

バイオリンモードの周波数について

端山 和大

KAGRA Detector Characterization

バイオリンモードスタディ資料

- <http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=2071>
- <http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=2127>
- <http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=1697>

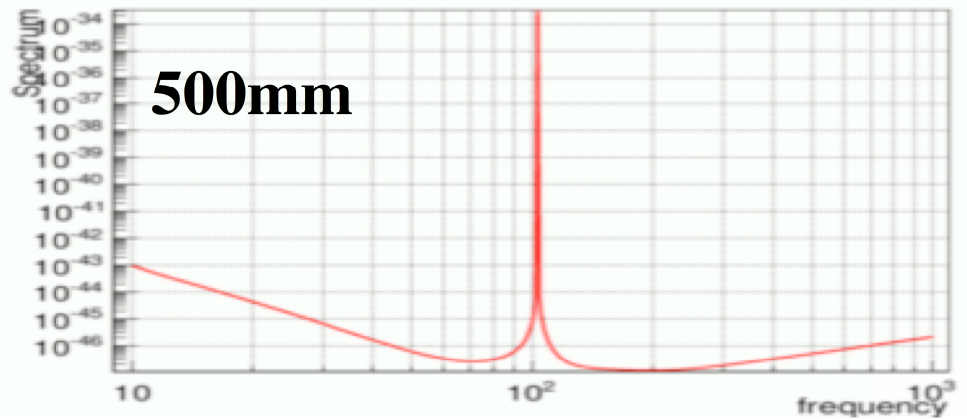
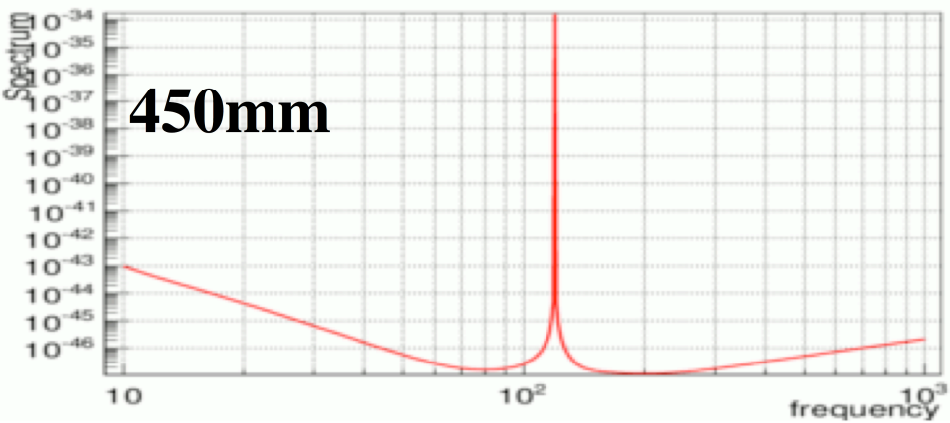
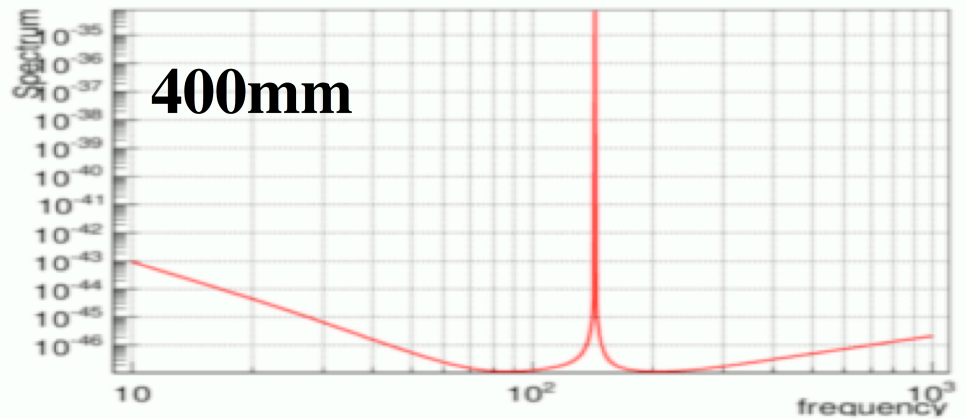
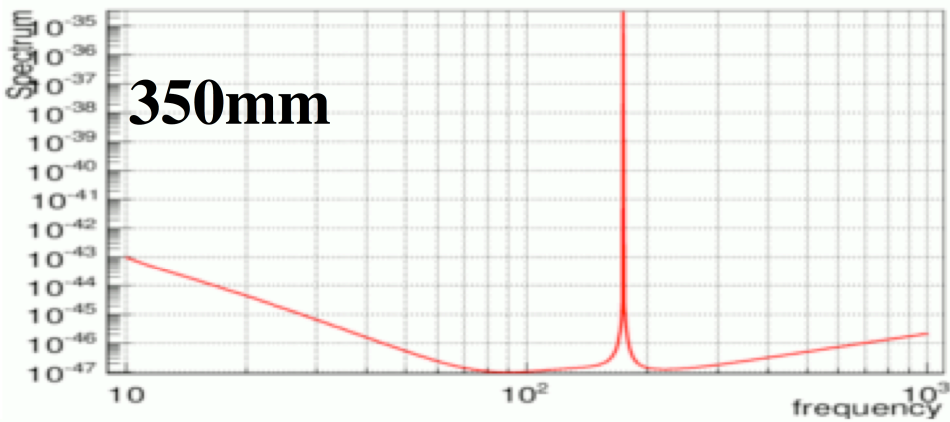
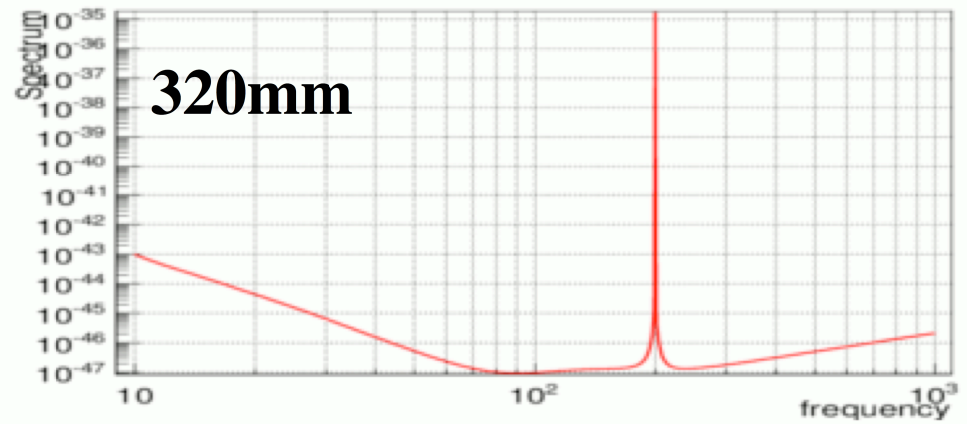
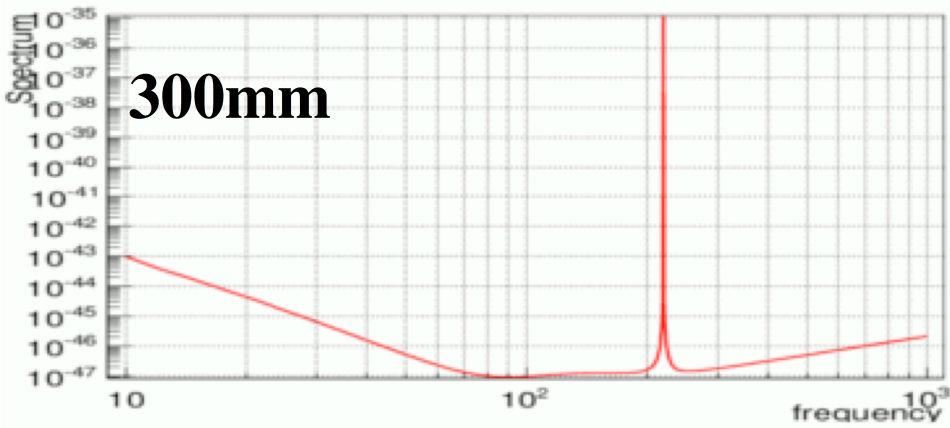
バイオリンモードの重力波探査への影響

- ワイヤの長さ等によって、1次バイオリンモードの周波数
が変化する。今回検討するパラメータはワイヤの長さが
300mm-500mm、周波数でいうと103Hz-220Hzである。
- 1次バイオリンモードの影響のみを調べるために、公式の
KAGRA感度スペクトルからラインを除去し、1次バイオ
リンモードのみを入れて、連星合体とリングダウンの探査
距離がどのように変化するかを調べた。
- 探査距離はSNR=8で最適感度での距離、SNRの定義は
LIGOのもので調べた。

ワイヤの長さバイオリンモード の特徴パラメータ

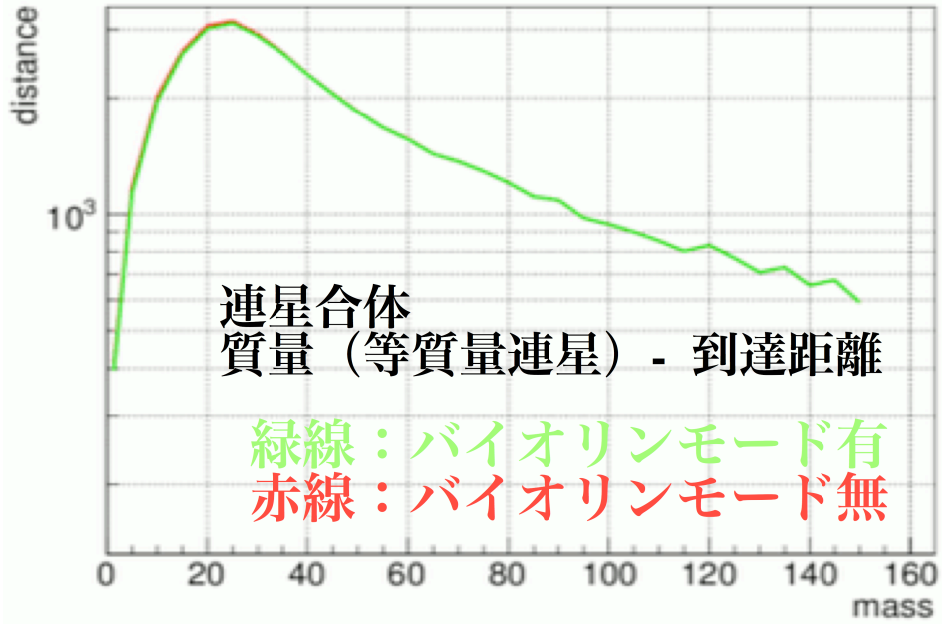
length(mm)	1st violin freq (Hz)	1st violin mass (kg)	1st violin Q
300	220	76488.6	9.6×10^6
320	200	68639.9	9.7×10^6
350	175	59057.8	1.0×10^7
400	143	47201.1	1.0×10^7
450	120	38732.9	1.1×10^7
500	103	32452.8	1.1×10^7

