Data analysis pipeline for the spherical gravitational wave detector MiniGRAIL

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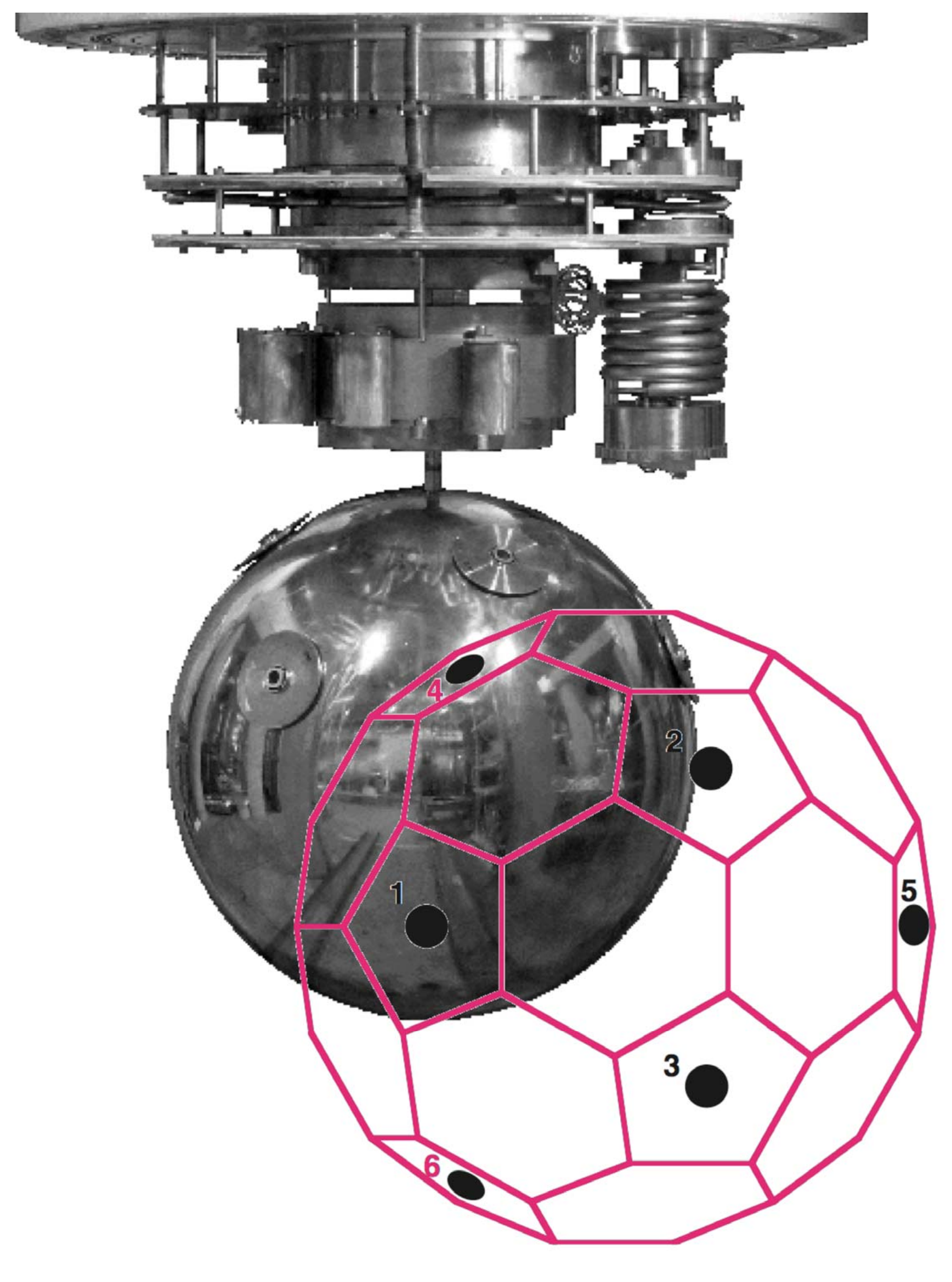


Photo of MiniGRAIL and a representation of the TIGA configuration

MiniGRAIL

MiniGRAIL (GRavitational Antenna In Leiden) is the first ultracryogenic spherical gravitational wave detector [1]. It has a resonant mass of 68cm diameter made of CuAl6%.

