Results from TOBAs

Cross correlation analysis to search for a Stochastic Gravitational Wave Background

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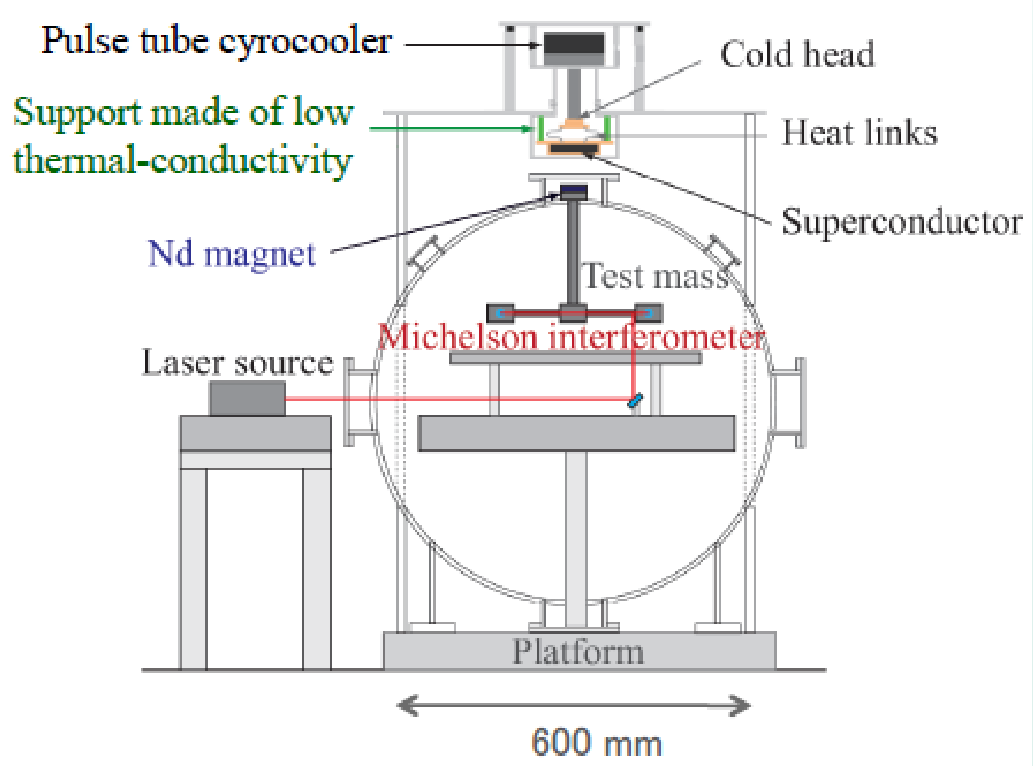
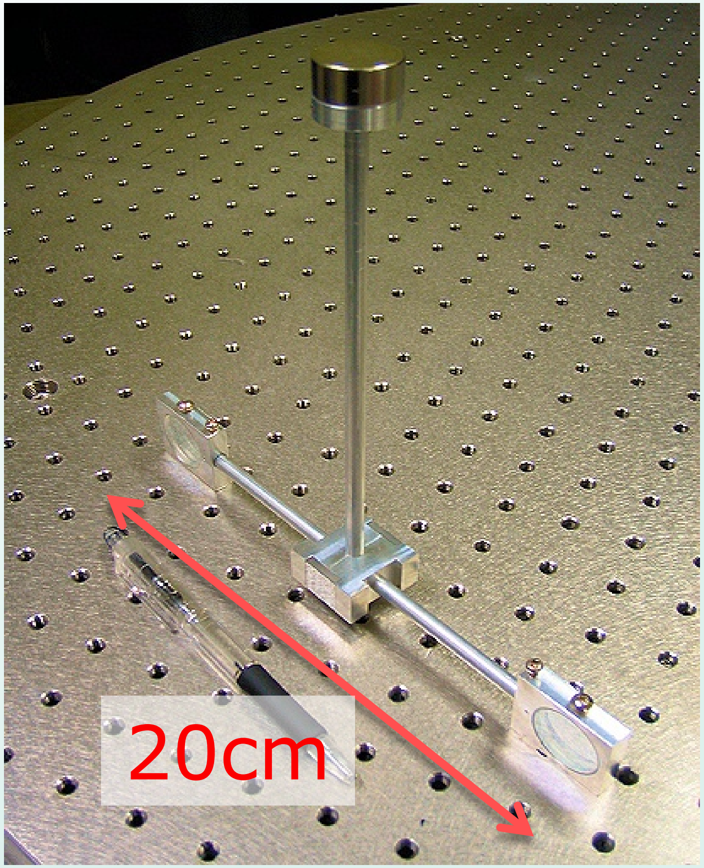
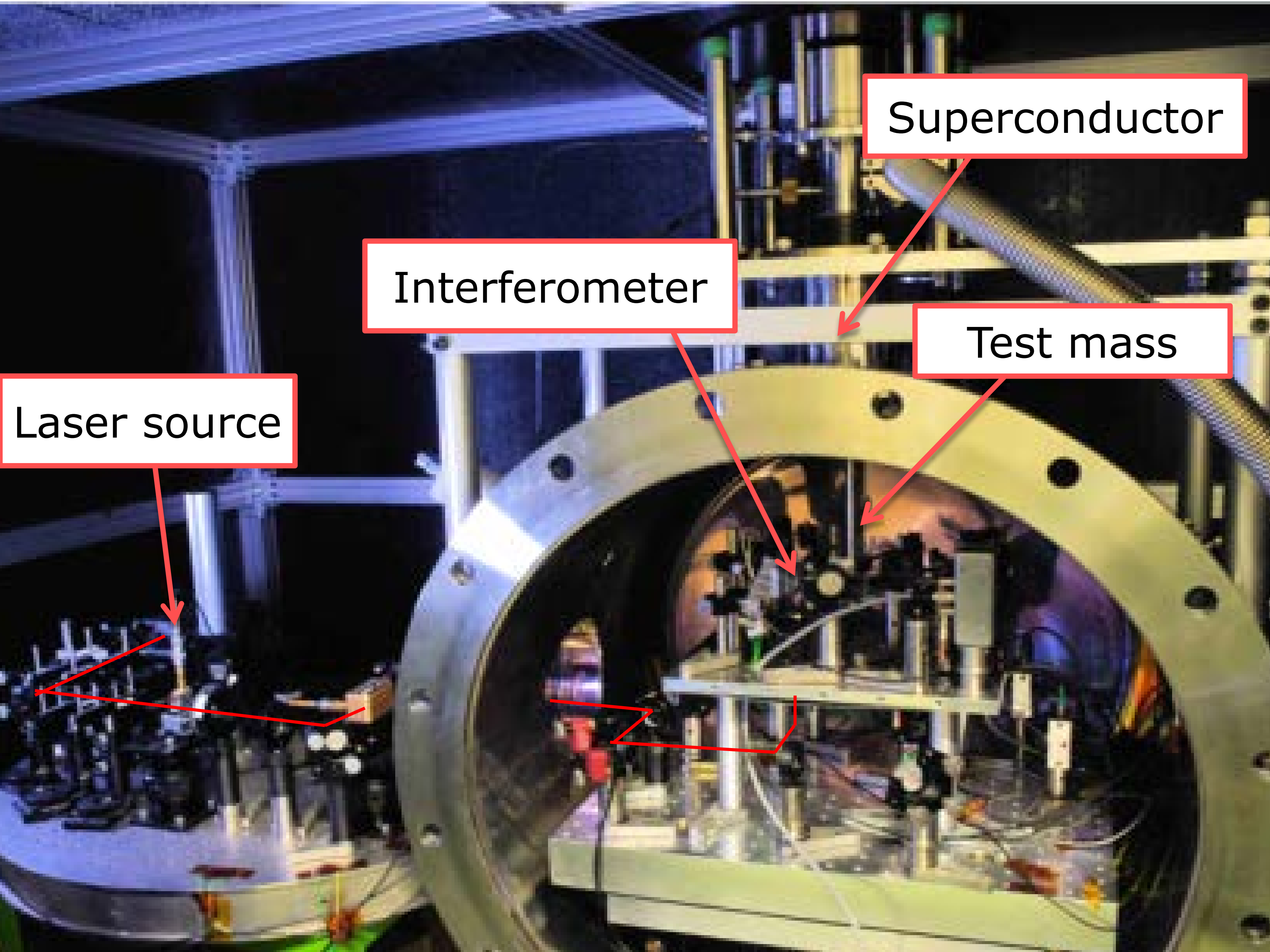
Prototype TOBA