望遠鏡スペクトル

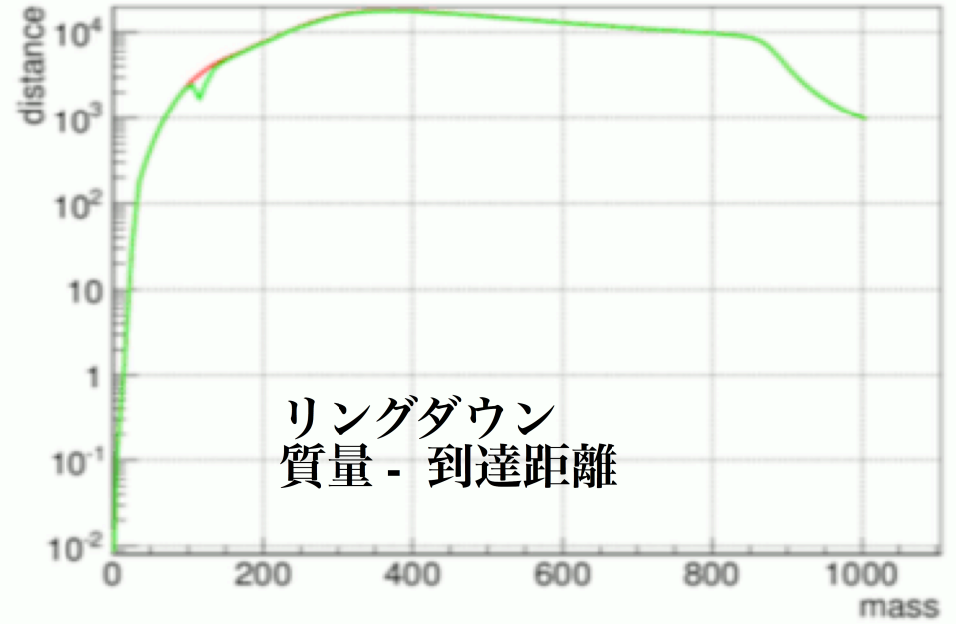


300m

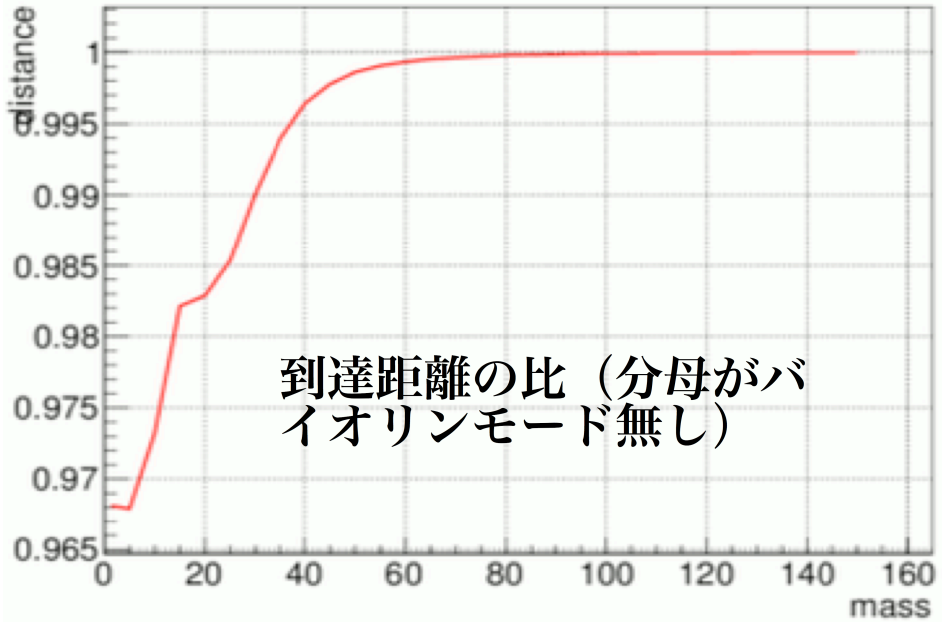
Inspiral mass-distance



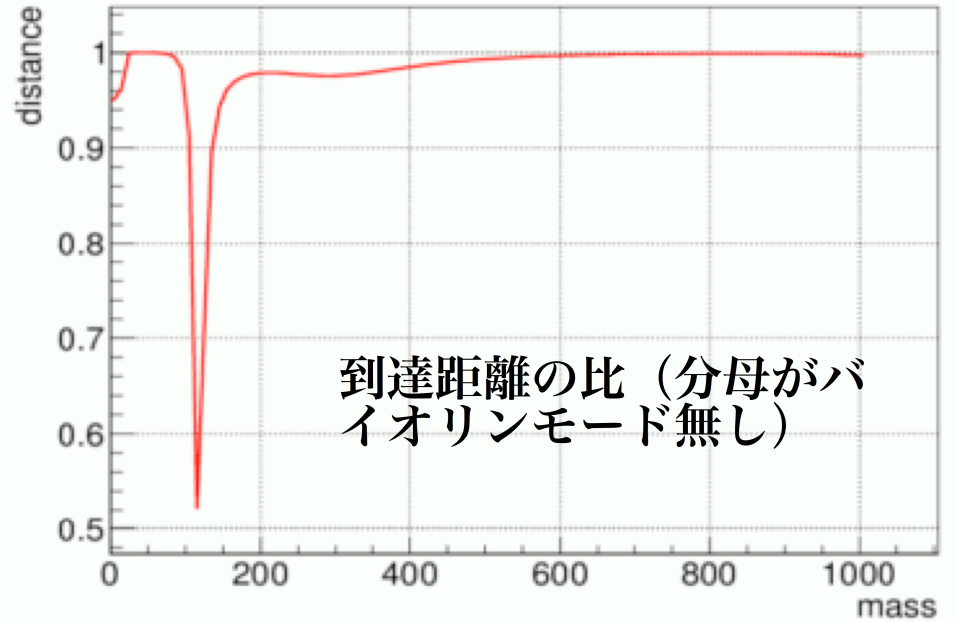
Ringdown mass-distance



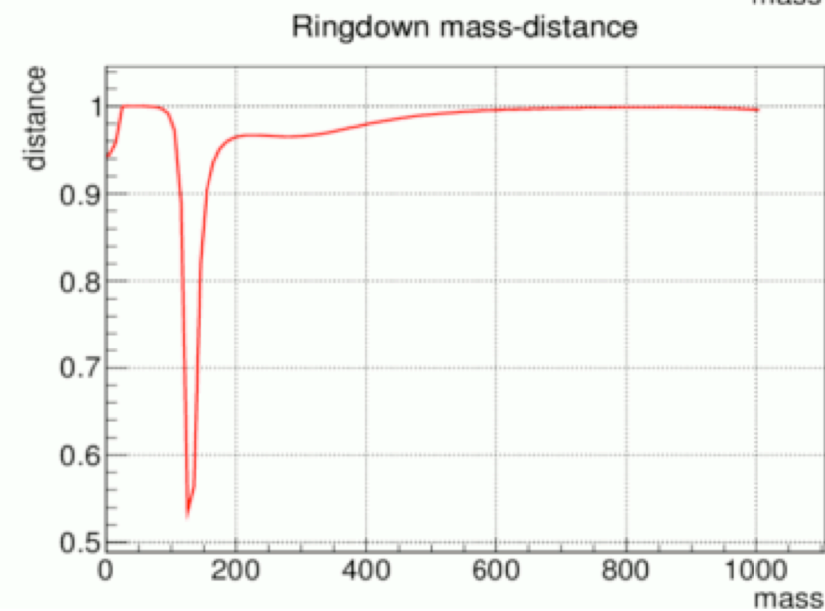
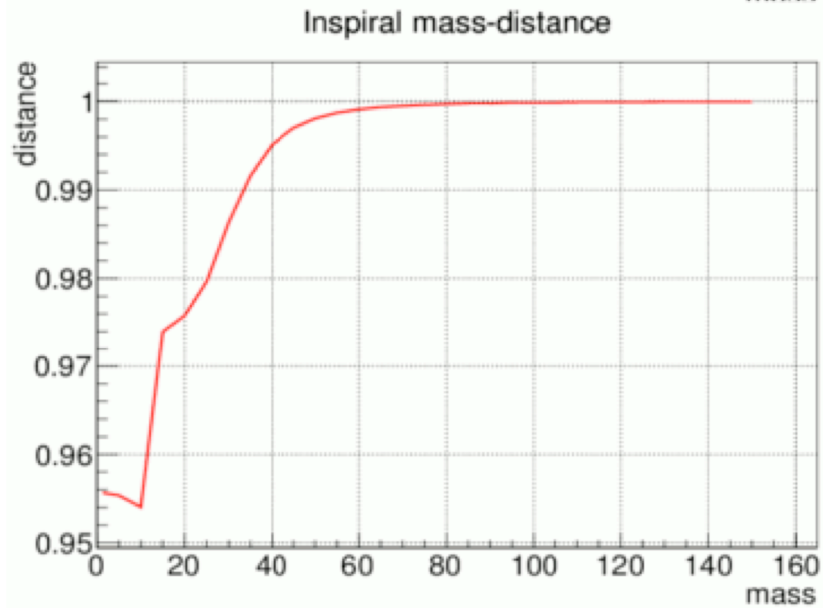
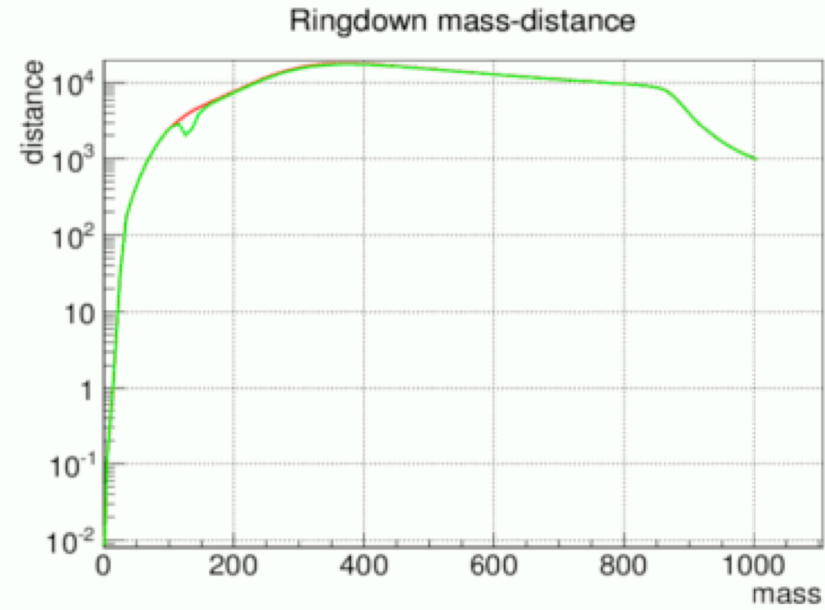
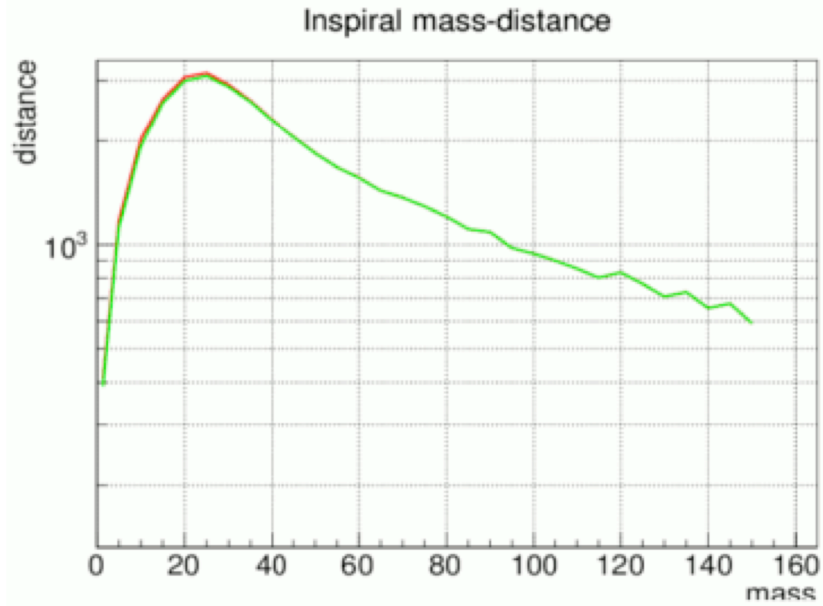
Inspiral mass-distance