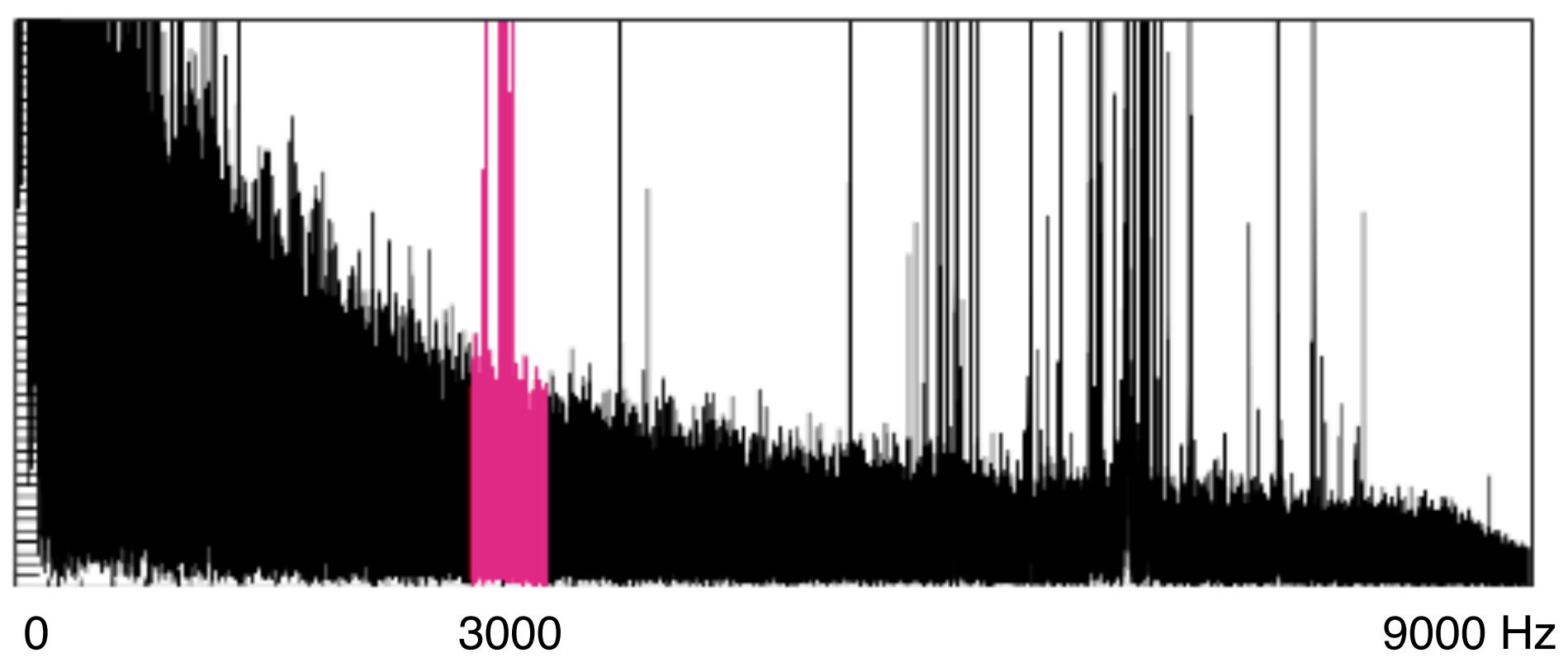
First measurements have already been obtained with three capacitive transducers at a thermodynamic temperature of 5K.
In the future, the detector will operate at 50mK with six transducers allowing a reconstruction of the gravitational wave direction.

These transducers are coupled to a two stage SQUID. The first stage is a SQUID from Quantum Design which is amplified in a second stage by a dc-SQUID.

The sensitivity to GW will be of the order of 10^{-22} $Hz^{1/2}$. The spheroidal quadrupole modes have a frequency around 2980Hz and a bandwidth of 400Hz [1].
MiniGRAIL could be sensitive to a pair of $0.5M_\odot$ BH just before coalescing [2], a collapse of Super Novae into BH, a collapse of white dwarf, BH ringing and other sources [3].