- 20-cm small torsion bar
- Suspended by the flux pinning effect of the superconductor
- Rotation monitor:
  laser Michelson interferometer
- Actuator: coil-magnet actuator

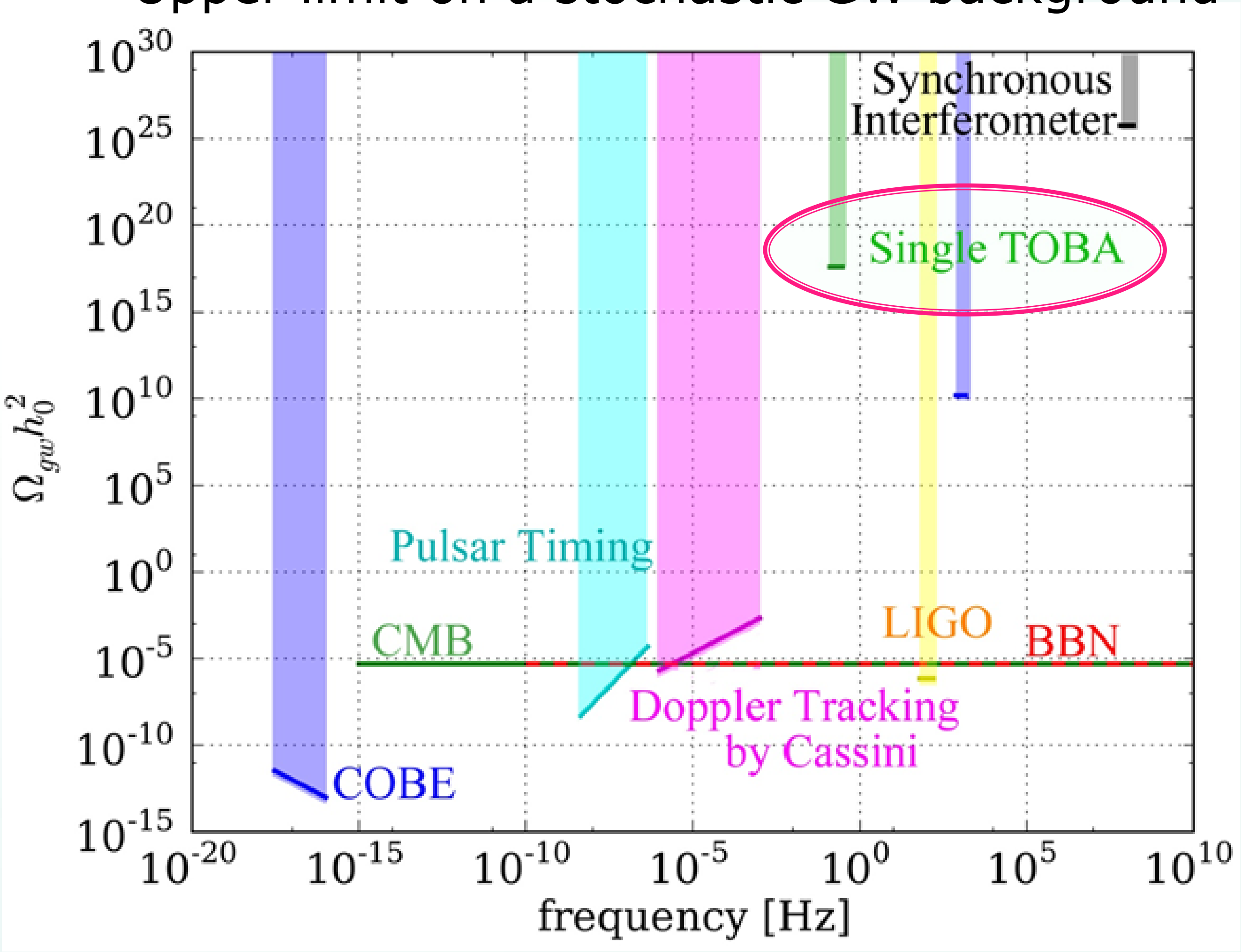





Superconductor
Interferometer
Test mass
Laser source

Previous Result

Upper limit on a stochastic GW background

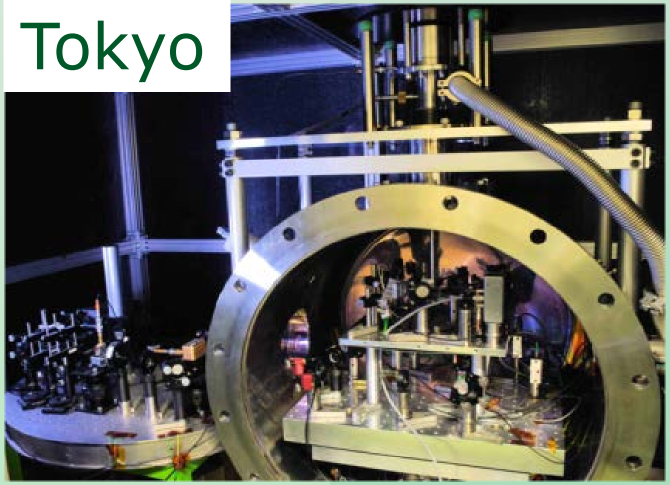


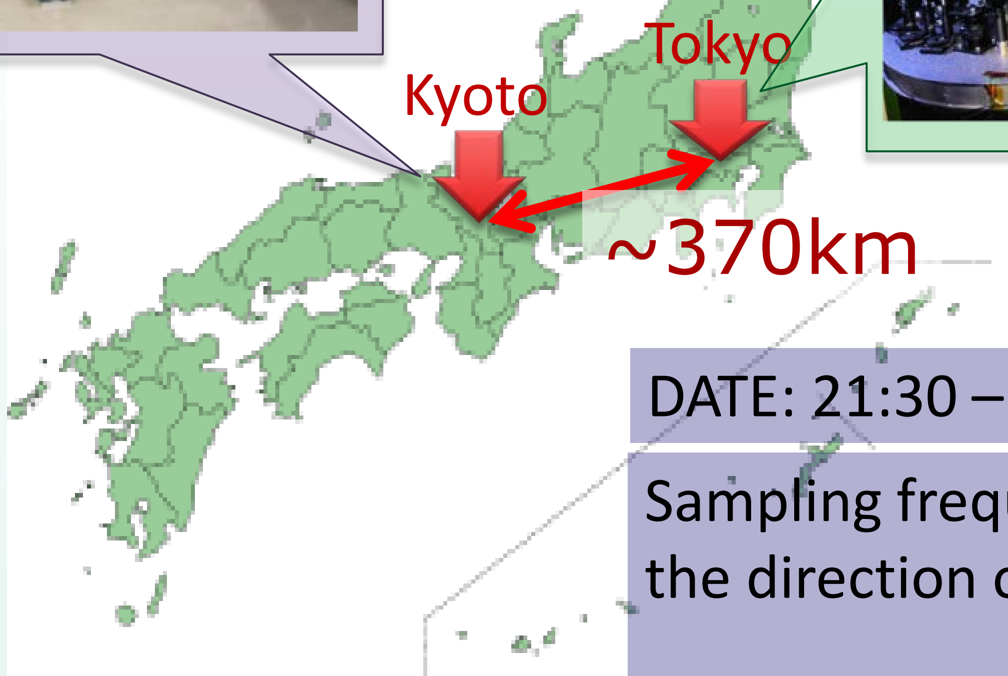
For the detection of a stochastic gravitational-wave background, simultaneous observation is necessary.