Ringdown mass-distance

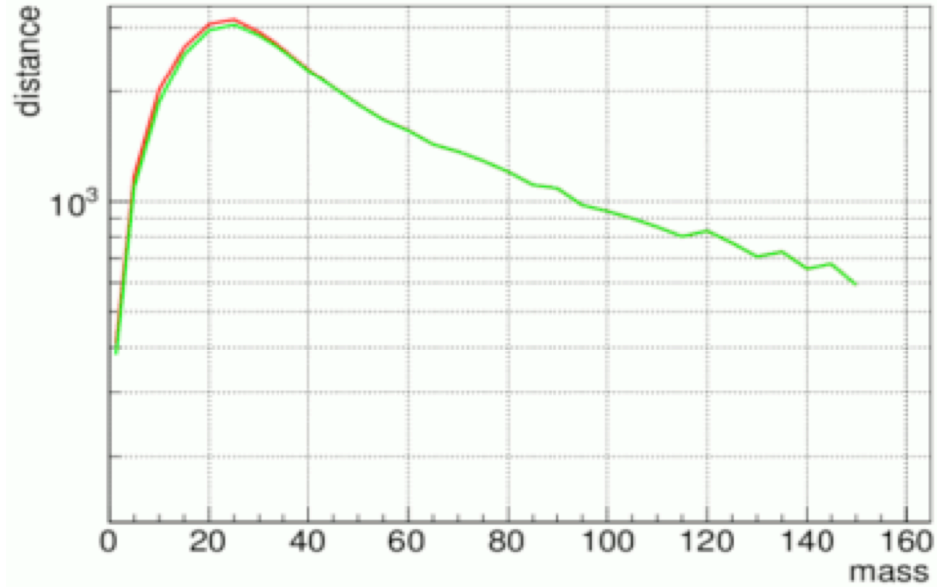


320mm

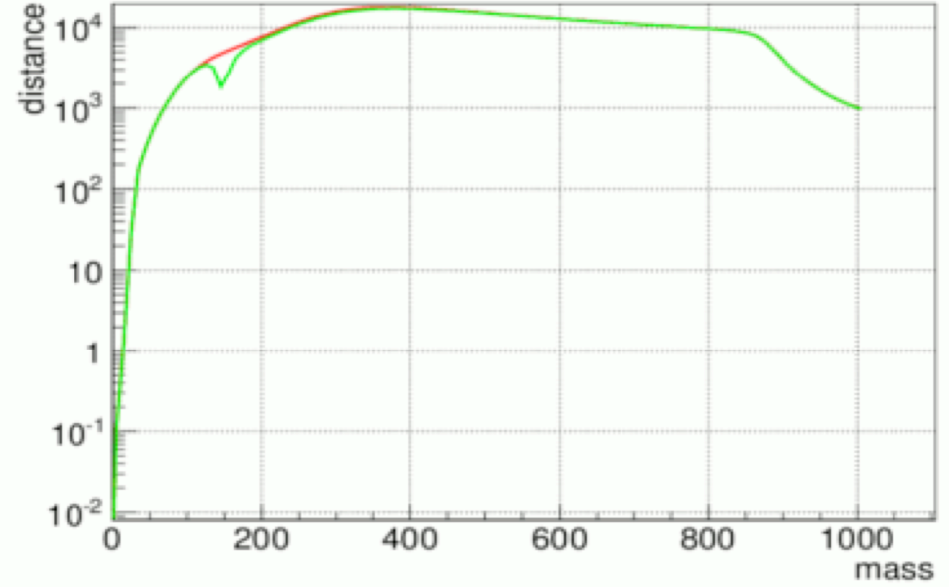


350mm

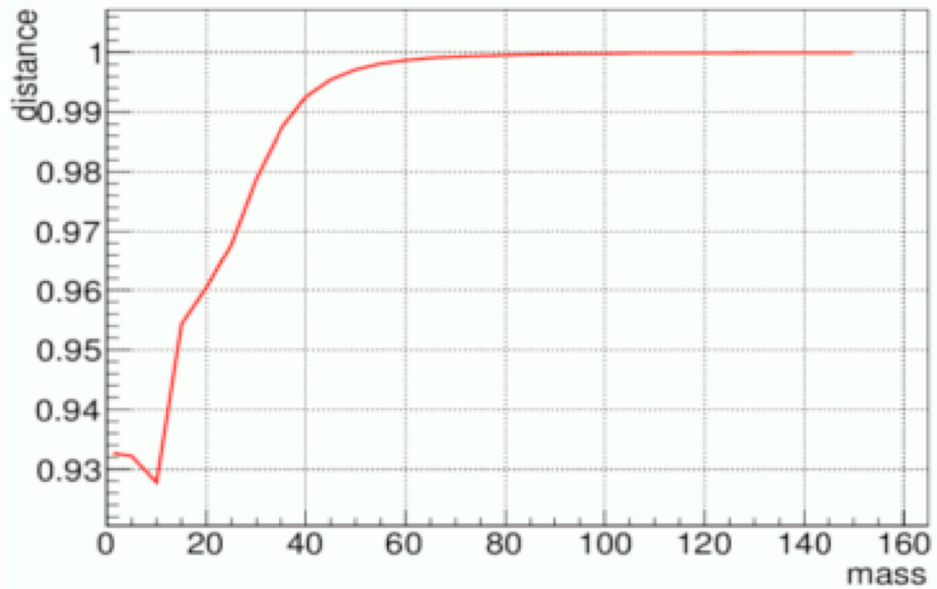
Inspiral mass-distance



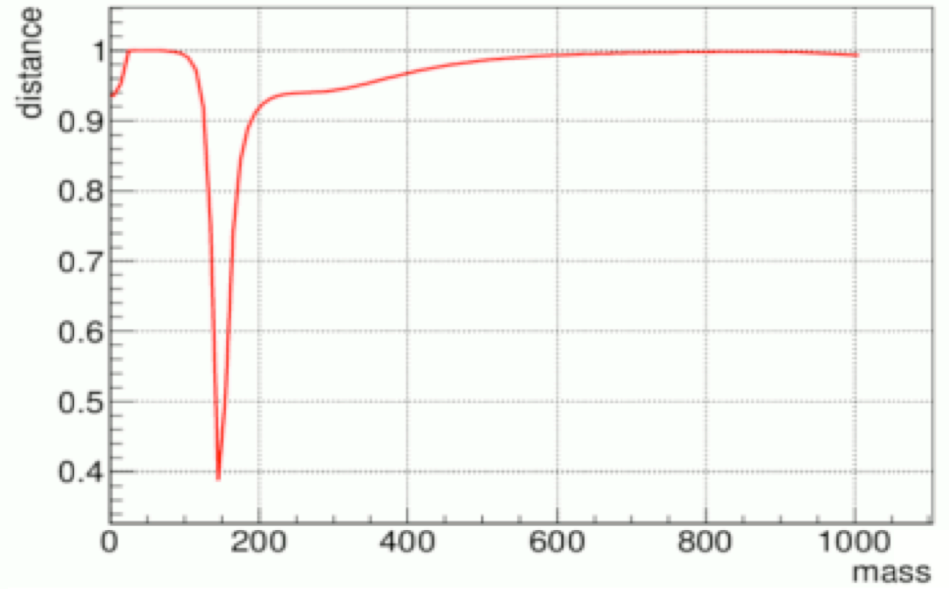
Ringdown mass-distance



Inspiral mass-distance

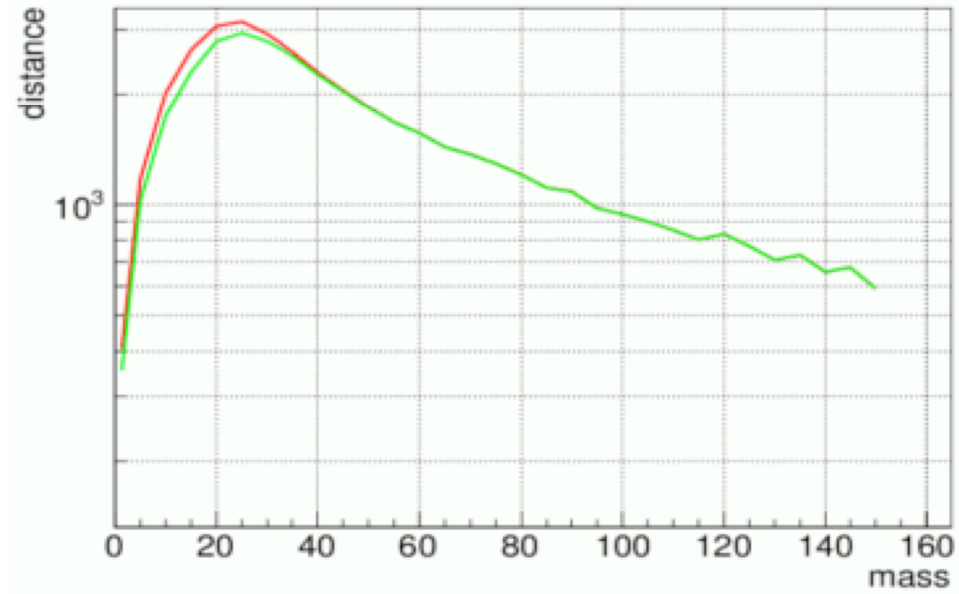


Ringdown mass-distance

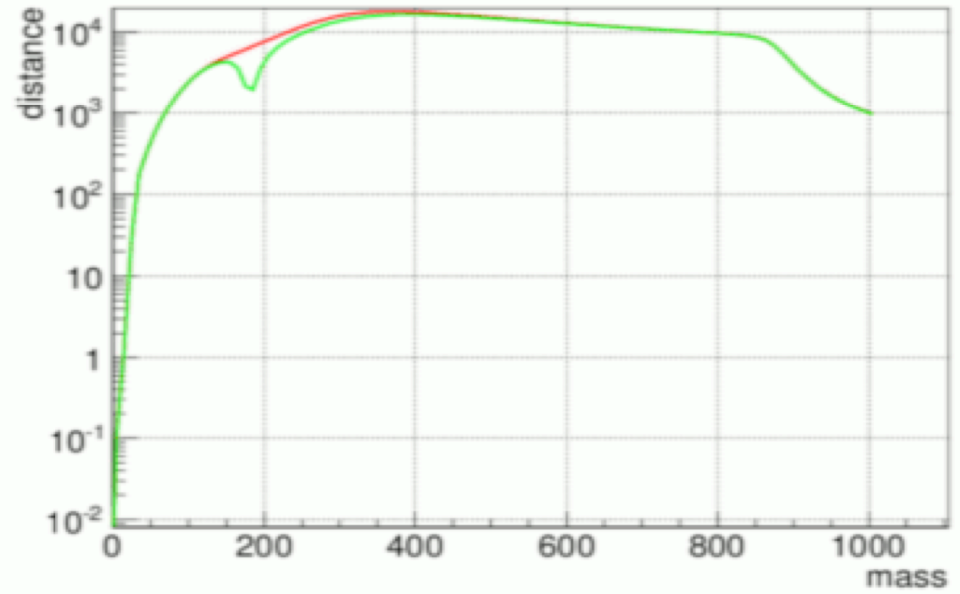


400mm

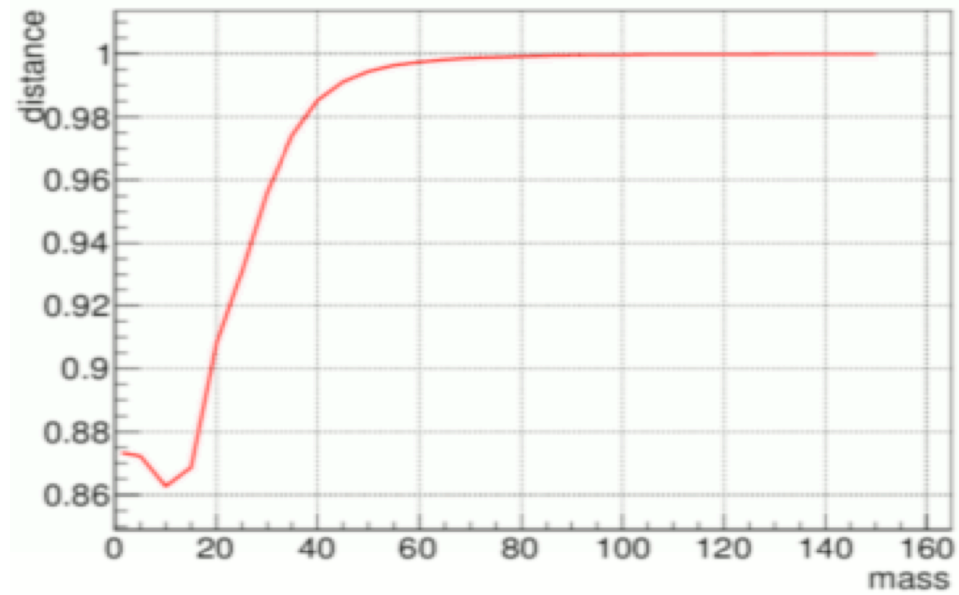
Inspiral mass-distance



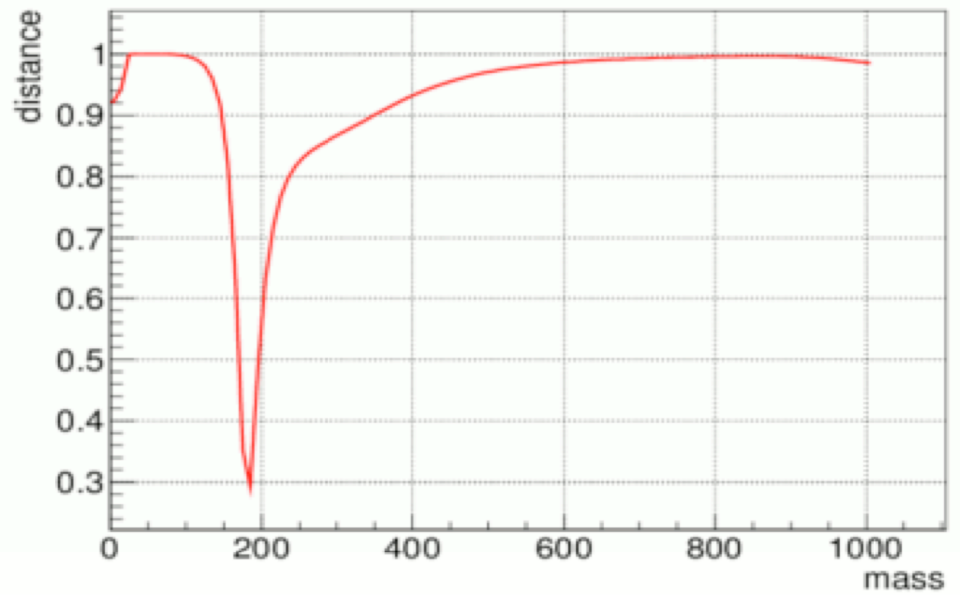
Ringdown mass-distance



Inspiral mass-distance

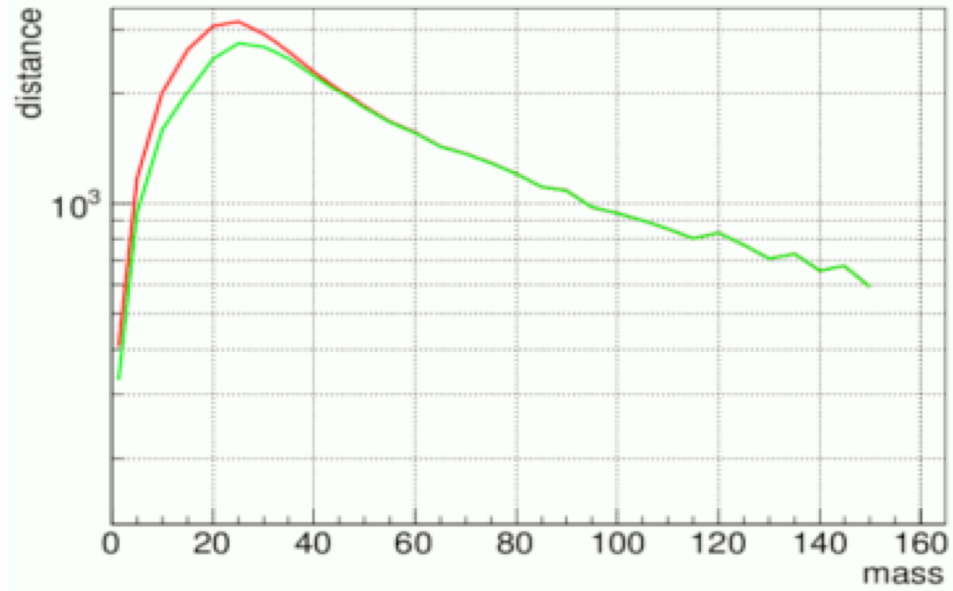


Ringdown mass-distance

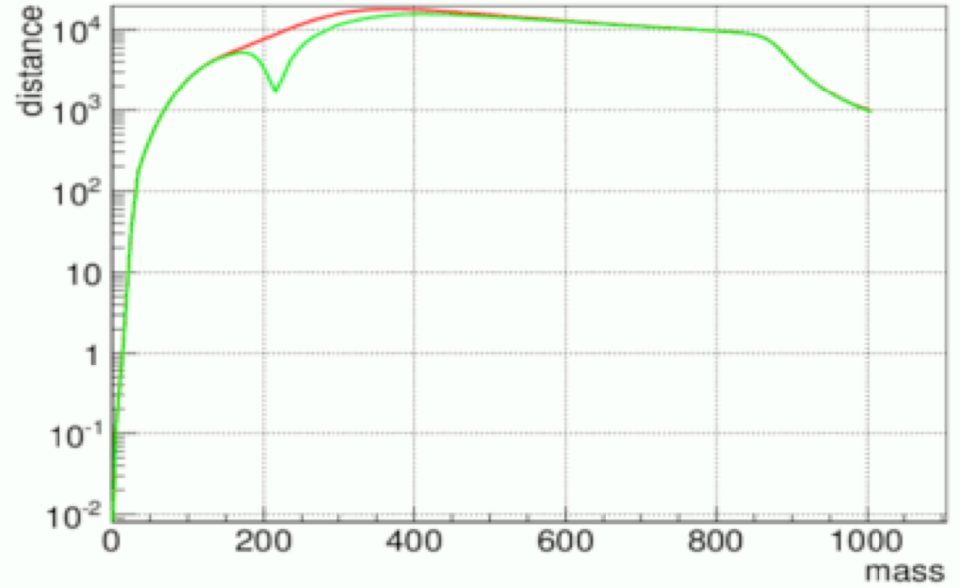


450mm

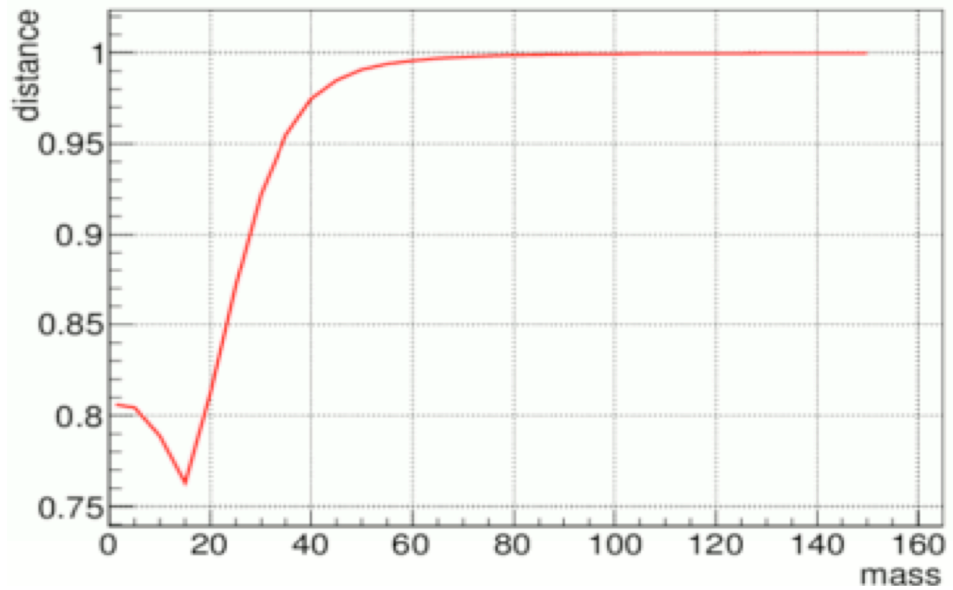
Inspiral mass-distance



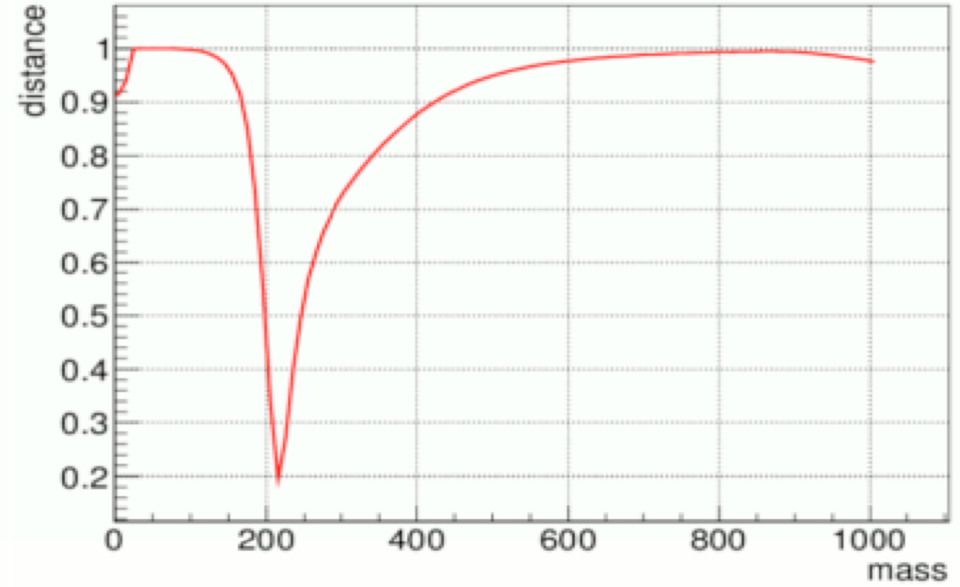
Ringdown mass-distance



Inspiral mass-distance

