
Plot of Integrated sky map vs power spectral density



Plot of Integrated sky map vs power spectral density

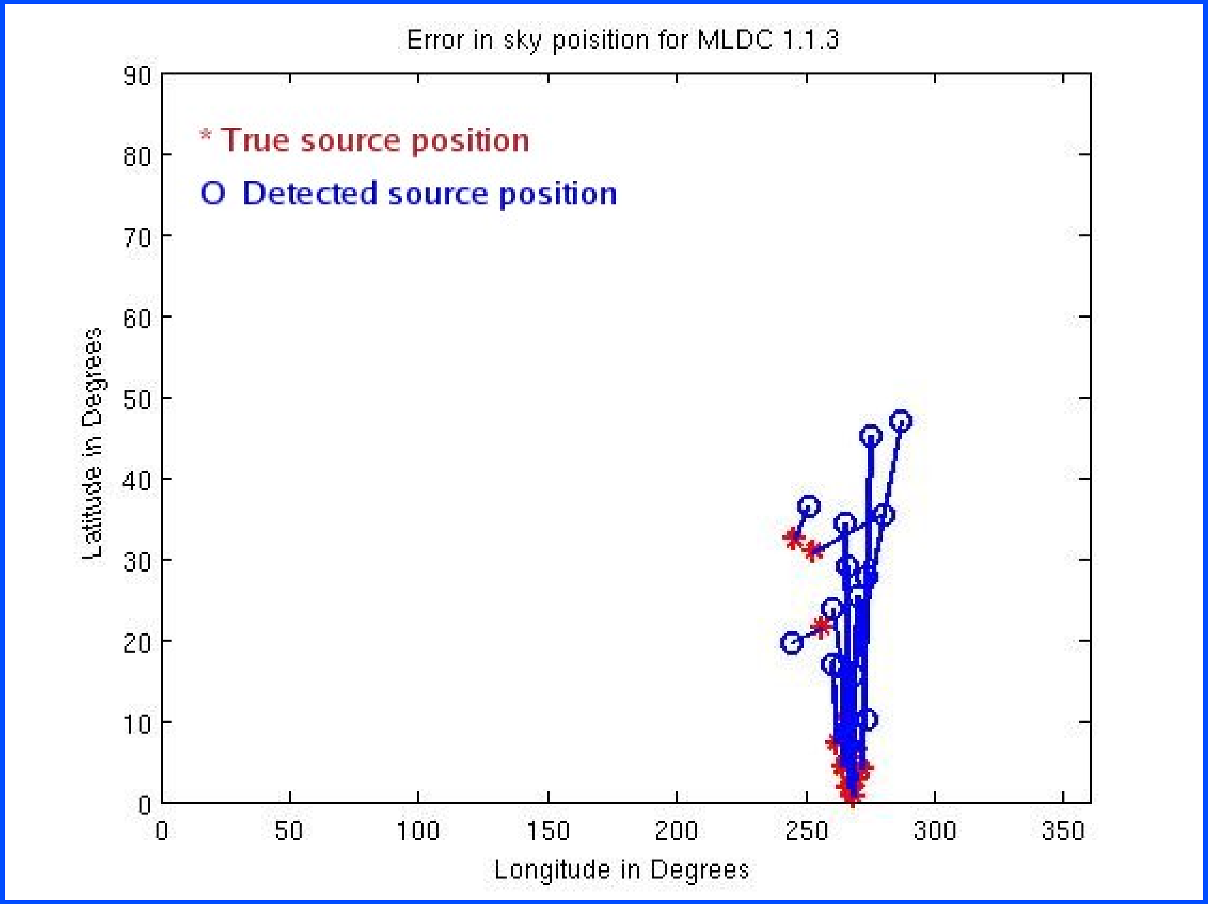






- Once source frequencies are known, their sky position can be obtained from full sky map.