Simultaneous Observation

Kyoto

Tokyo

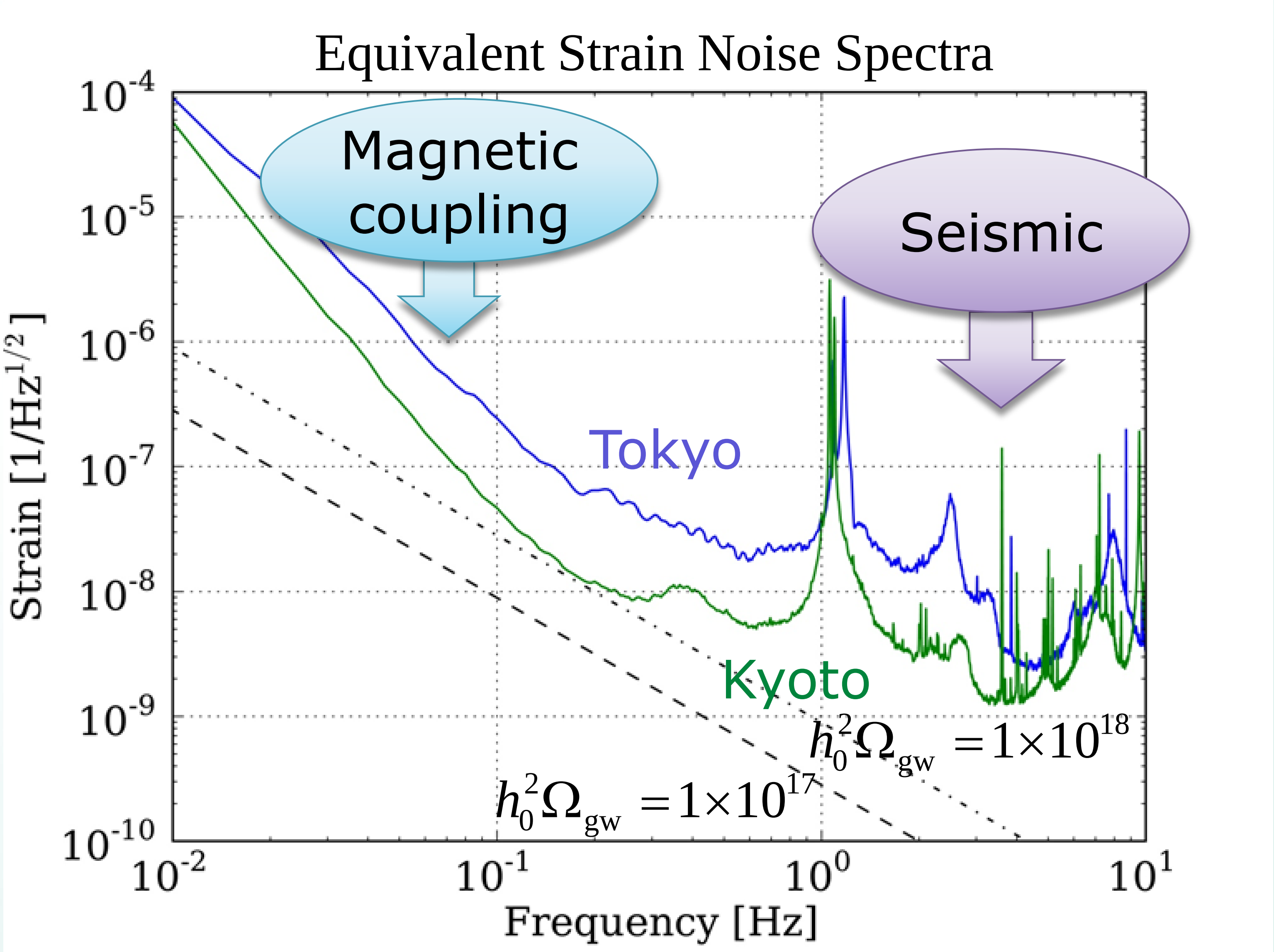




DATE: 21:30 – 7:30, Oct. 29, 2011

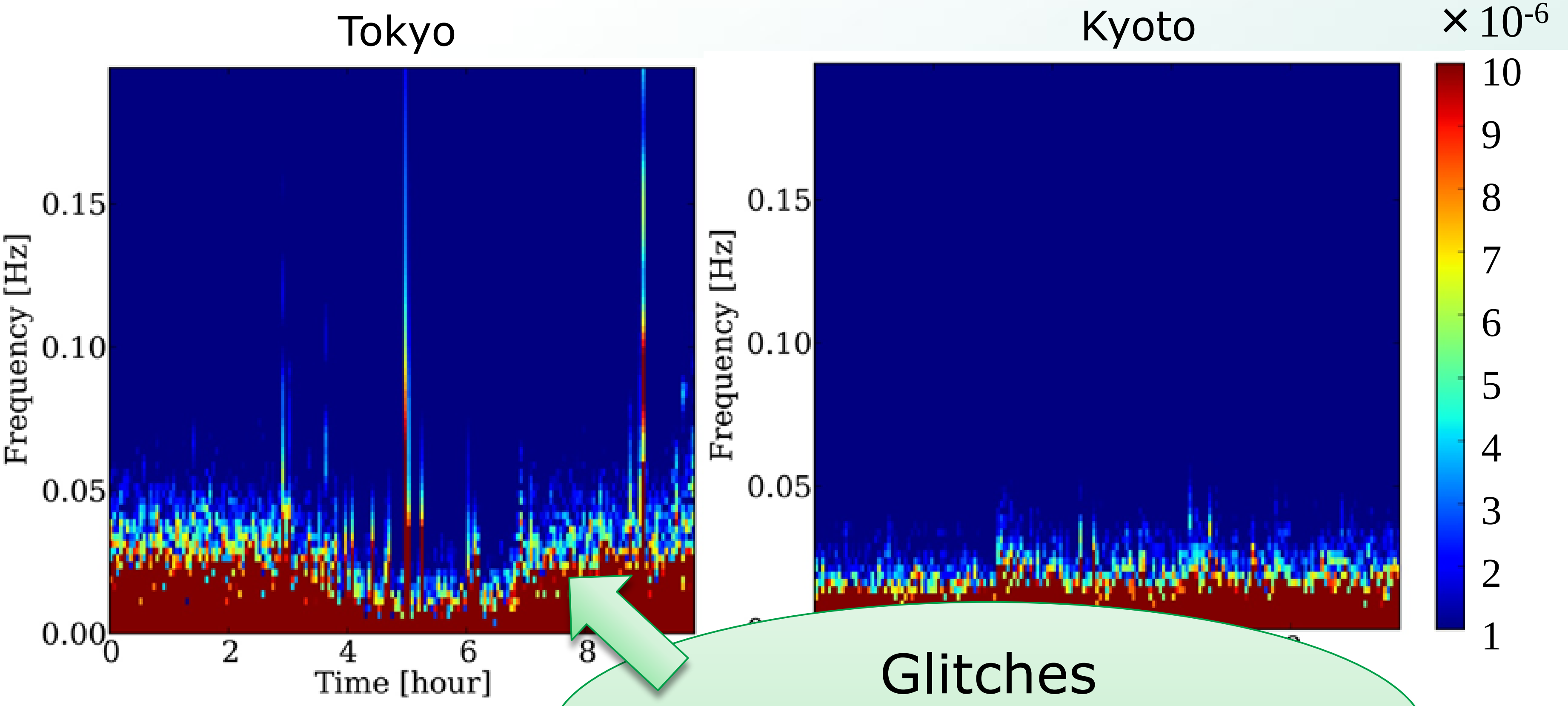
Sampling frequency: 500 Hz,
the direction of the test mass:
north-south