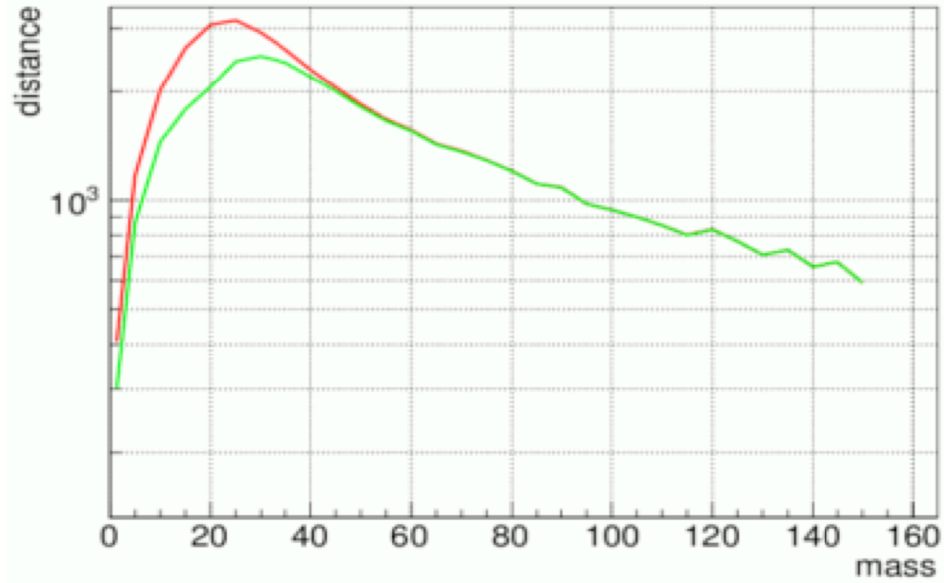


Ringdown mass-distance

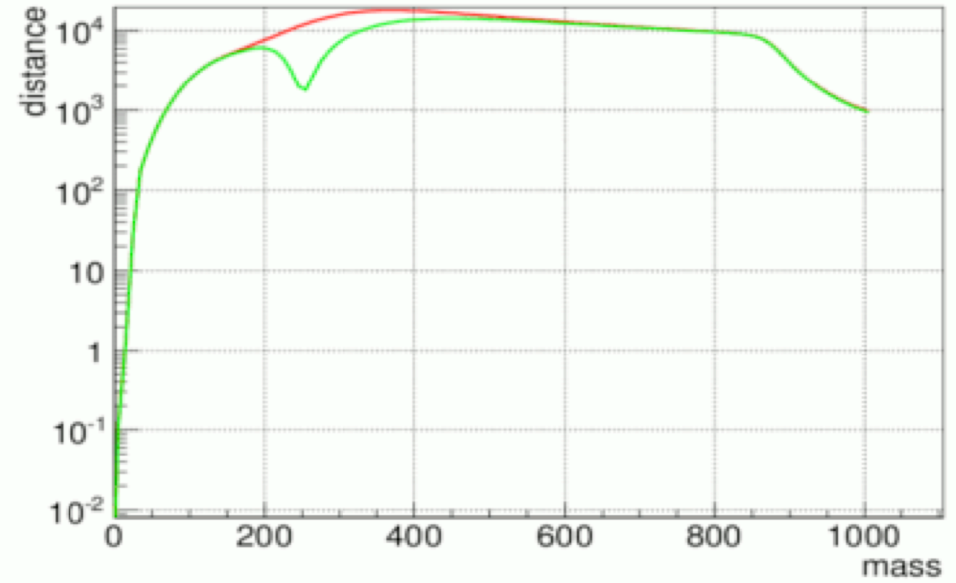


500mm

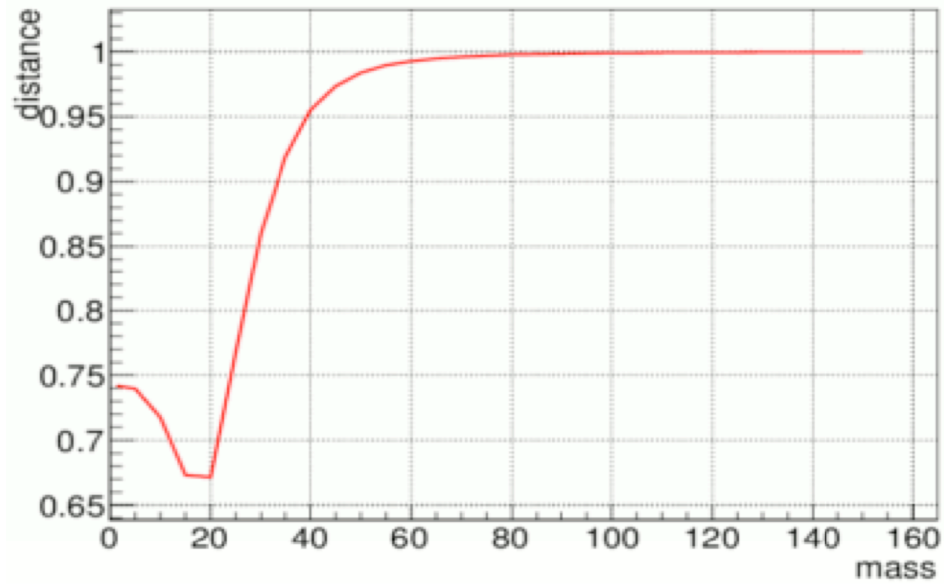
Inspiral mass-distance



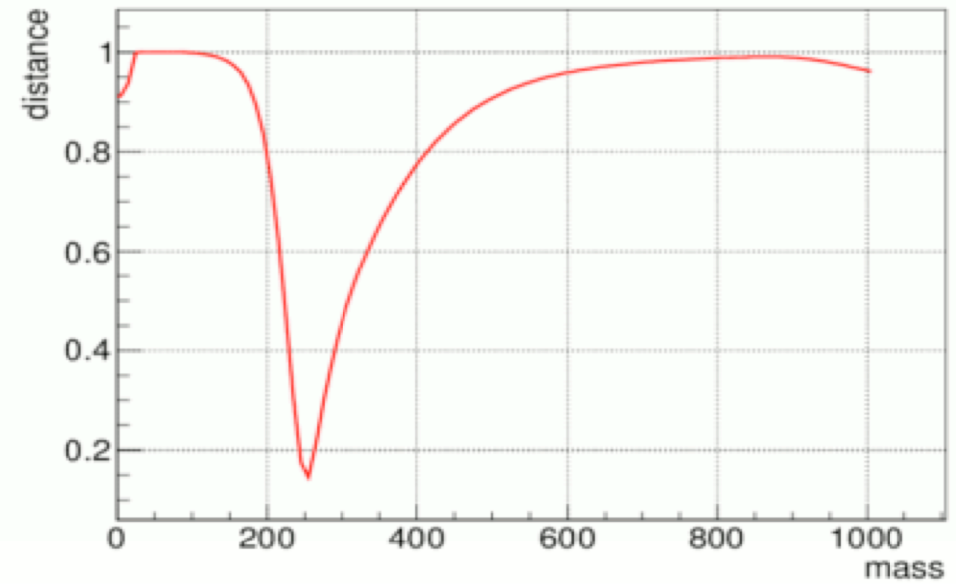
Ringdown mass-distance



Inspiral mass-distance



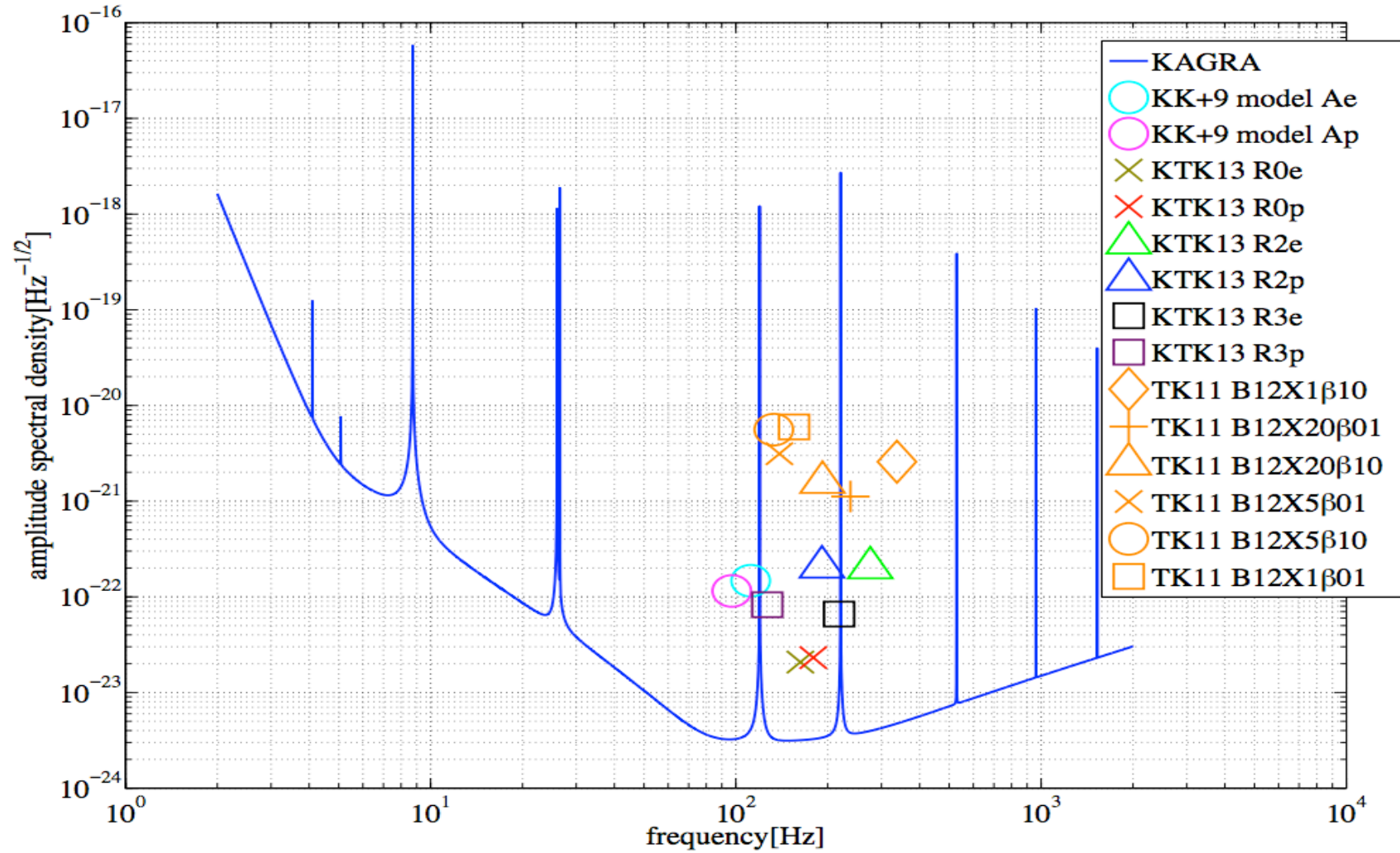
Ringdown mass-distance



バースト重力波について

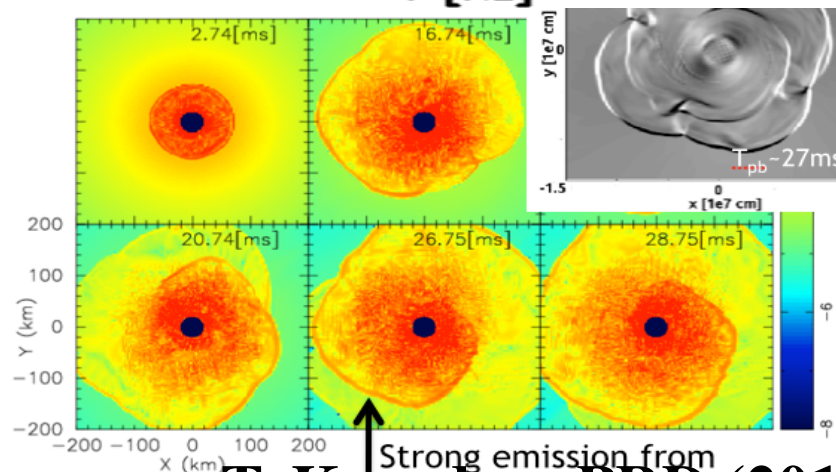
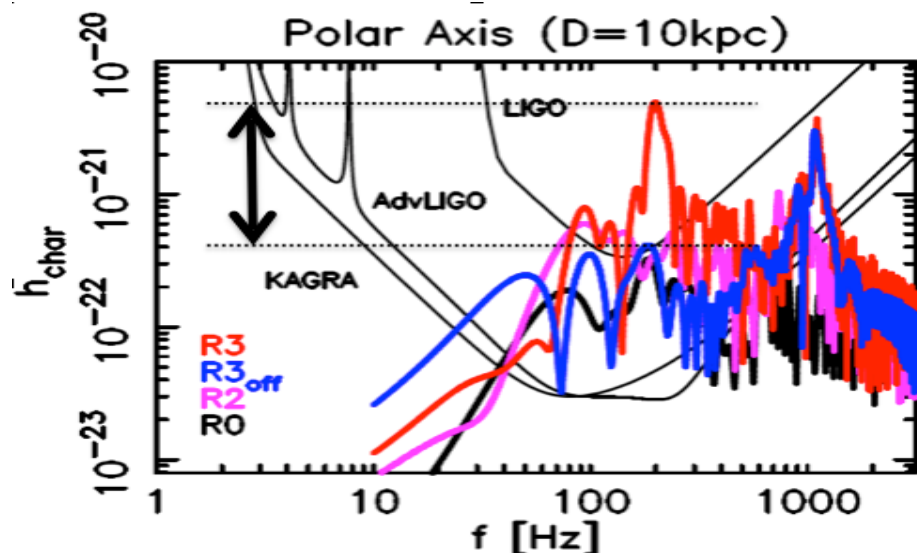
- バースト性重力波は広範囲の周波数に広がるため、結局全周波数帯で感度が良いことが望まれる。そのため、検出という視点から見ると、ある特定の周波数というよりも、裾、分裂したバイオリンモードがなるべく観測周波数に無いがよいので汚れる領域が一番小さくなる高周波の方が良いことになる。
- KAGRAの場合、特に100-200Hzの感度が良くなるため、超新星爆発からの重力波シミュレーションを見てみると、検出特徴周波数は100-200Hzになる。
-

超新星爆発からの重力波

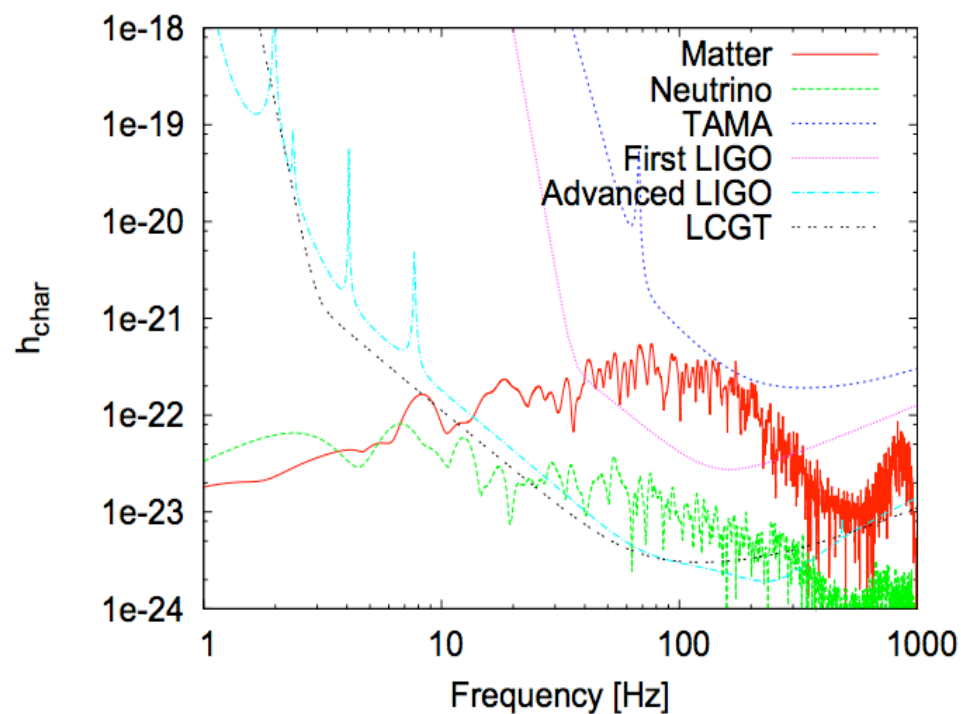


超新星爆発からの重力波

- 検出とは別に、超新星爆発のメカニズム解明という視点から見ると、特徴的な周波数がある。

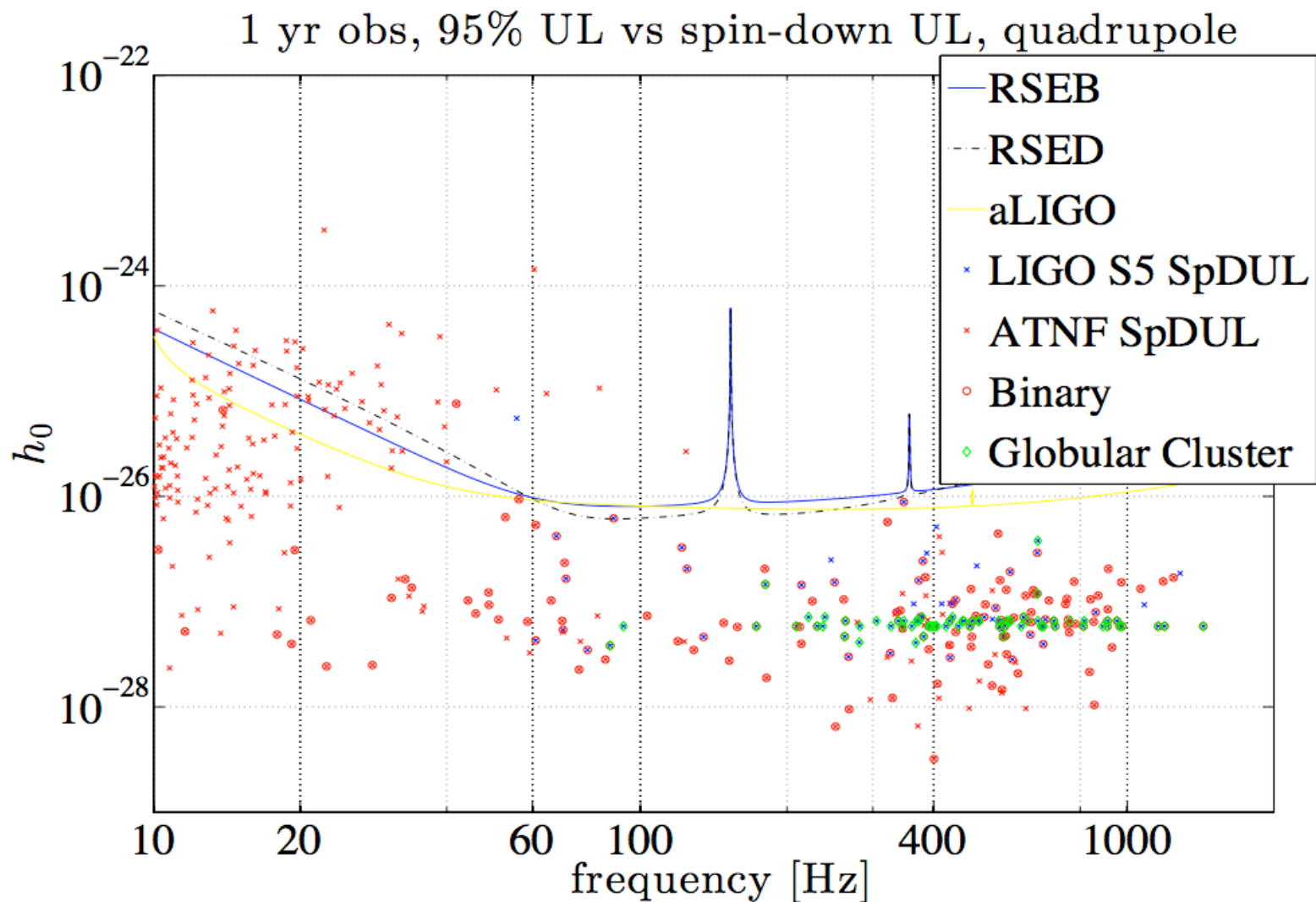


T. Kuroda et al. PRD (2014)



Kotake+ApJ (2009)