Aliasing

Output spectrum of one transducer



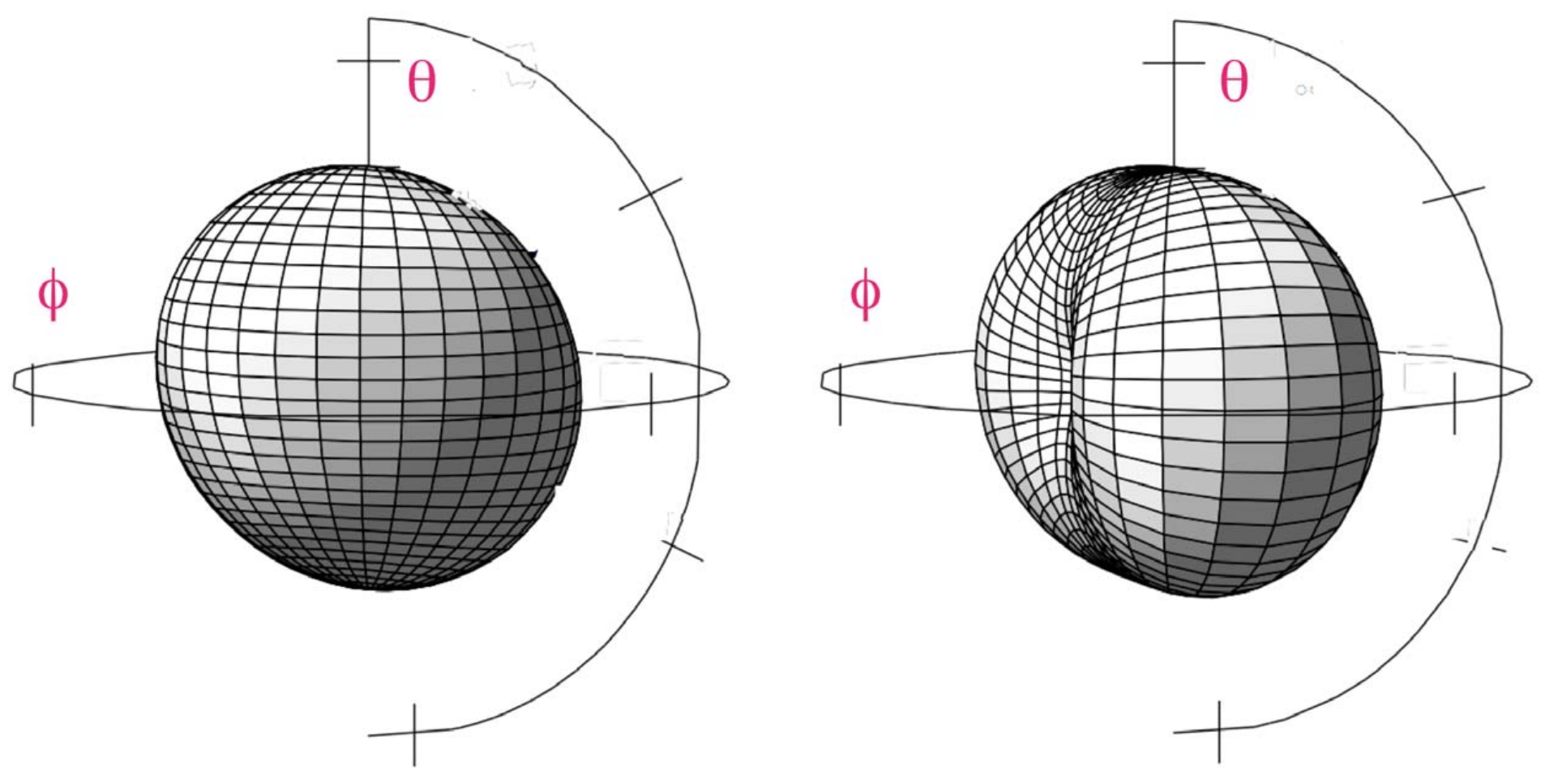
The experimental data are composed of the six transducers signals and a GPS signal. These temporal series are sampled at 18'642Hz, which represents 448Mb of data for 15mn of operation.

Our first step is to reduce this amount of data cutting out the region of interest from Fourier's modes, a window of 400Hz around 2980Hz.

We use common aliasing techniques. We Fourier transform finite periodograms, select the frequency band of interest and reconvert this band into temporal series.

The total amount of data is reduced by a factor 30.
The aliased data are saved and used for further analysis.

Mode conversion



Two different quadrupolar modes of one sphere

The six transducers are disposed in the TIGA configuration [4]. This configuration allows a linear de-convolution of the quadrupolar modes and thus of the GW signal.