Data Quality



Data Quality

Spectrogram



Glitches
→The data should be selected

Cross Correlation Analysis

Concept

difficult to predict the waveform of a stochastic GW background

⇒ **Search the coherent signal on the data of the two detectors.**

$$\text{Correlation Value} = \int_{f_{\min}}^{f_{\max}} df\, \tilde{s}_1^*(f)\tilde{Q}(f)\tilde{s}_2(f)$$

$\tilde{s}_i(f)$: The signal of *i*-th detector

$\tilde{Q}(f)$: The optimal filter (Weighting function)

Cross Correlation Analysis

Data selection

- Divide the time series data into 200sec long segments
- Delete 10% of the segments whose noise level is worst

↓

Calculate the cross correlation value

- Choose the analyzed frequency band as 0.035 – 0.84 Hz

↓

Detection test

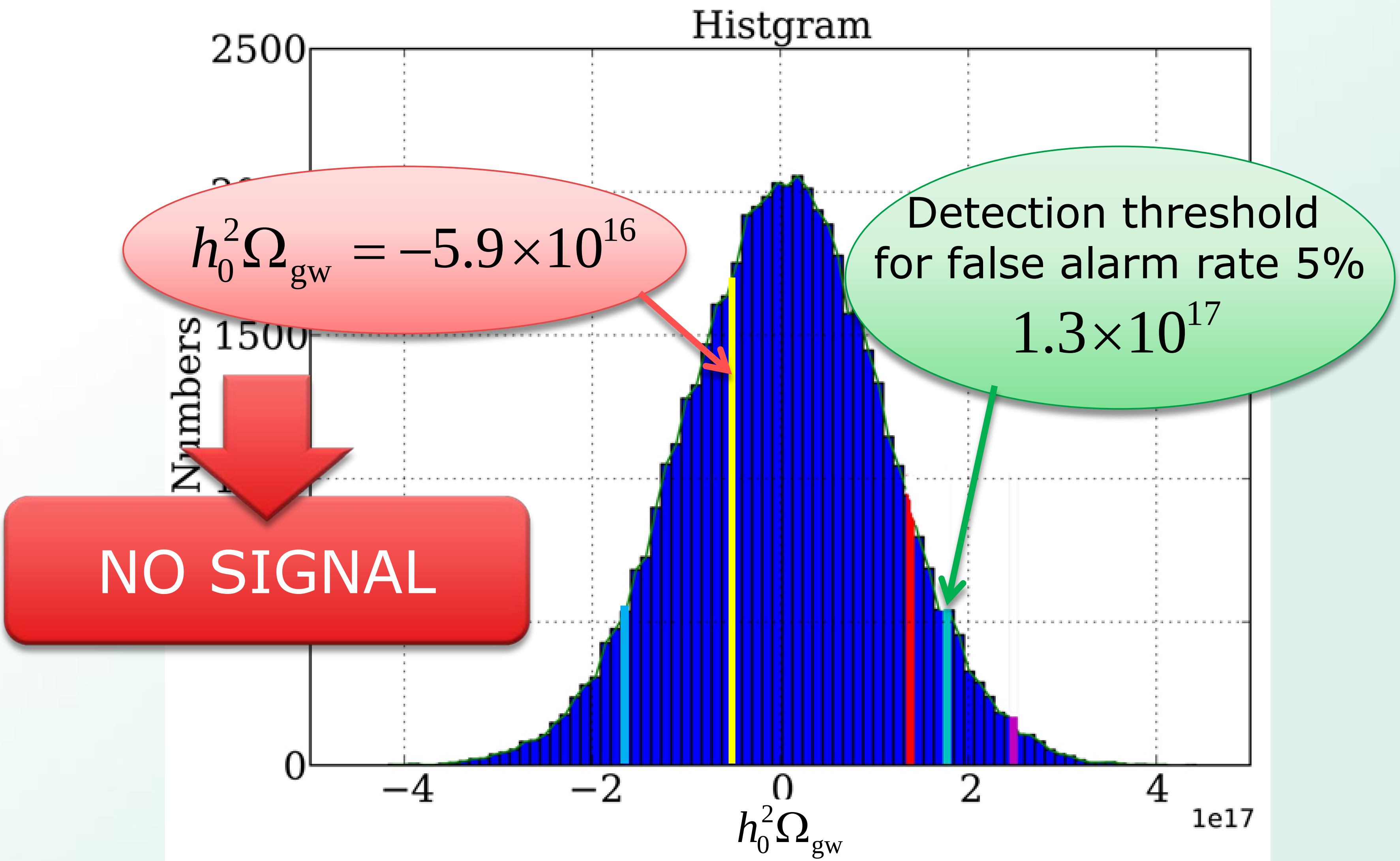