パルサーについて



パルサーで守ってほしい周波数

J0537-6910 123.94 Hz

J0900-3144 180.02

J1022+1001 121.56

J1603-7202 134.75

J1623-2631 180.57

J1641+3627A 192.72

J1745-0952 103.22

J1748-2446A 172.96

J1802-2124 158.13

J2140-2310A 181.50

J2145-0750 124.59

特にJ0537-6910の重力波周波数123.96付近は避けてほしい (伊藤)

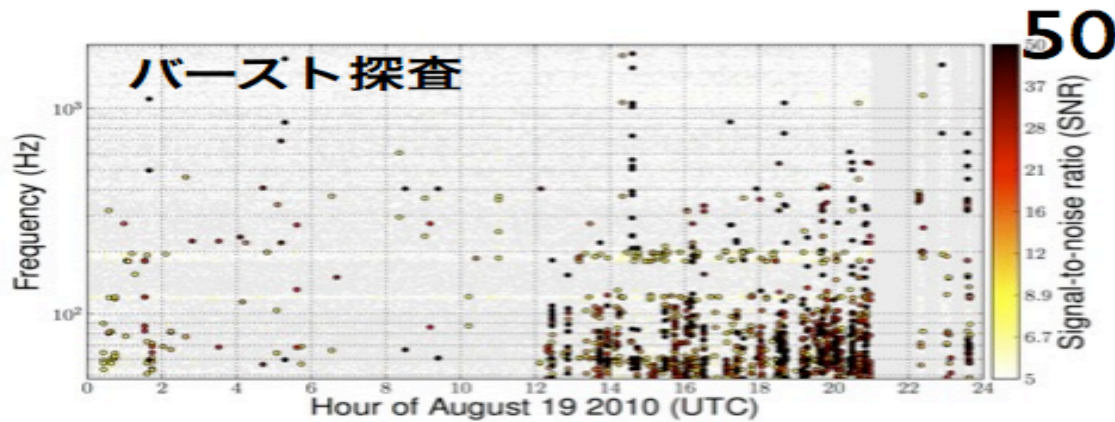
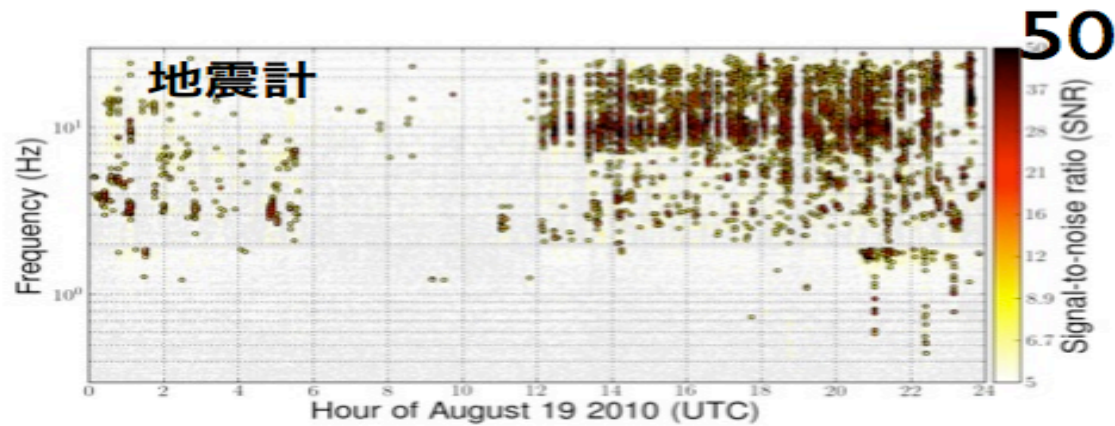
一般論としては、スイートスポットの100Hz-200Hzにバイオリンを置くのは非常によくないと思いますが、置かざるを得ないなら、パワーラインの120Hz (のちょっと下で110Hz-120Hzあたり) や180Hzと重ねてしまっても使えなくなるバンドを少なくするとかできないでしょうか??? (伊藤)

非定常雑音による Violin mode の励起

- 突発的に入ってくる seismic motion のアップコンバージョンノイズなどが、バイオリンモードを励起するエネルギーになりうる。
- これは Q が高ければ高いほど、バンド幅が狭くなり、こうした雑音の影響を受けにくくなるので、 Q が高いほどありがたい。
- 一方で、 Q が高いと、励起状態が長期間続く (Q が 10^8 で 3 日程度) ので、困ったことになりうる。
- 何らかの方法でダンピングできると解析側はうれしい

S6 LIGOでのseismic events

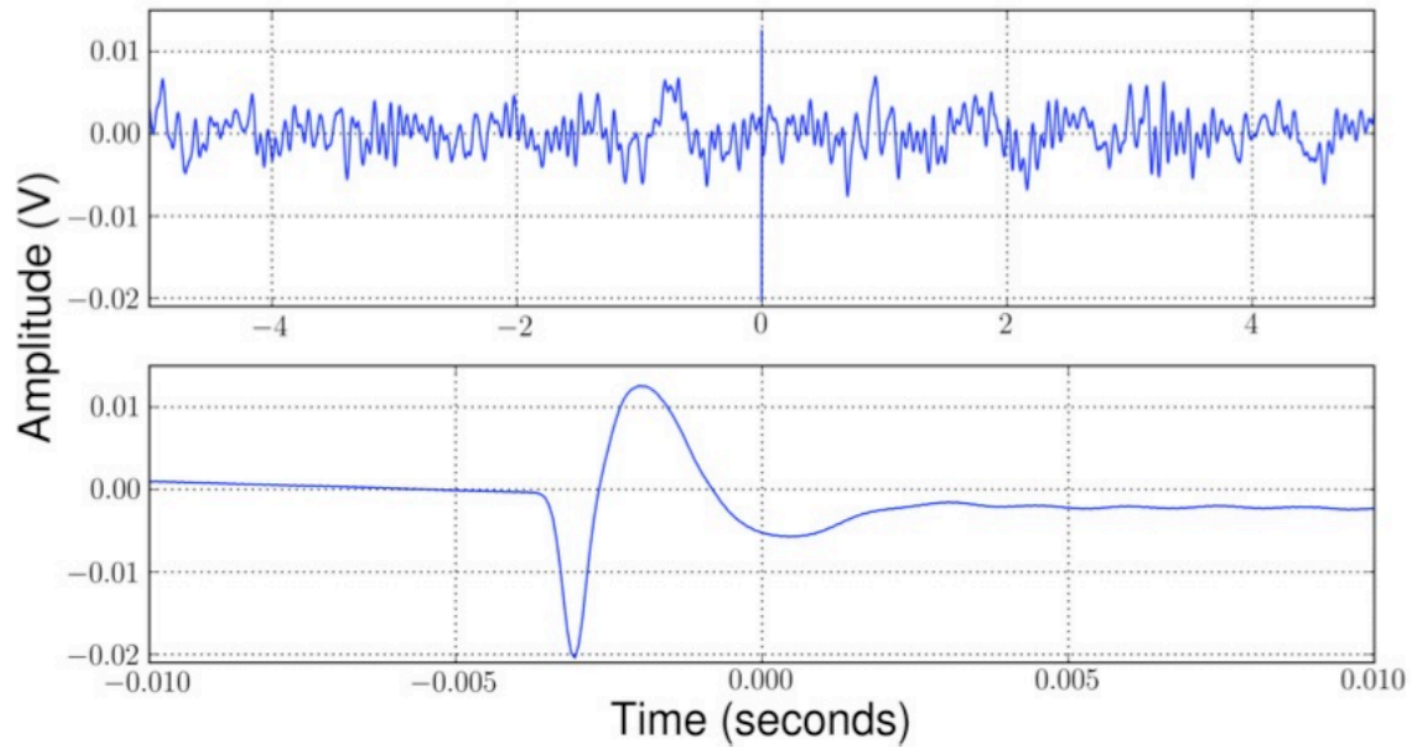
- SNR~50のイベントが1日のうちに多数出現



LIGO-P1000142

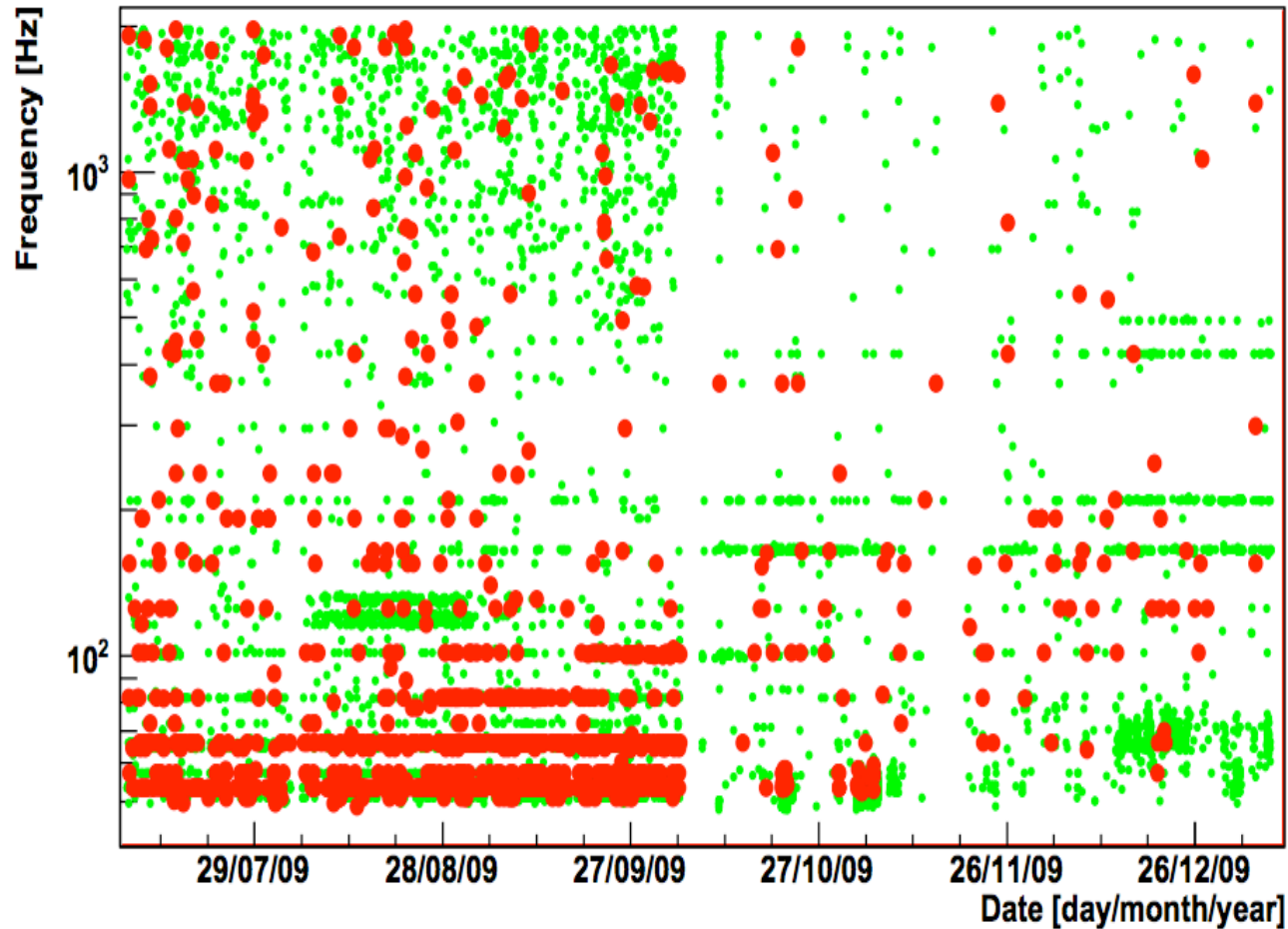
S6 unknown spike glitch

- バースト探査でSNR ~ 200-20000



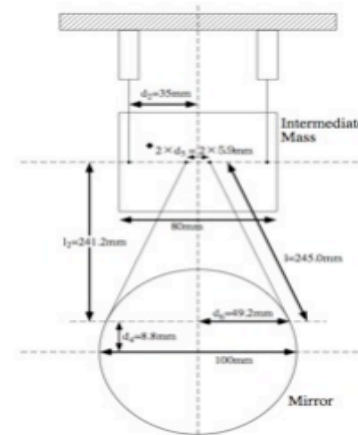
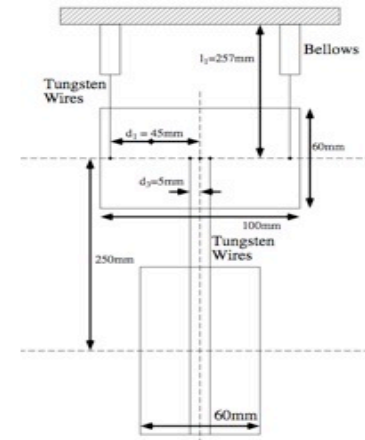
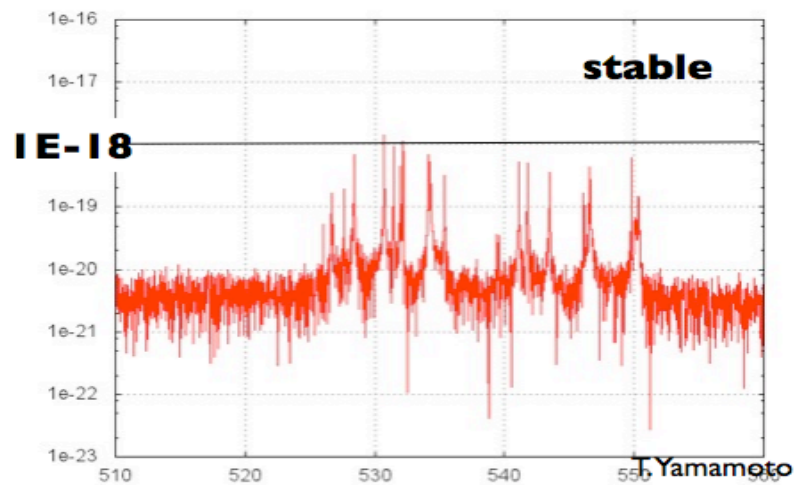
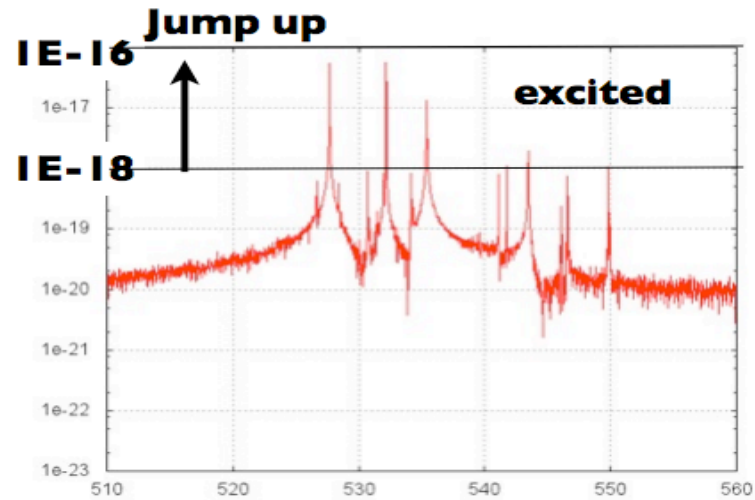
LIGO-P1000142