Our algorithm converts electrical amplitude [V] of the transducer signals into GW amplitude h(V) and simultaneously expresses the signals in the mode channels h_m.

$$h_{ij}(h_+,h_\times,\theta,\phi)=\sum_m h_m Y_m^{ij}(\Theta,\Phi)$$

The amplitude conversion is adaptive, re-computing all main parameters in real time. The quadrupolar modes are obtained by a base transformation of the Fourier modes.

The temporal series of the modes h_m are saved.

Burst events searching

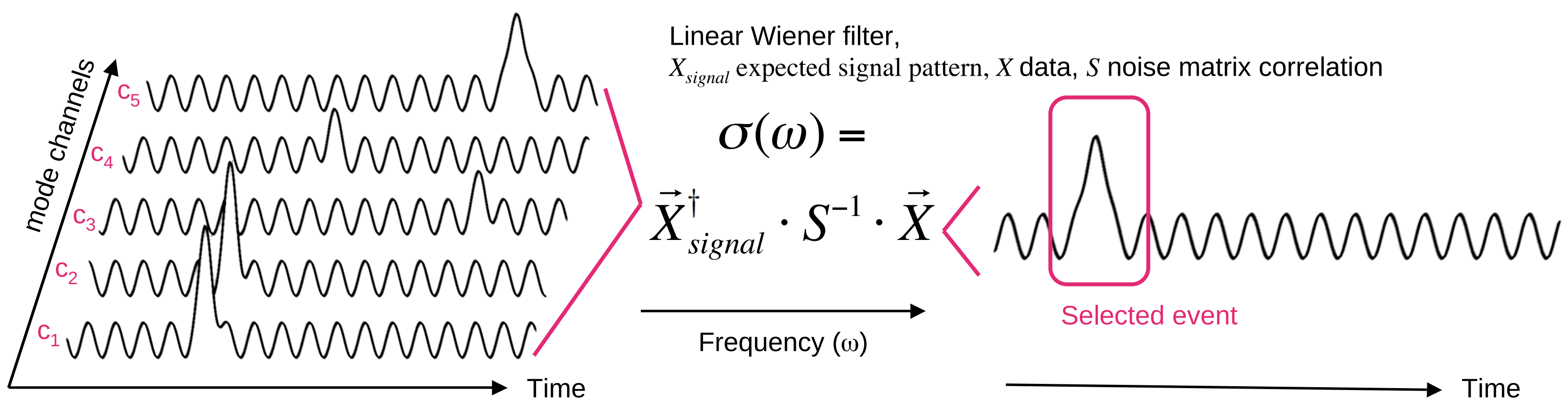
Two different event search strategies are used, according to whether the signal direction and shape is known or not.

Wavelets analysis

For unknown direction, we apply the "waveburst" [5] method adapted to the sphere.

Wiener filter

We use a linear Wiener filter [6] that takes into account the noise correlation among the five channels and the noise evolution.
We do burst search with delta and others GW patterns. Events above a threshold are selected.
If another GW detector finds candidate events, we can perform a parallel search. Our method can be quickly adapted to the shape of the candidate.