↓ If not detected

Set the upper limit

- Inject mock signals into the real data and calculate the detection efficiency

Result

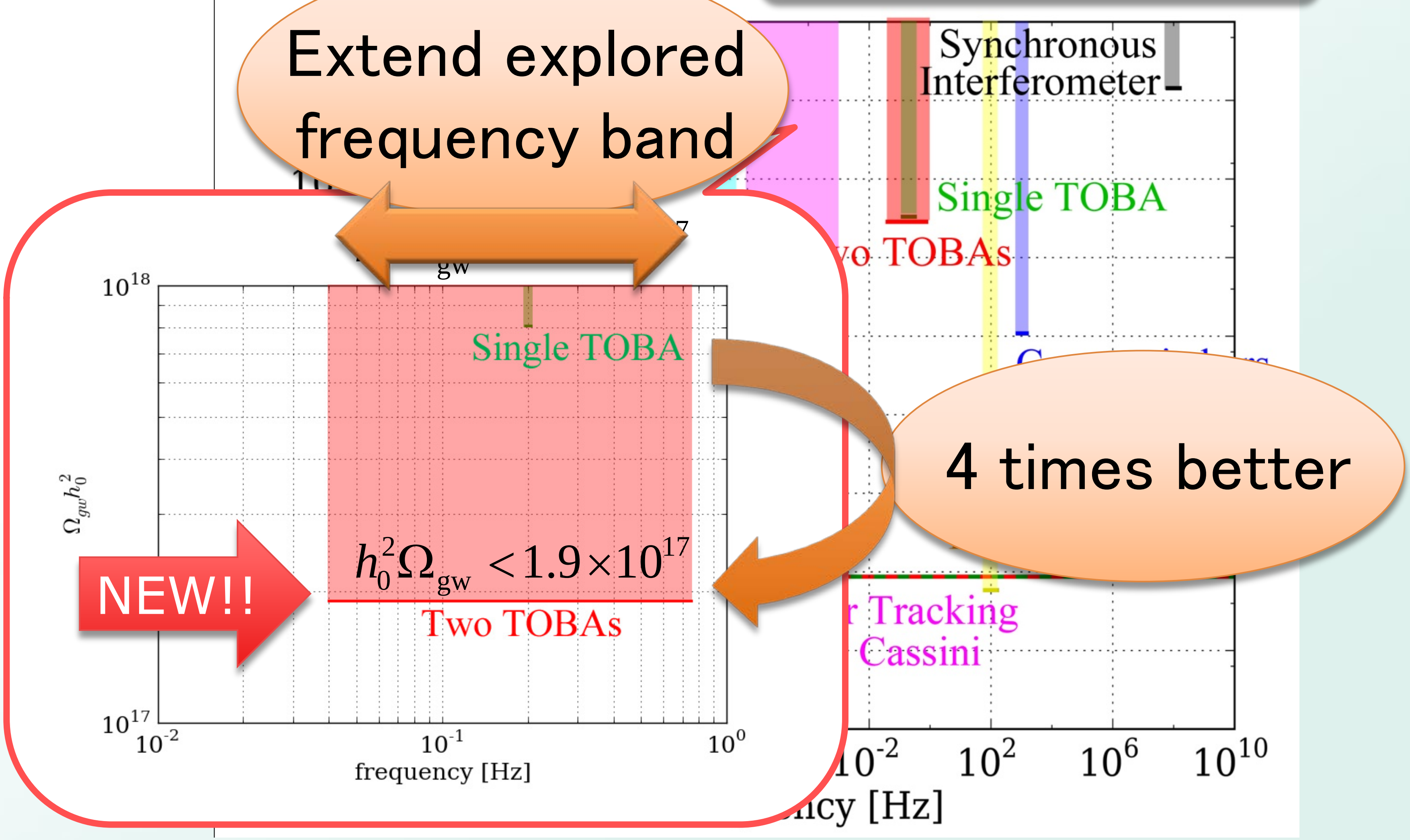
Histogram and Cross correlation value



Result –upper limit

95 % confidence upper limit

$$h_0^2\Omega_{gw} < 1.9\times10^{17}$$

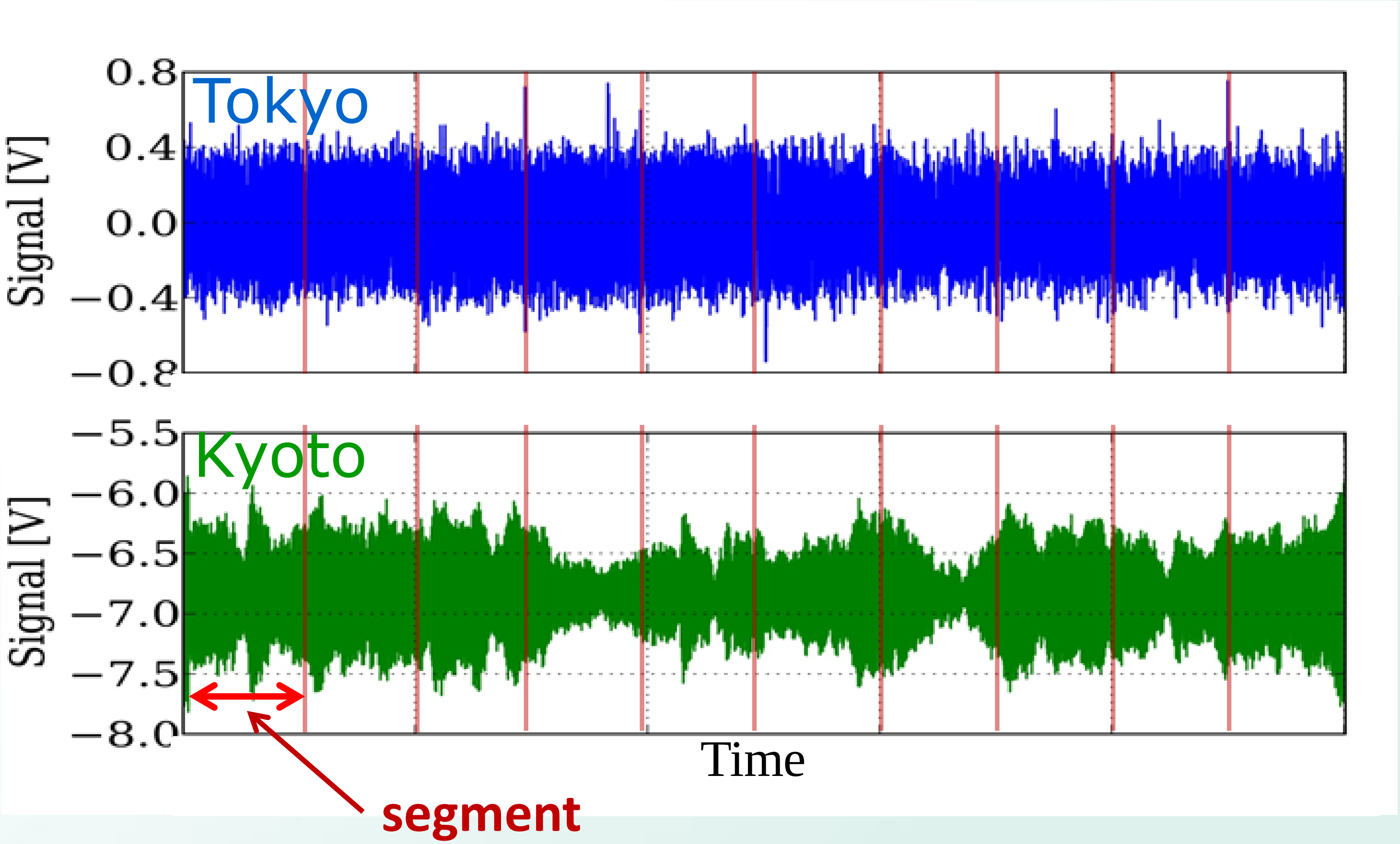


Summary

- Established the pipeline of the cross correlation analysis with TOBAs
- The stochastic GW background signal is not detected.
- Update the upper limit on a stochastic GW background at 0.035~0.840 Hz: $h_0^2 \Omega_{\mathrm{gw}} < 1.9 \times 10^{17}$

Backup slides

Data Selection



- Divide time series data into several segments
- Remove the segments in which RMS is big
- Calculate cross correlation with the survived segments