Virgoでのグリッチイベント



SNR>5のイベント
が毎秒1.8個

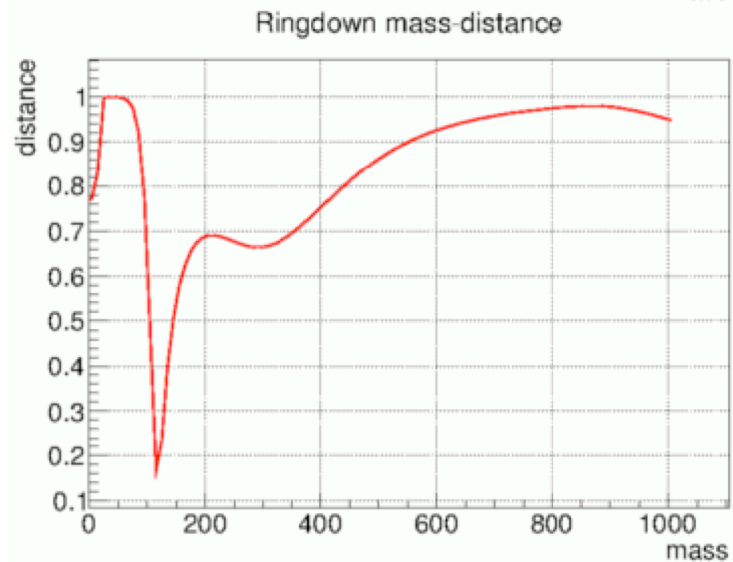
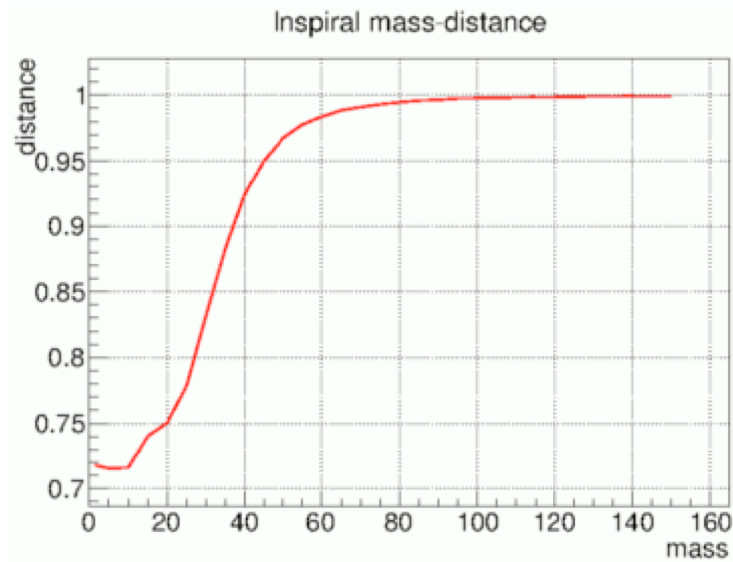
TAMAバイオリンモードの励起



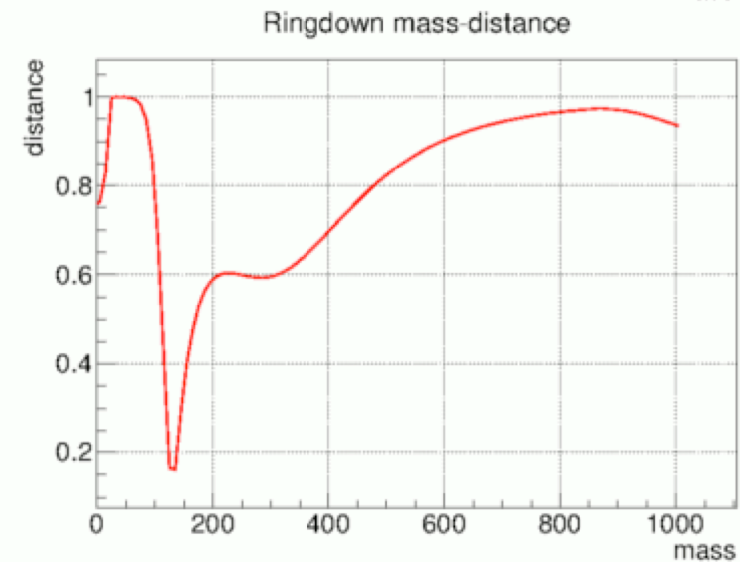
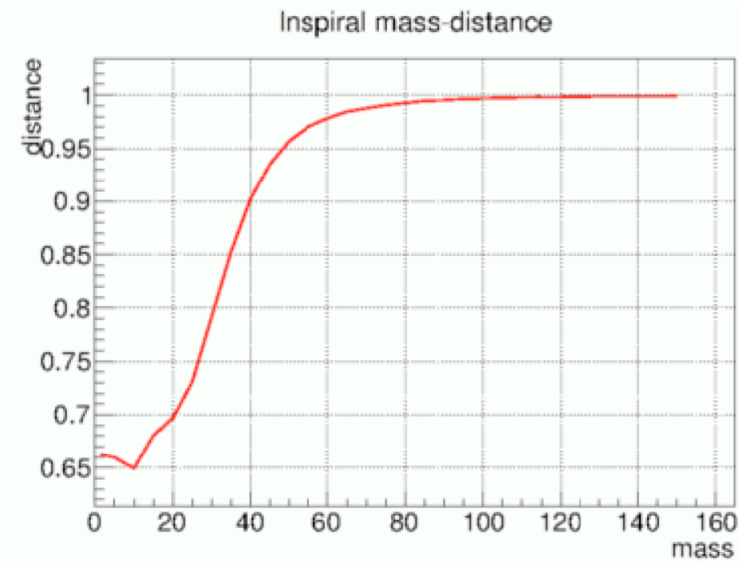
K. Yamamoto M. thesis

バイオリンモードが5倍励起された場合

300mm

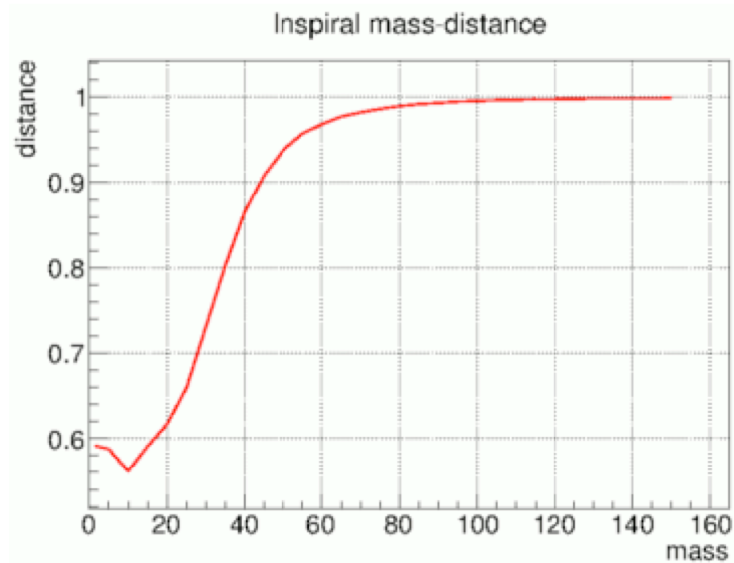


320mm

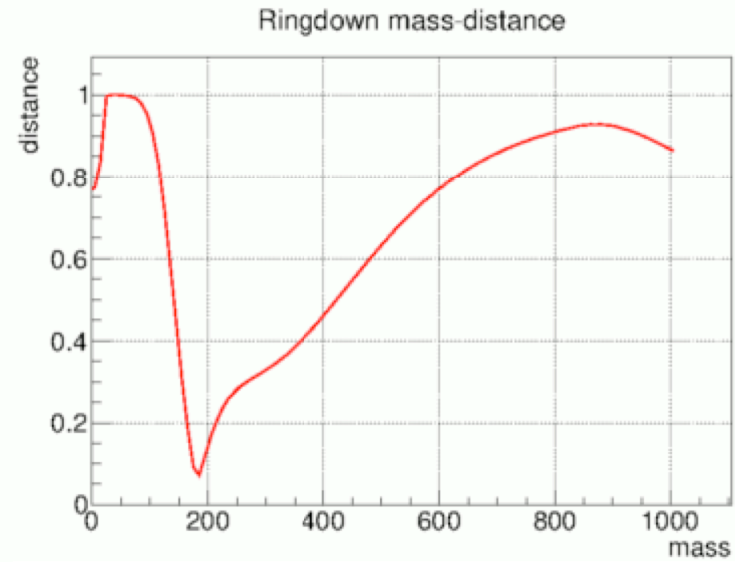
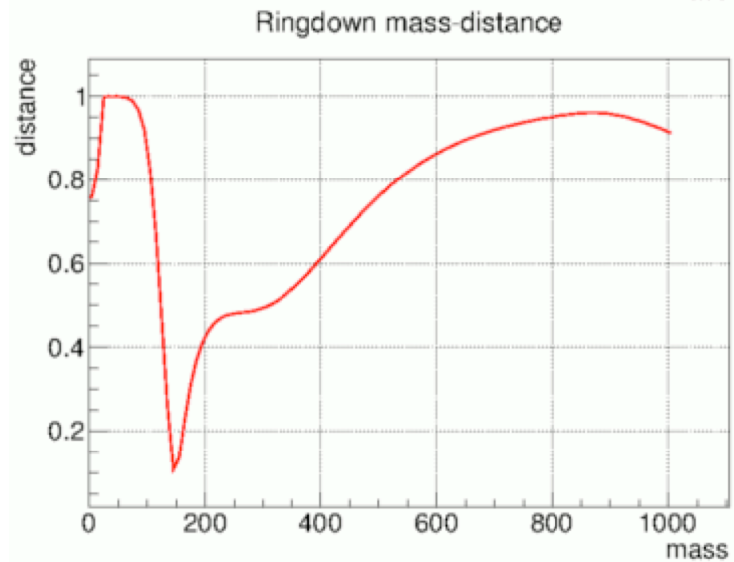
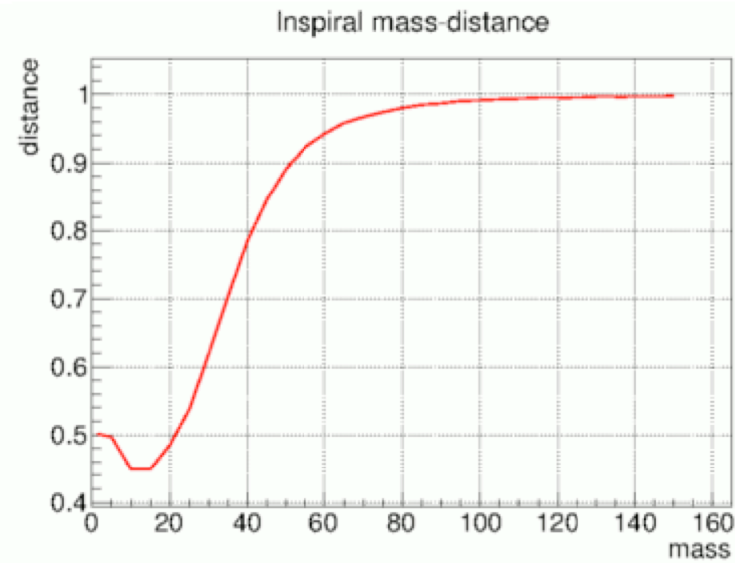


バイオリンモードが5倍励起された場合

350mm

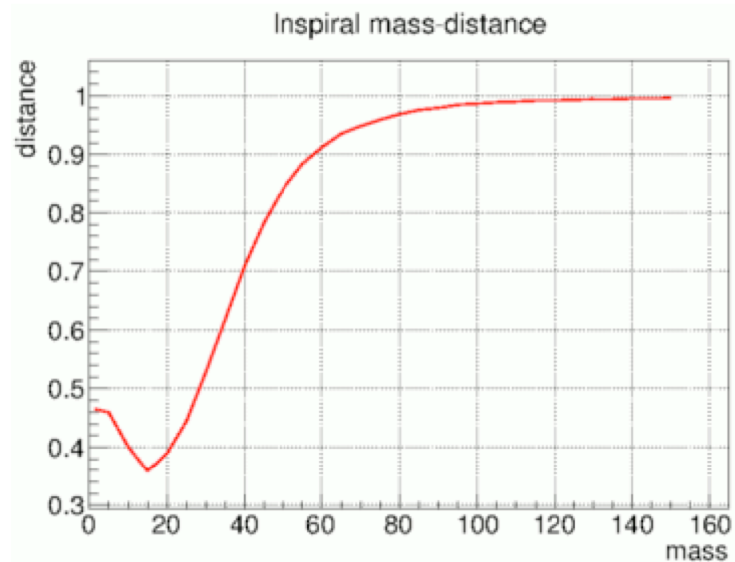


400mm

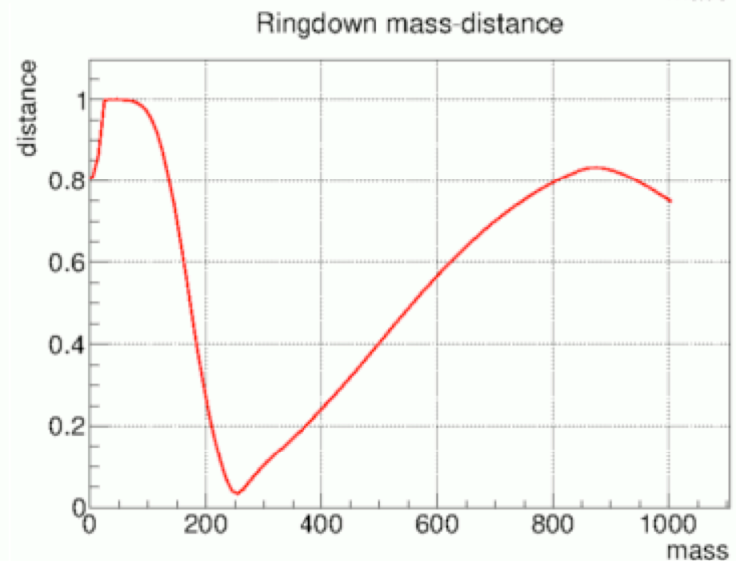
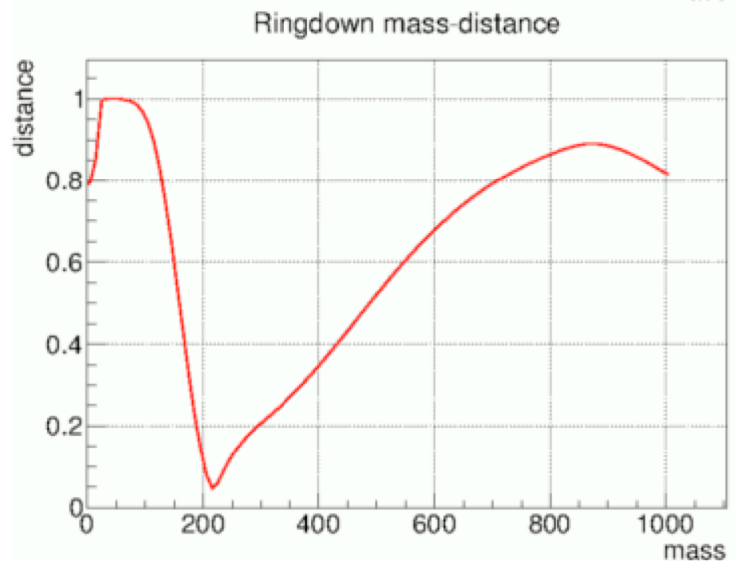
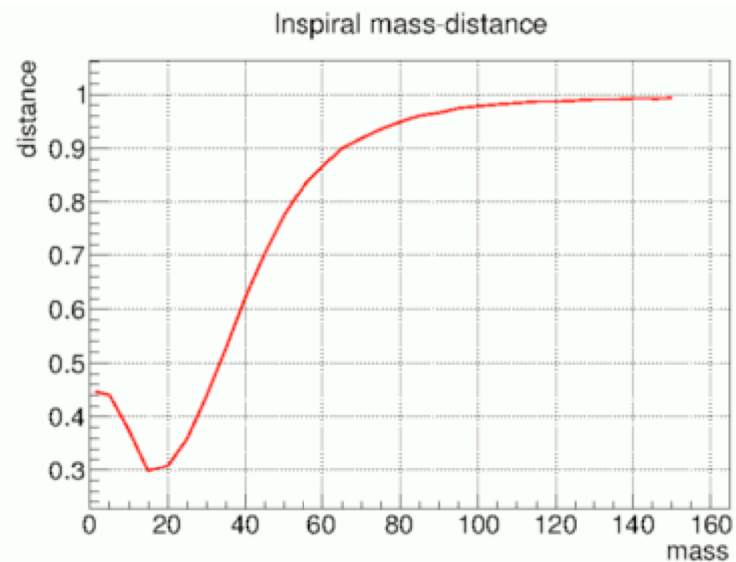