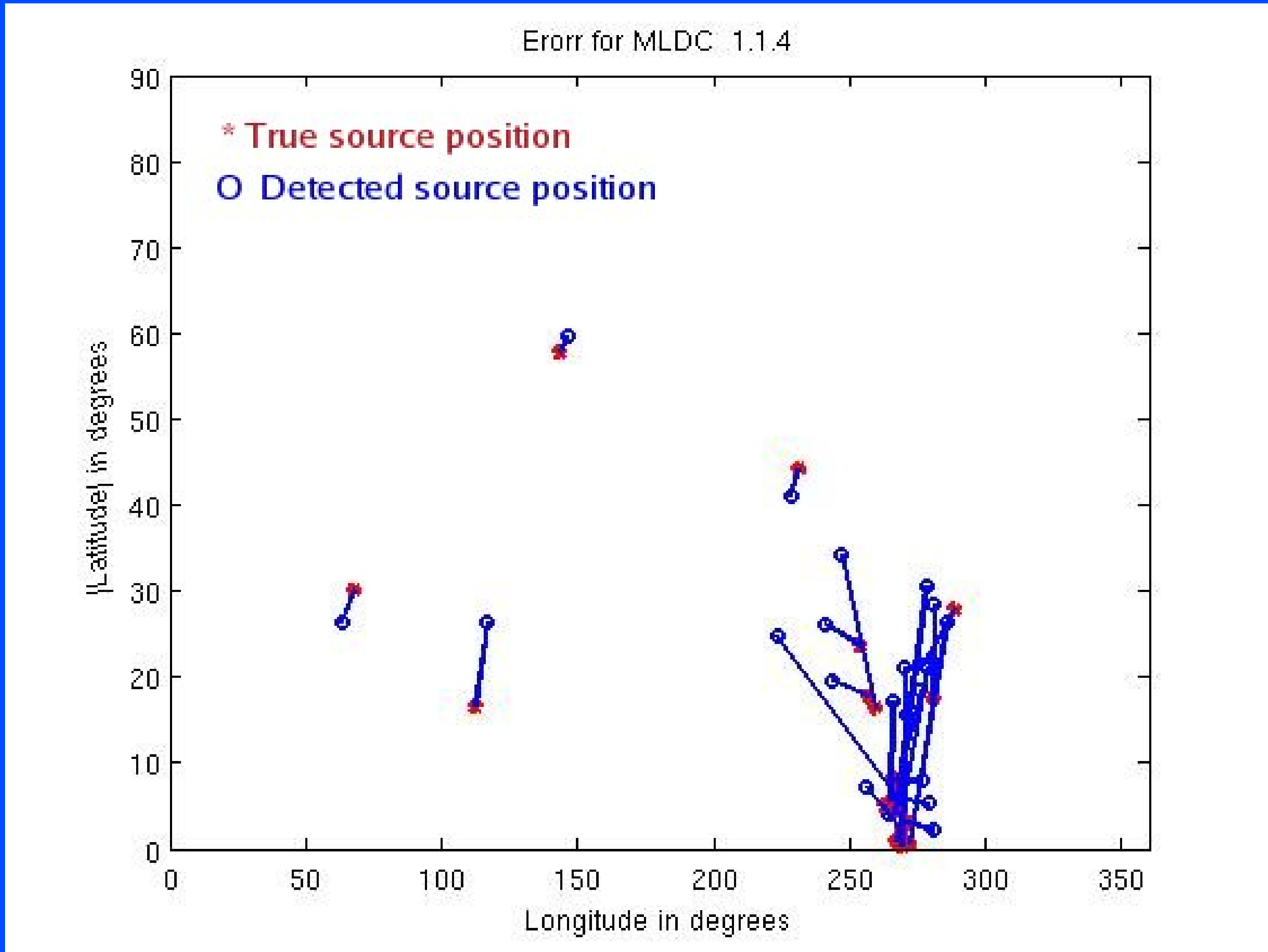
Errors in sky positions for MLDC 1.1.3



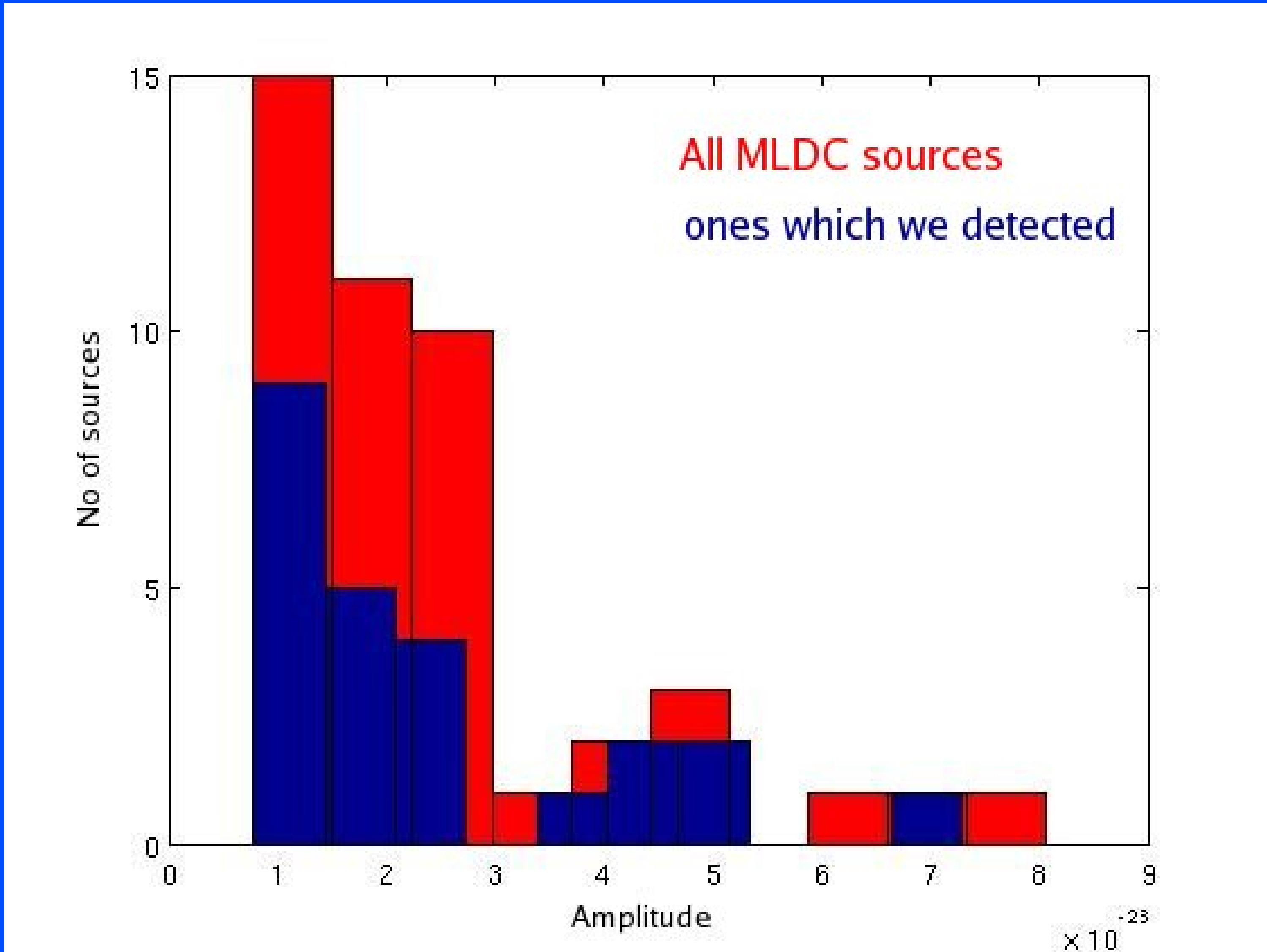
MLDC 1.1.4

- ☞ Sky maps are computed for 500 frequency bins starting from 3 mHz.
- ☞ Computational cost is about 1 Hr on Desktop with better sky resolution.
- ☞ We identified 36 sources,
  - ✍ 24 source frequency matched with MLDC key values within one bin
  - ✍ 3 source frequency matched with MLDC key values within two bin
  - ✍ 9 source frequency did not match with MLDC