Cross Correlation Value

$$Y \approx \int_{f_{\min}}^{f_{\max}} df\, s_1^*(f) s_2(f) Q(f)$$

Optimal Filter : a filter which maximizes the signal-to-noise ratio

$$Q(f) = N \frac{\gamma(f)}{f^3 P_1(f) P_2(f)}$$

$P_i(f)$: PSD of i-th detector

Overlap reduction function

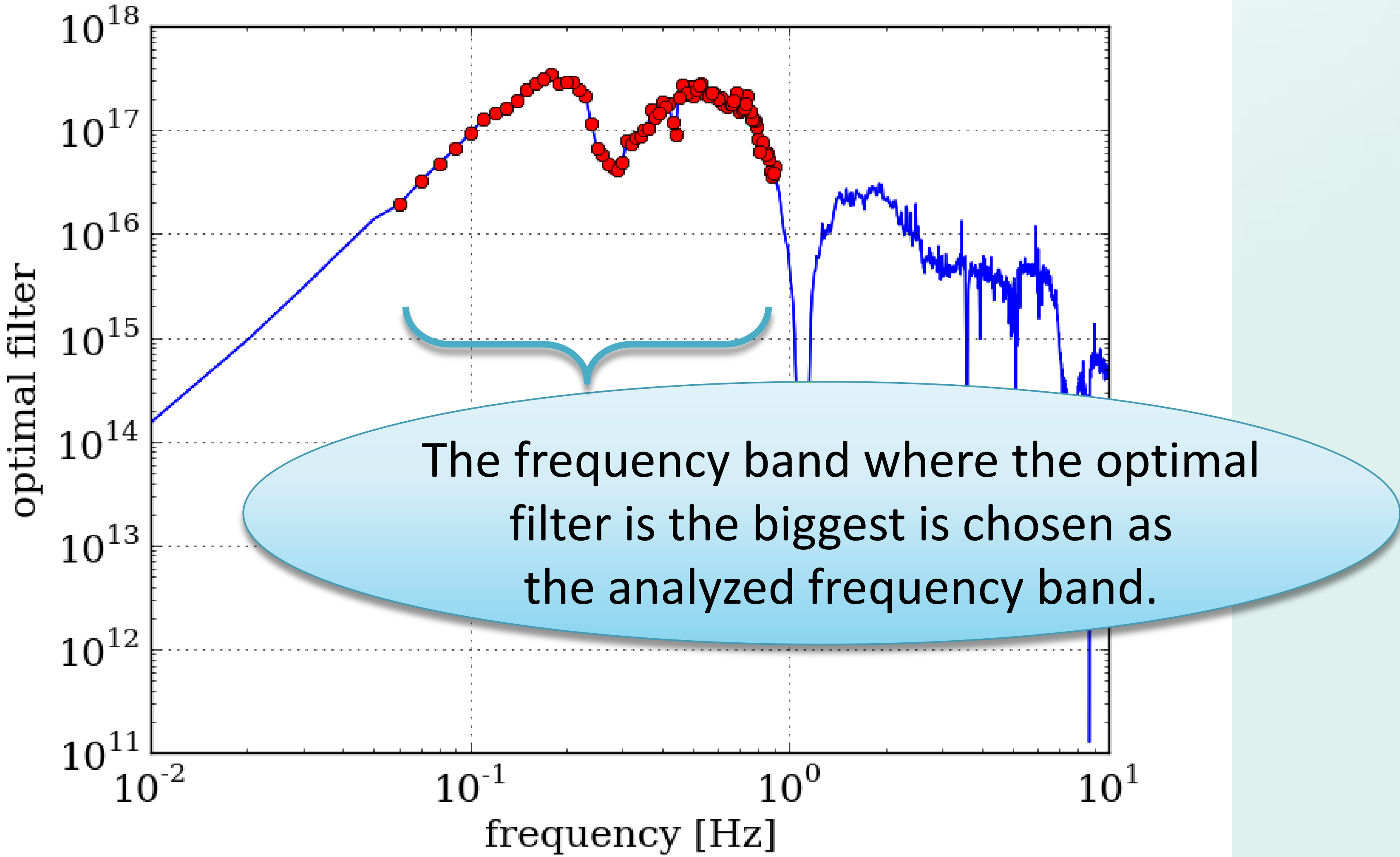
: a function which represents the difference of response to the GWs between two detectors

In the case of TOBAs, same as the interferometer's one

In this case, $\gamma(f) \approx 1$

Optimal filter

Optimal filter =
big when the sensitivity to a stochastic GW background is good



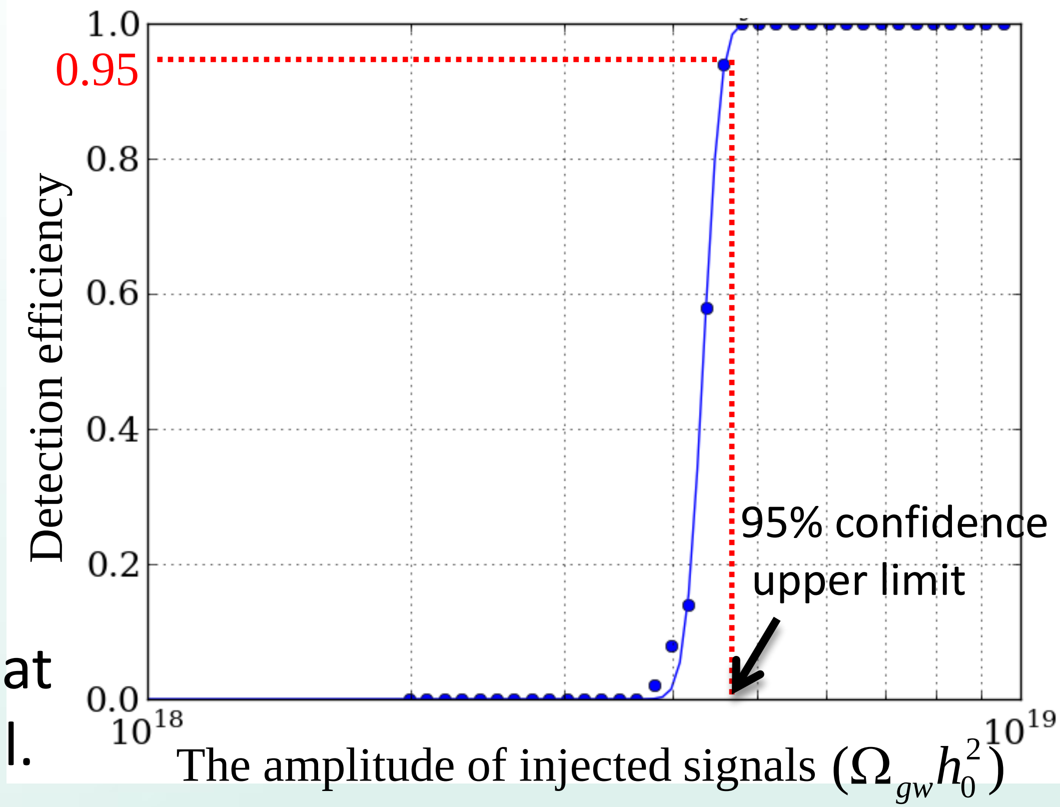
Upper Limit

How big a stochastic GW background can we detect if it would come to this data set?

1. Make a mock signal of a stochastic GW background
2. Inject the signal into the observational data
3. Perform same analysis as explained above

Repeat 1-3 to compute the rate at which we detect the mock signal.