バイオリンモードが5倍励起された場合

450mm



500mm



Line characterization

6 Oct. 2014

K. Ueno (Osaka Univ.)

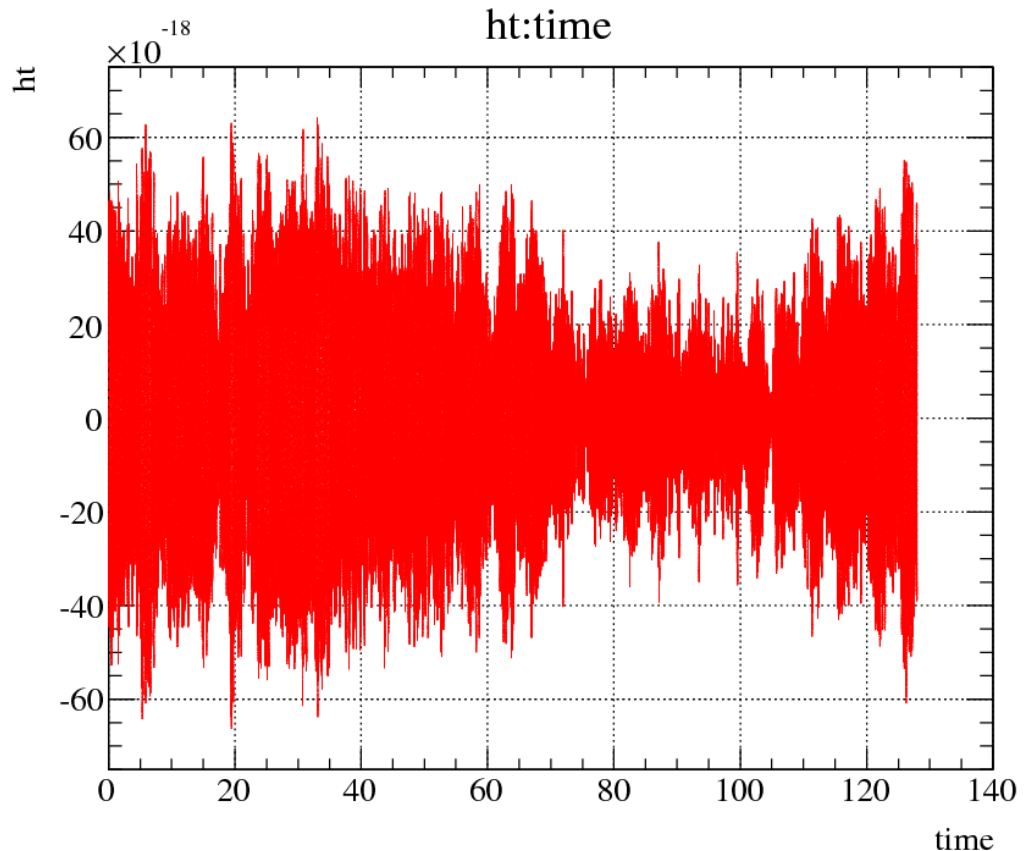
S6 data (example)

- I analyzed LIGO S6 data

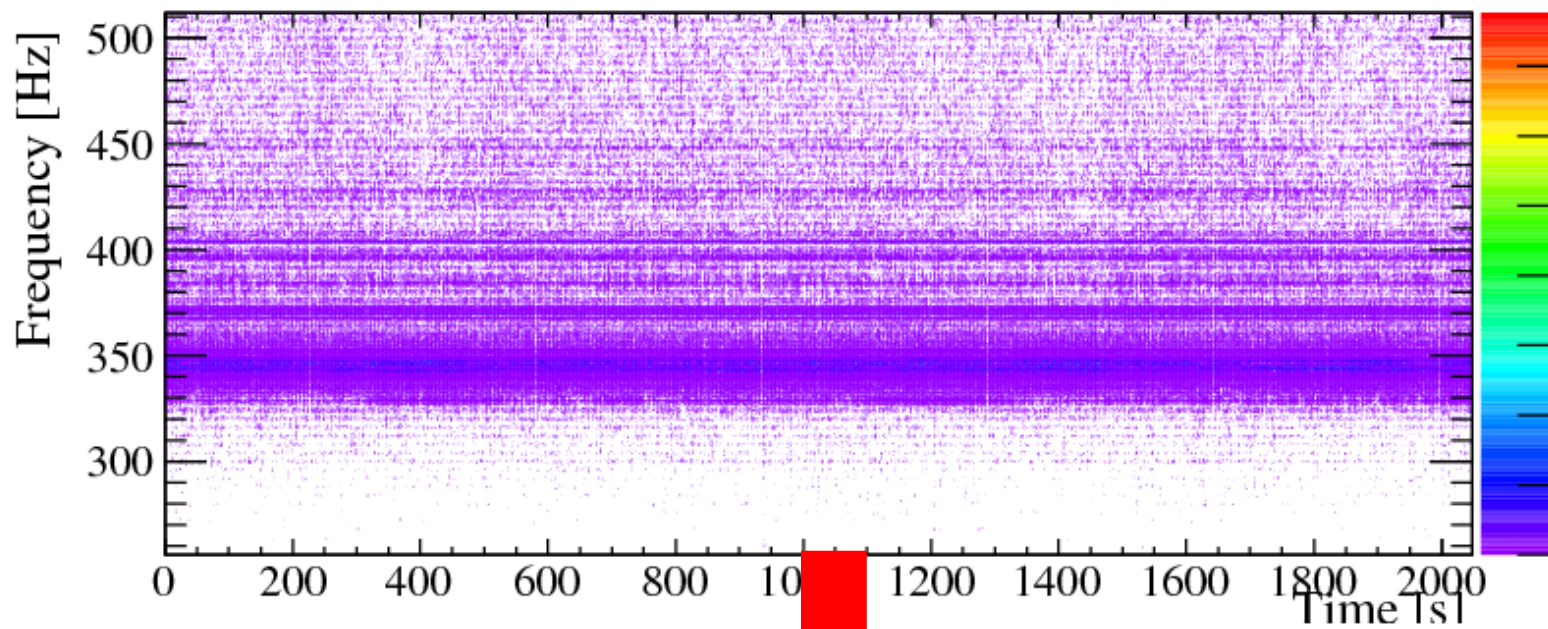
L-L1_LDAS_C02_L2-959200000-128.gwf

– $T = 128$ s

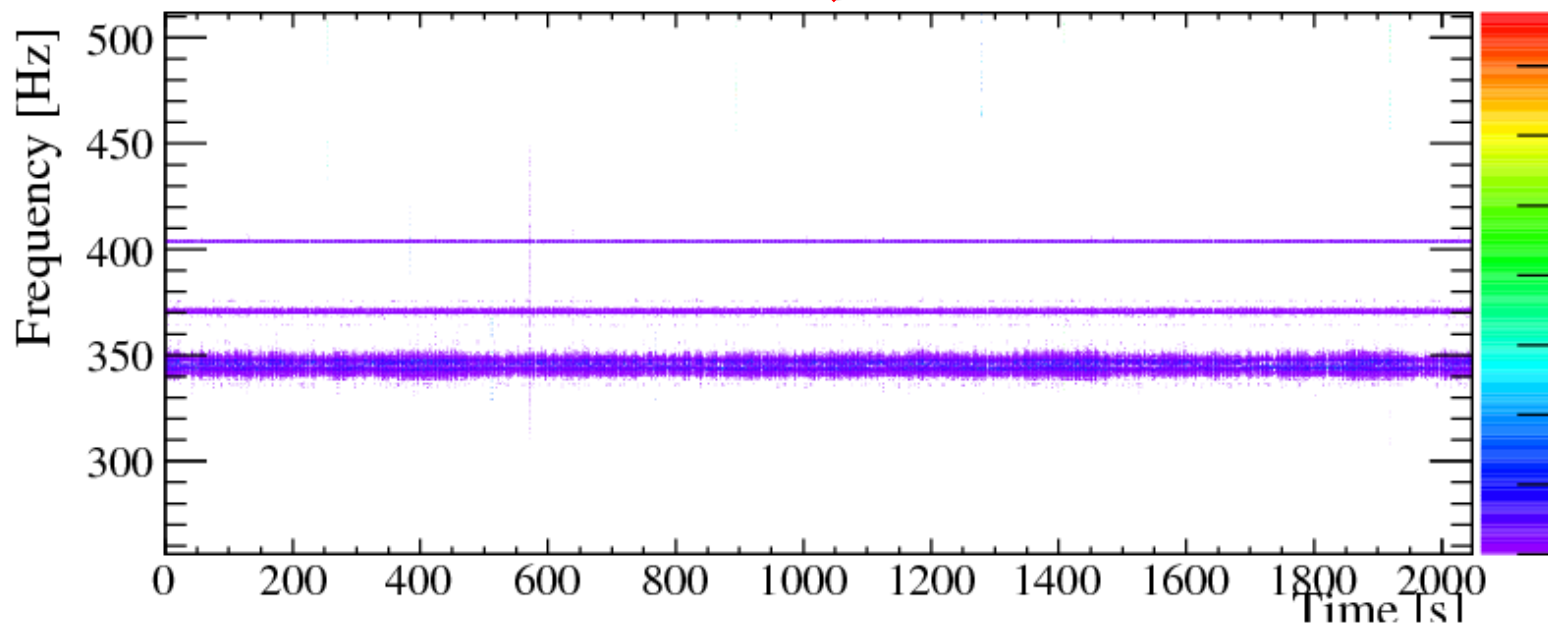
– $f_s = 16384$ Hz



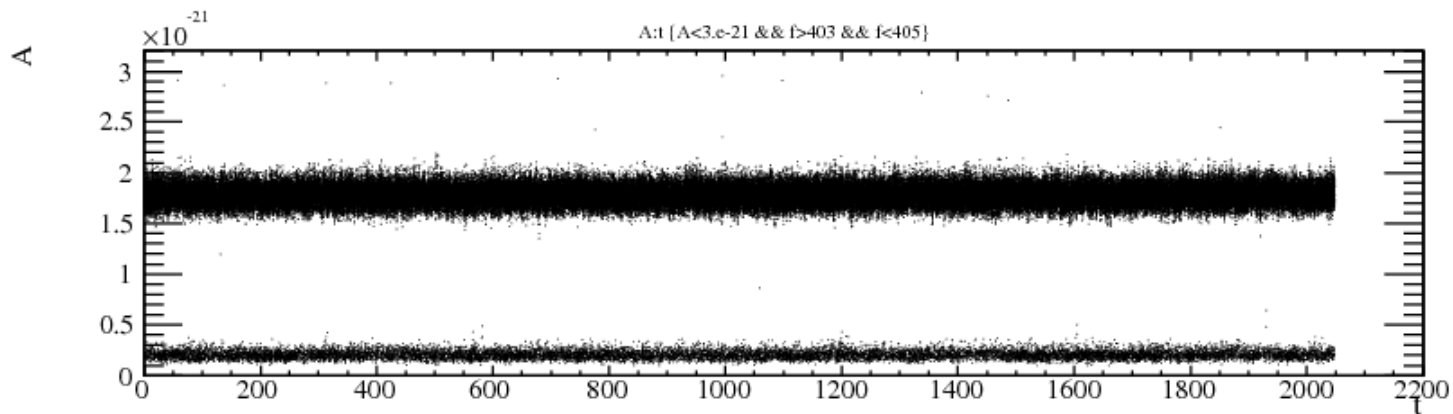
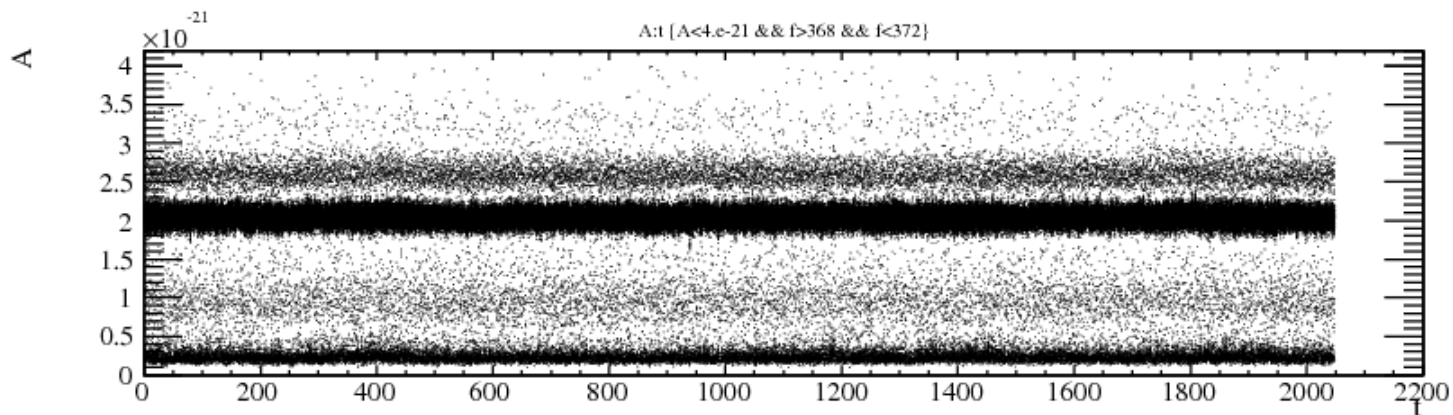
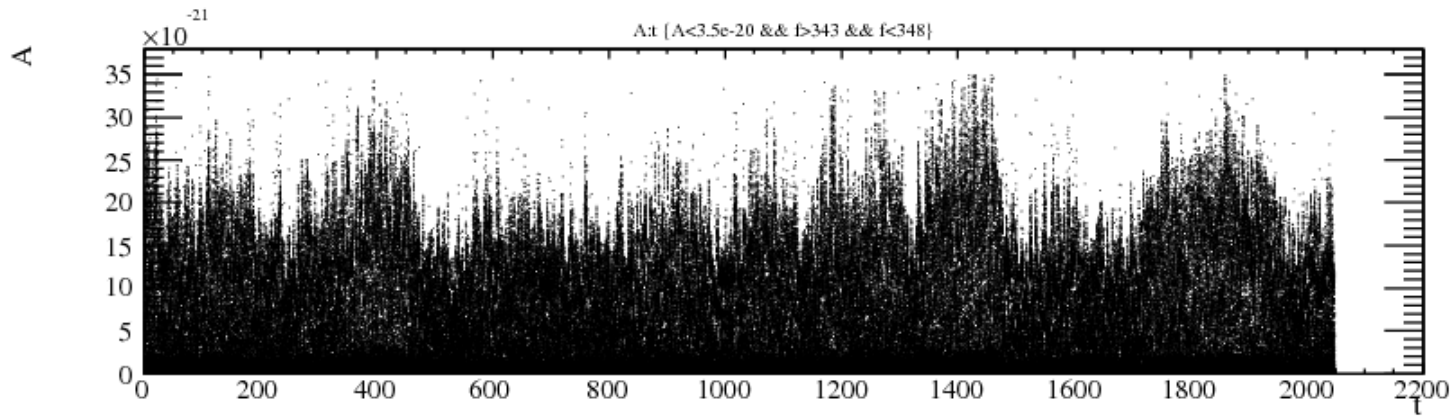
fs=1024Hz; frame=256; shift=16; #spectrum=20