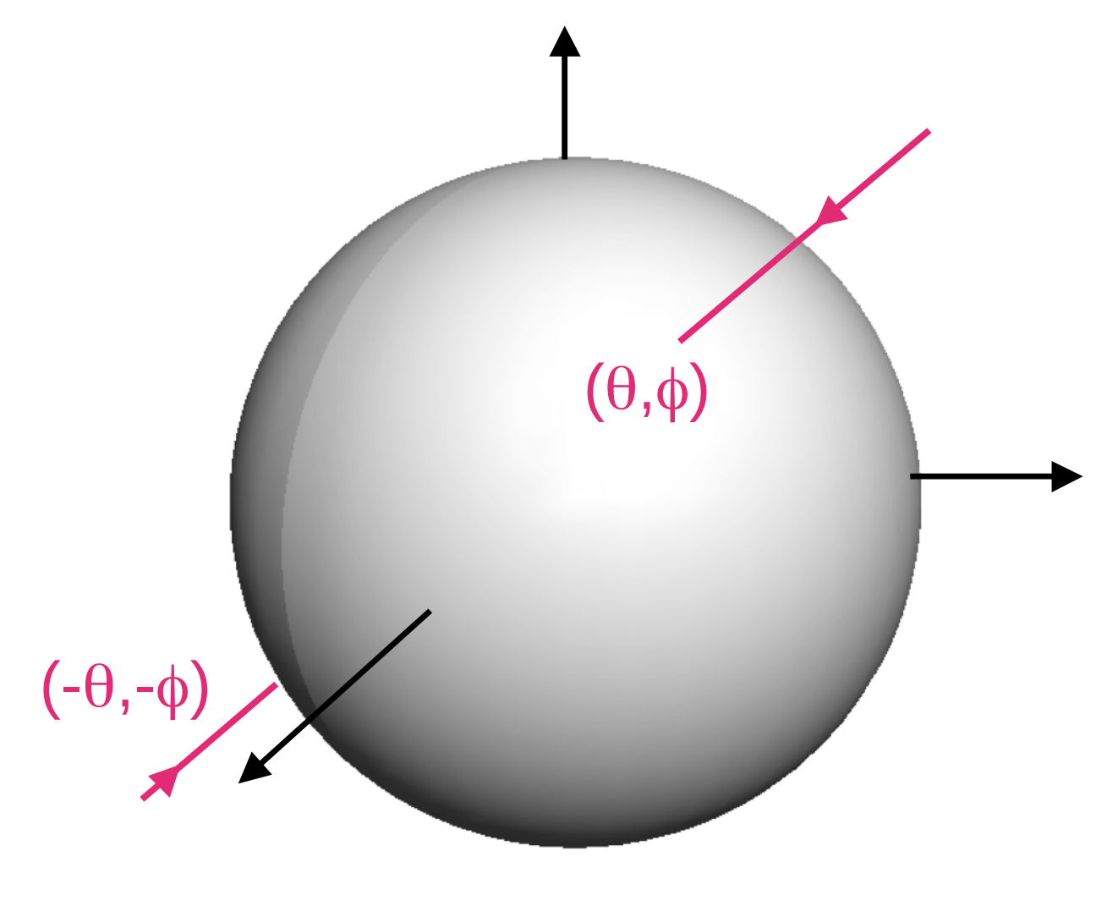


Linear Wiener filter,
X_{signal} expected signal pattern, X data, S noise matrix correlation

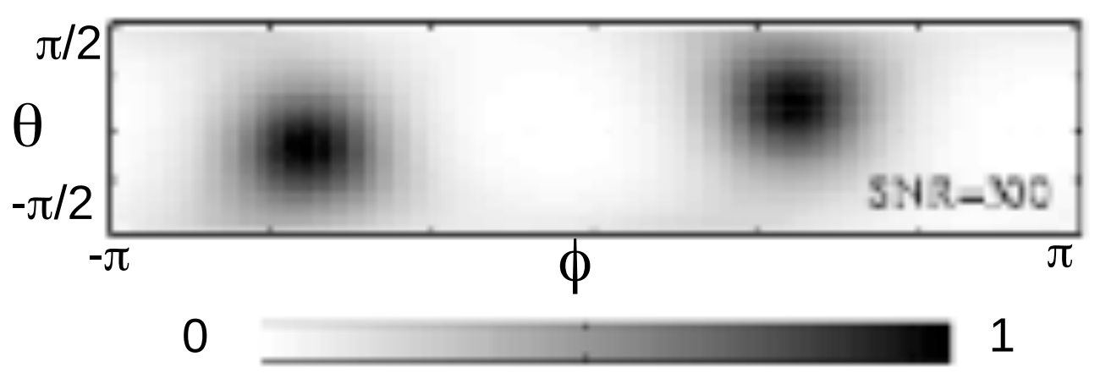
$$\sigma(\omega) = \vec{X}^{\dagger}_{signal}\cdot S^{-1}\cdot\vec{X}$$

All events are saved into lists with usual parameters (starting time, duration, amplitude, quadrupolar mode channel, possible shape, ~30 parameters).

Directional analysis



Likelihood map of the direction [7]



For all candidate events, we perform a maximum likelihood method to find the GW arrival direction. The GW events have only one most probable direction, so events with many probable directions are rejected [8].

Moreover, we reconstruct the h_{ij} matrix of the GW. This matrix has to be TT.

The GW direction given by the h_{ij} matrix [9] will be compared with the likelihood one. If directions are not compatible, we reject the event [8].

Extension to other experiments

Our data analysis pipeline was developed in a way to be open to new techniques and information about sources.
For more readability and modularity, the pipeline is written in C++. All used libraries are open source.
To share our results, we dedicate a special effort to write it in the common data frame developed by Ligo-Virgo.

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