= **Detection efficiency**



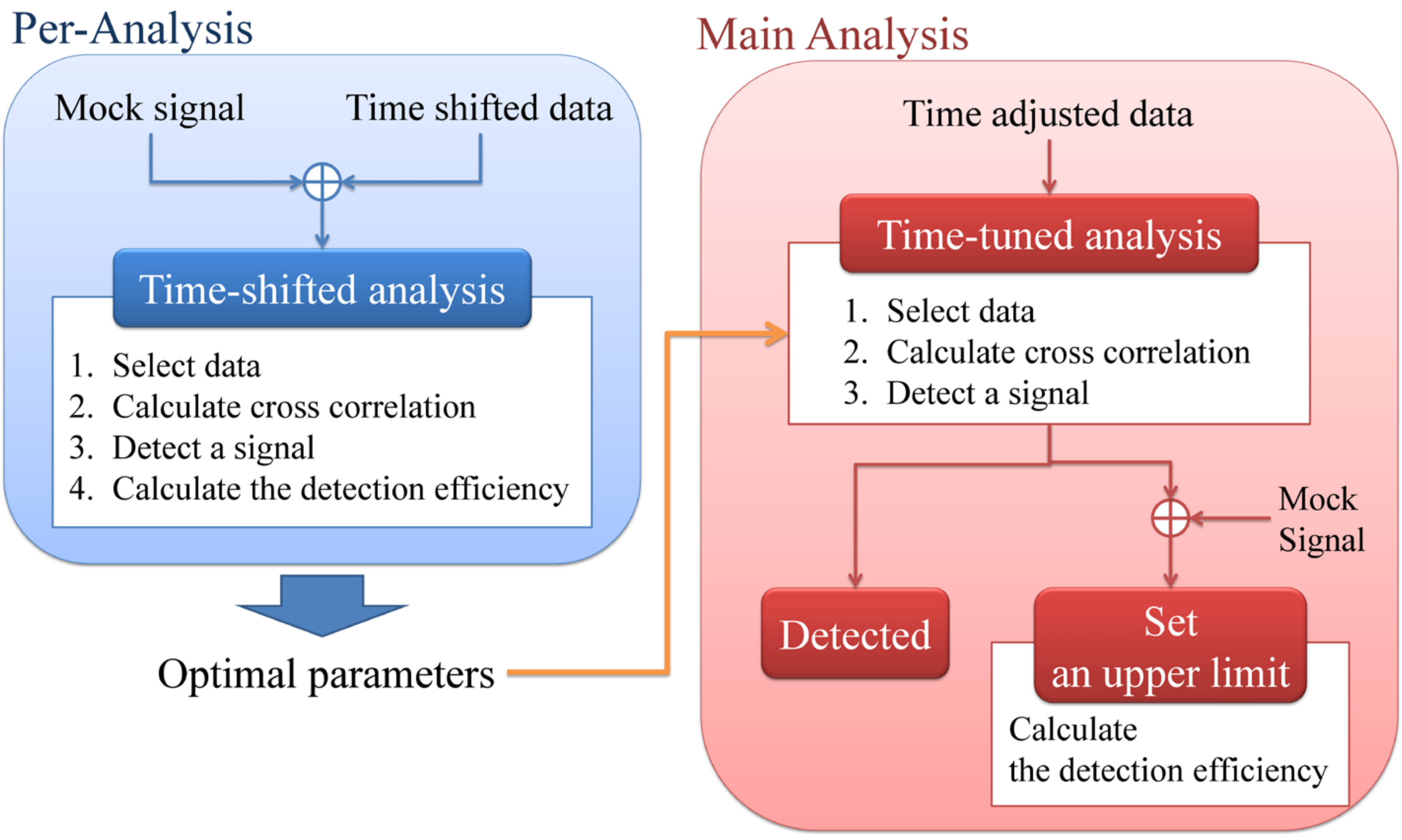
Parameter Tuning

There are some parameters whose optimal values are depend on the data quality

- The length of the segments →200 sec
- The amount of the segments removed by data selection →10 %
- The bandwidth of the analyzed frequency band →0.8 Hz

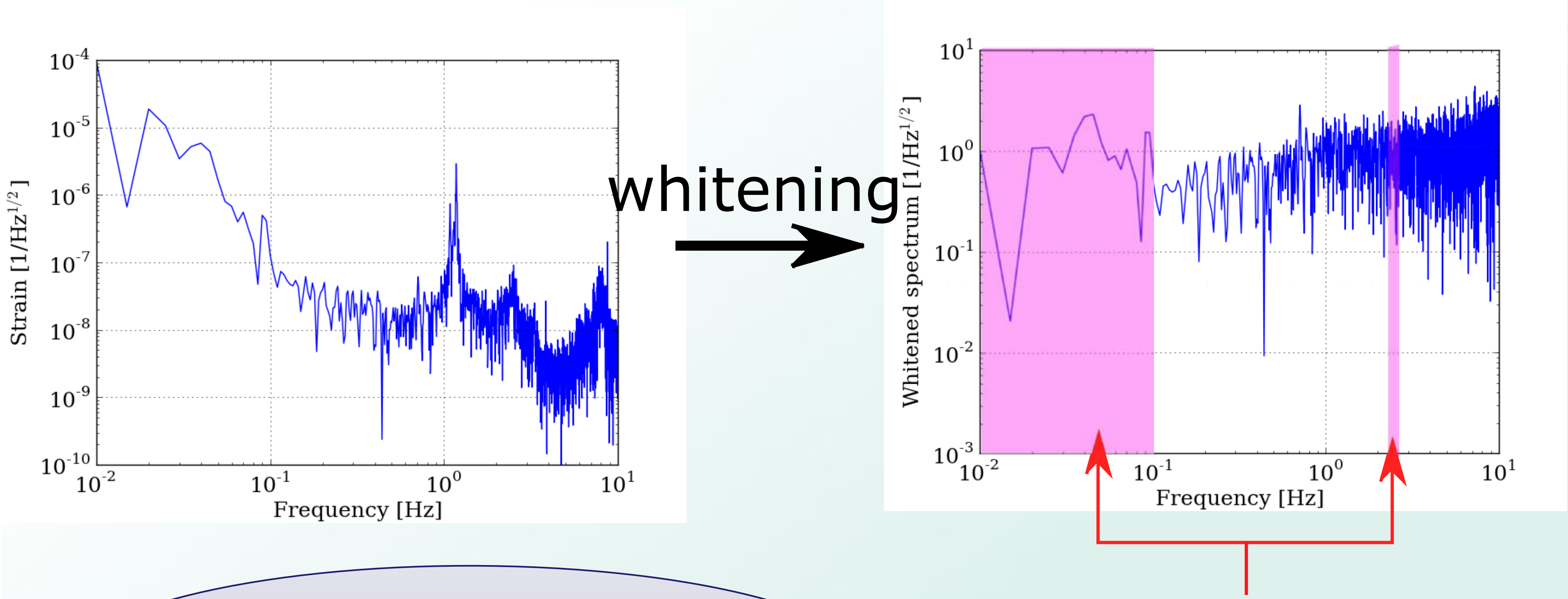
Determined
by the time shifted data.
The values which make the upper limit calculated with time shifted data best is used.

Summary of Analysis



Data selection

The indicator of the noise level = Whitened RMS



Avoid making the result intentionally better

The analyzed frequency band is excluded from RMS calculation

Cross correlation anlysis

$$s(t) = h(t) + n(t)$$

signal GW signal noise

Cross correlation value
$$= \int_{-T/2}^{T/2} s_1(t) s_2(t) Q(t) dt$$
$$= \int_{-T/2}^{T/2} \left(h_1(t) + n_1(t)\right)\left(h_2(t) + n_2(t)\right) Q(t) dt$$

Noise is reduced

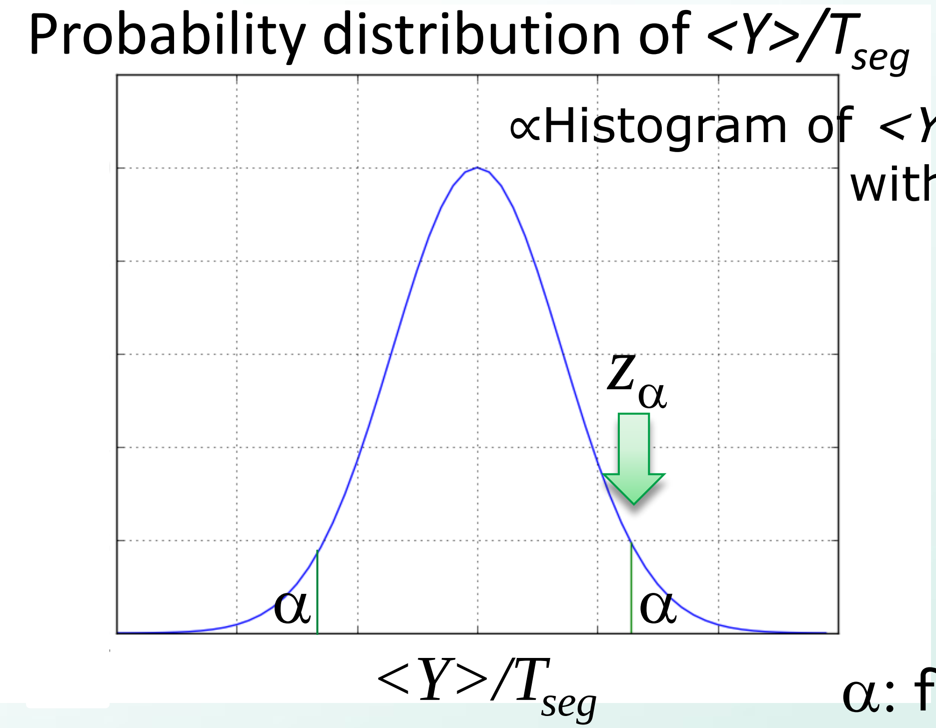
$$= \int_{-T/2}^{T/2} h_1(t) h_2(t) Q(t) dt$$

Fourier transformation

Cross correlation value
$$= \int_{f_{\min}}^{f_{\max}} df \, \tilde{s}_1^*(f) \tilde{Q}(f) \tilde{s}_2(f)$$

Detection Criteria

By the Neuman-Peason criterion,



$\propto$Histogram of $<Y>/T_{seg}$ calculated with time shifted data

α: false alarm rate

Note: we do not know the sign of the two signal.