- ☞ 1 in 5 sources were wrong identification. This may be avoided with a proper deconvolution methods.

Error in sky position for MLDC 1.1.4



Amplitude distribution of detected sources



☞ The overlap of side lobes are bigger problem than SNR.

Effects Amplitude modulation

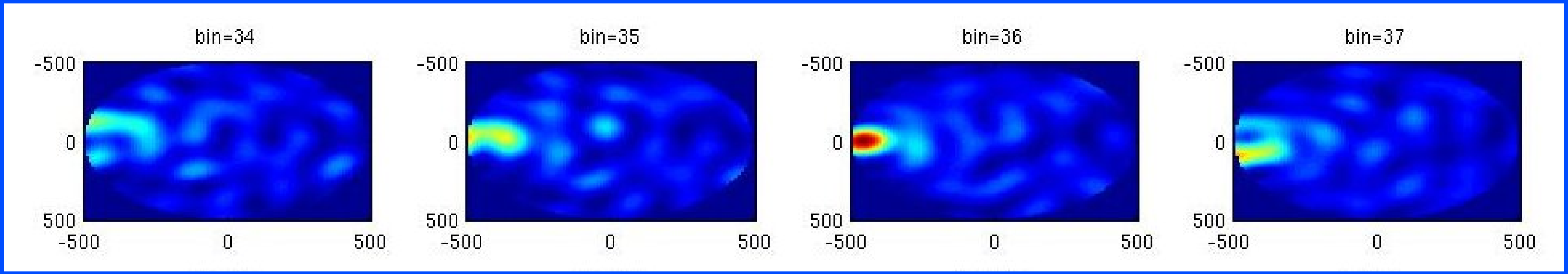
- ☞ Error in latitude is systematic not Random
- ☞ This is because of sub-optimal treatment of amplitude modulation.
- ☞ This error is larger as we get closer to Ecliptic plane.