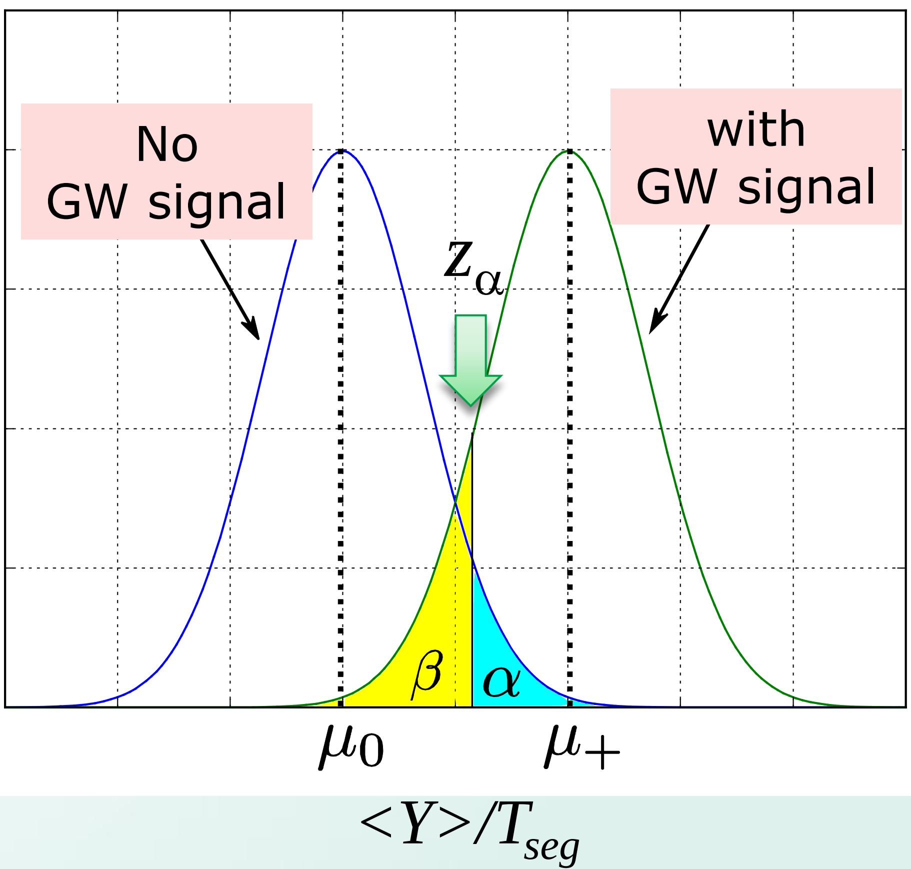
$$\langle Y \rangle / T_{seg} \geq |z_\alpha| \quad \textbf{Signal is present}$$

$$\langle Y \rangle / T_{seg} < |z_\alpha| \quad \textbf{Signal is absent}$$

Signal detection

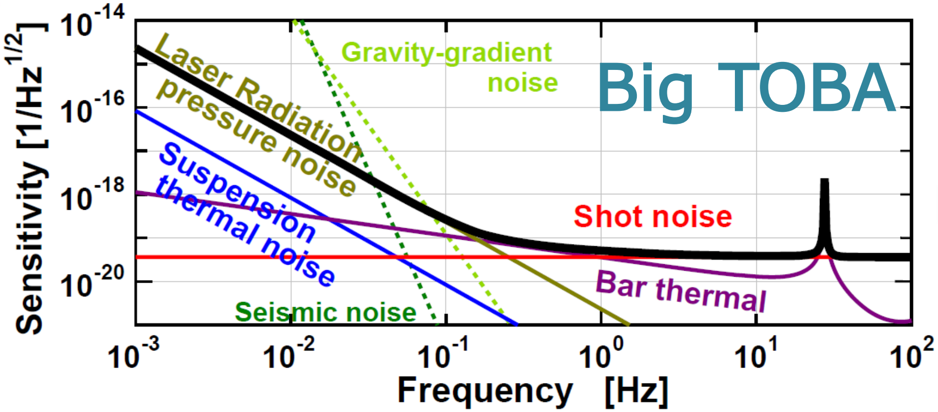
How to decide z_α:

- Calculate $\langle Y \rangle / T_{\mathrm{seg}}$ with diversely time shifted data
- Histogram of calculated $\langle Y \rangle / T_{\mathrm{seg}}$
  = Histogram of $\langle Y \rangle / T_{\mathrm{seg}}$ when the signal is absent.

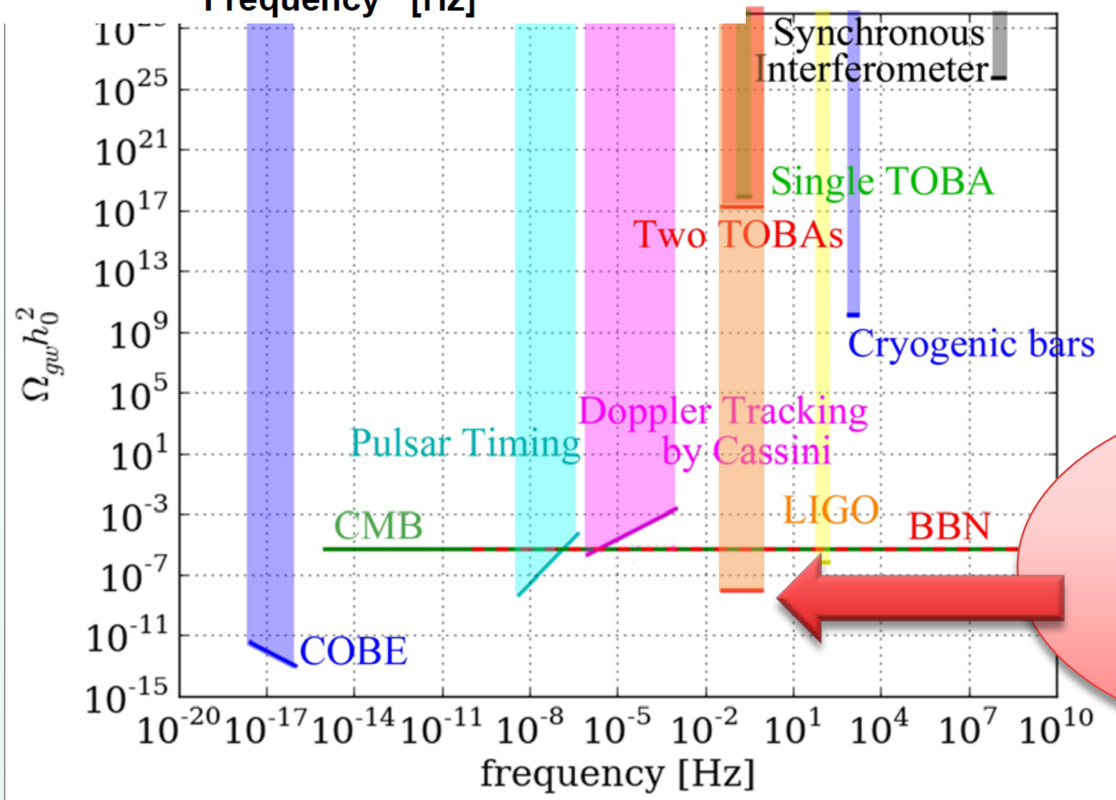


α: false alarm rate
β: false dismissal ra

Future plan



+ This cross correlation analysis



1 year observation

$$h_0^2 \Omega_{gw} \sim 10^{-8}$$