we use the optimized TDI data combinations, to get better localization of source position

$$f_+ = \cos\chi\, E - \sin\chi\, A\,,$$
$$f_\times = \sin\chi\, E + \cos\chi\, A\,,$$
$$\chi = 2\phi + \frac{\pi}{3}$$

Conventions and Notations!

Signal generated with our code and MLDC parameters:



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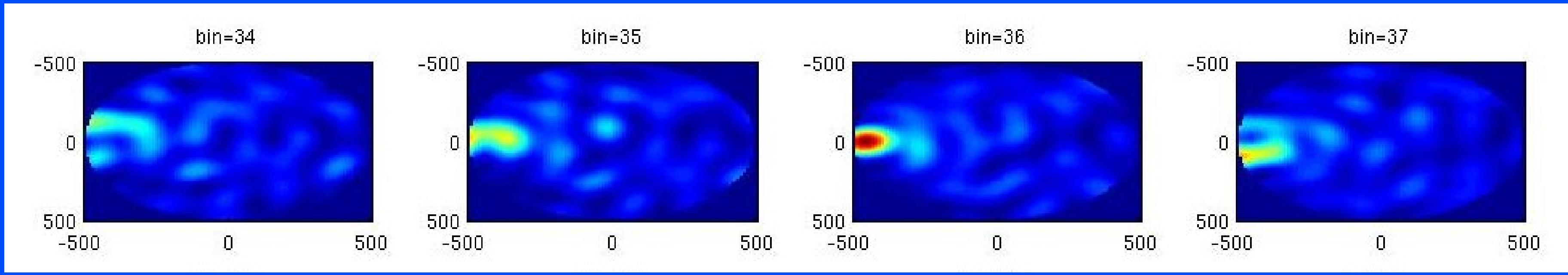
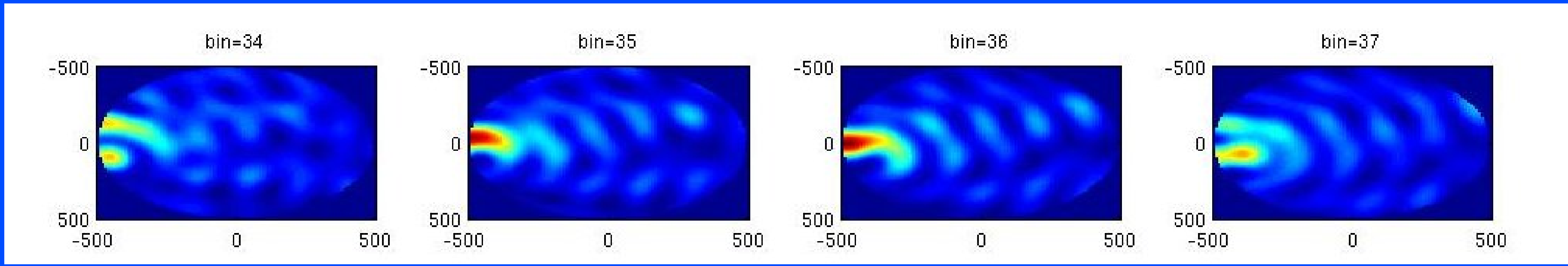


This optimization scheme has problems:

MLDC 1.1.4 signal:



What we learned from MLDC

☞ We can identify the sources with frequency errors less than one bin corresponding to one year observation time.

☞ Errors in sky positions are systematic.

- ✍ Errors are due to sub-optimal treatment of amplitude modulation.
- ✍ This may be improved in the next step (MLDC 2 ?).
- ✍ We get absolute value of latitude.

☞ Deconvolution methods are needed for reducing false sources and to reduce the effect of bright sources.(Talk by Hayama).