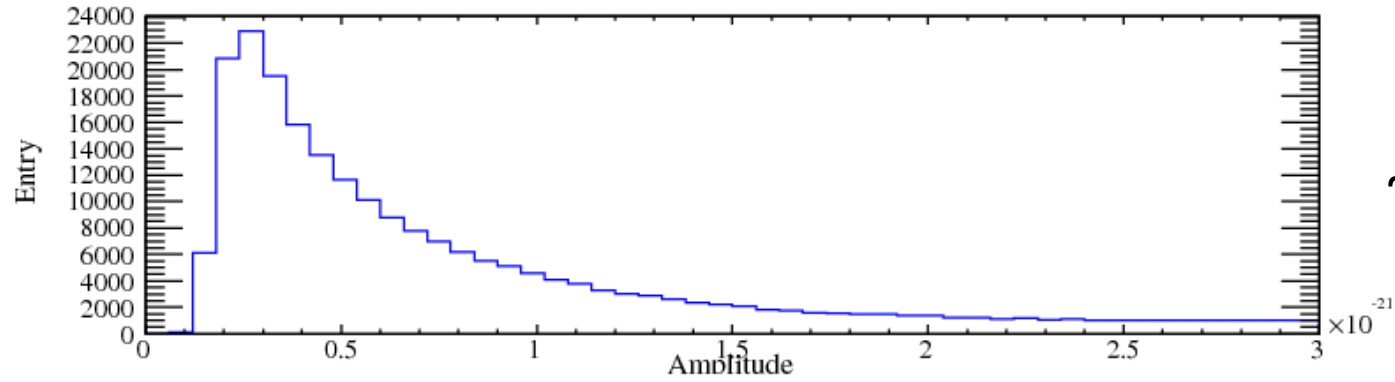
After $A > 1.5e-21$ cut



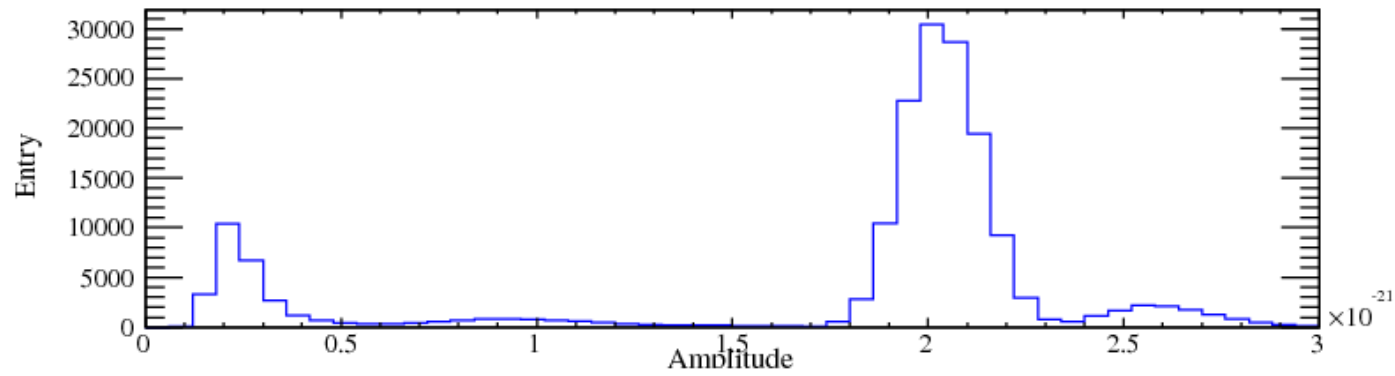
Time variation of amplitudes



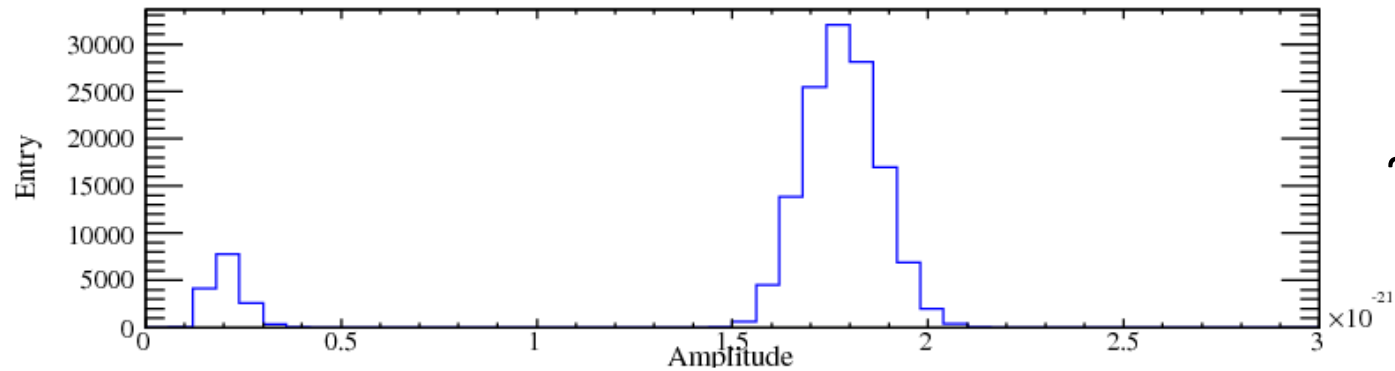
Amplitude distribution



~ 345 Hz

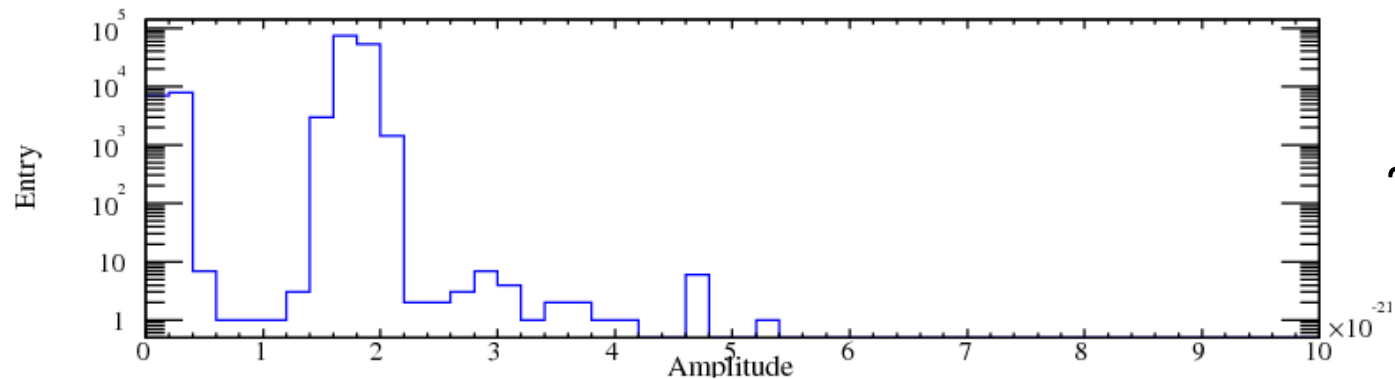
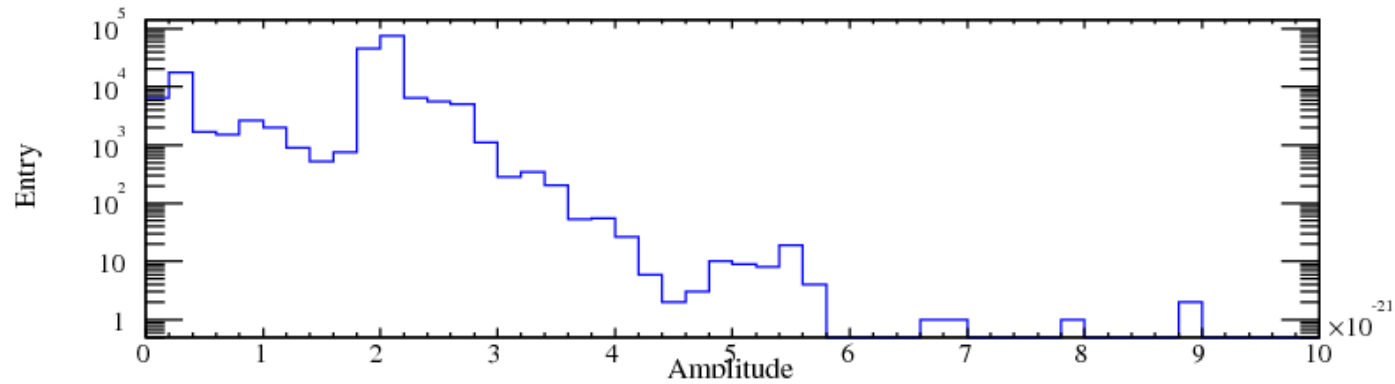
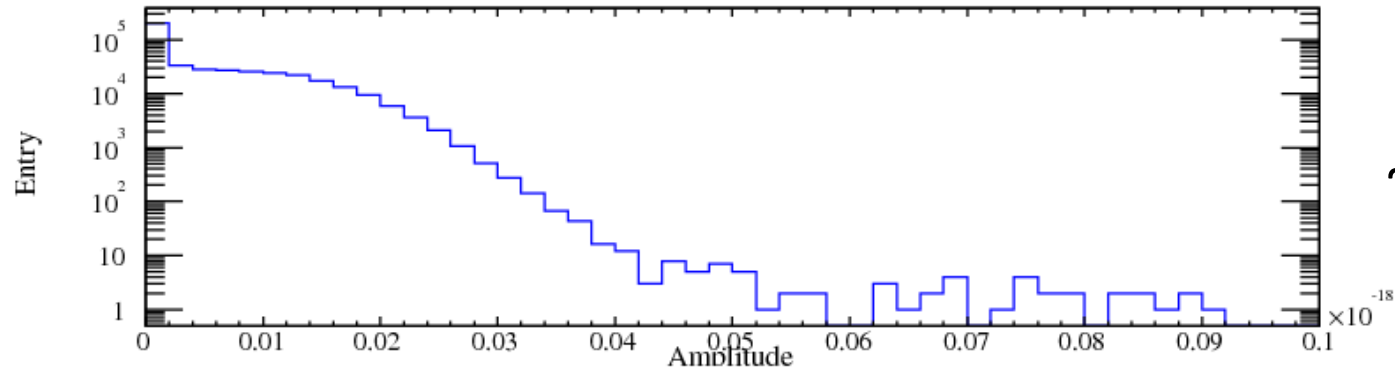


~370 Hz



~403 Hz

Amplitude distribution (logy)



Backups

Non-Harmonic Analysis (NHA)

- NHA is a method to extract dominant frequency components in given time-series with high resolution, developed by a Toyama Univ. group which is led by Hirobayashi-san.
- The method itself is **patent-protected** and so not publicly available (even to the other KAGRA collaborators), but there are some papers which describe the **outline** of the method, especially,
 - “Noise reduction for periodic signals using high resolution frequency analysis” Yoshizawa et al., EURASIP Journal on Audio, Speech, and Music Processing 5, 2011

Basic Algorithm

- 1) FFT the given time series $x(n)$ and find the frequency which gives the largest amplitude.
- 2) You somehow minimize the following cost function about A, f , and ϕ ,

$$F(A, f, \phi) = \frac{1}{N} \sum_{n=0}^{N-1} \left\{ x(n) - A \cos \left(2\pi \frac{f}{f_s} n + \phi \right) \right\}^2$$

starting from A and f estimated at 1). This is just a **least square fit with a sinusoidal function**.

- 3) Once the best-fit values of A, f , and ϕ are found, the waveform of converged spectrum is **subtracted from $x(n)$** .
- 4) Repeat the procedure 1 \sim 3 as many times as one would like.

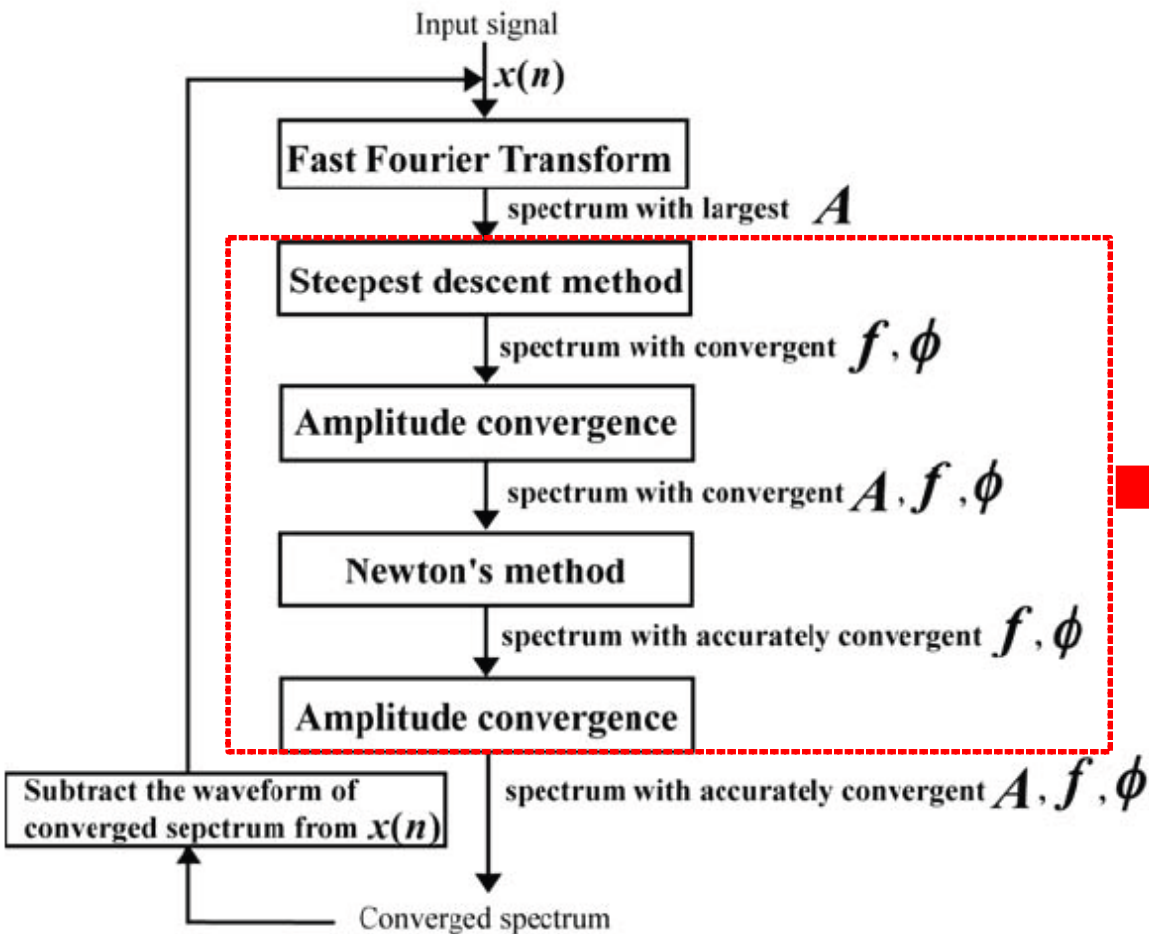
Problems

- According to Hirobayashi-san, you need some specific environments such as MATLAB or GPGPU to execute their NHA code.
- In order to do data analysis ourselves efficiently, it's better to develop our own **simple version** of the code instead of using their real one.
- So I tried to implement this method from the scratch. But when I followed the paper faithfully, the solutions were found not to be stable and soon diverge.
- Instead of following the whole procedure written in the paper, I took another way to meet the same purpose. I'll refer to the new way (next slide) as "Iterative Least Square (ILS)" instead of NHA to avoid confusion.

Difference from NHA's paper

NHA paper

Iterative Least Square (ILS)



At one time with
3D Newton's method

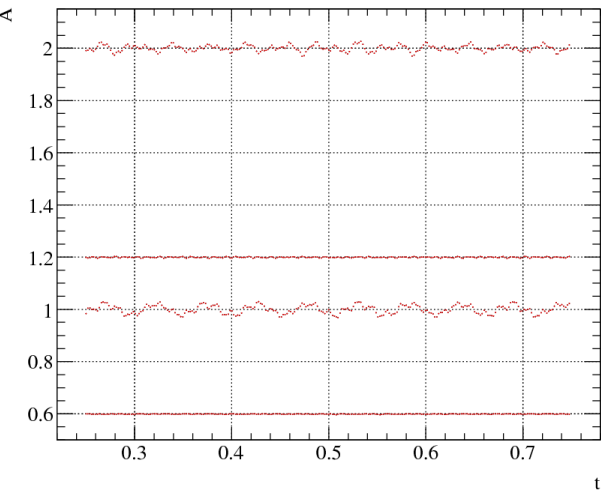
Test Example

- To test the performance of the ILS code, I artificially generated a signal time-series with some input parameters and tried to reconstruct them with ILS.
- The time-series is composed of four different signals, each of which has a constant amplitude and frequency.
- The sampling rate is 512 Hz, and the duration is set to 1 s.

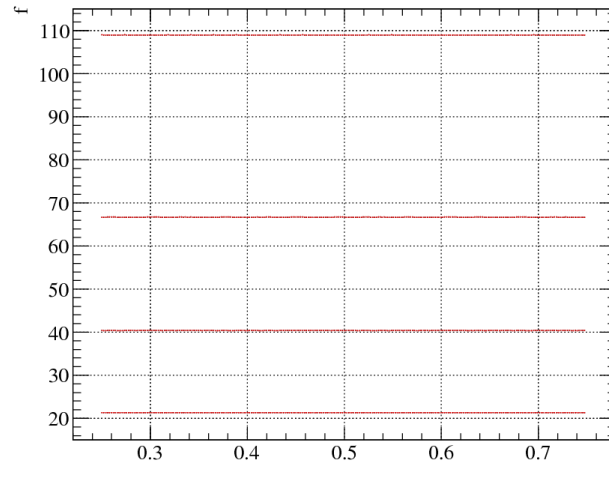
Amplitude	Frequency [Hz]	Initial phase [rad]
2.0	66.7	-0.15
1.2	109.0	0.46
1.0	40.4	2.40
0.6	21.3	0.10

Result (absolute)

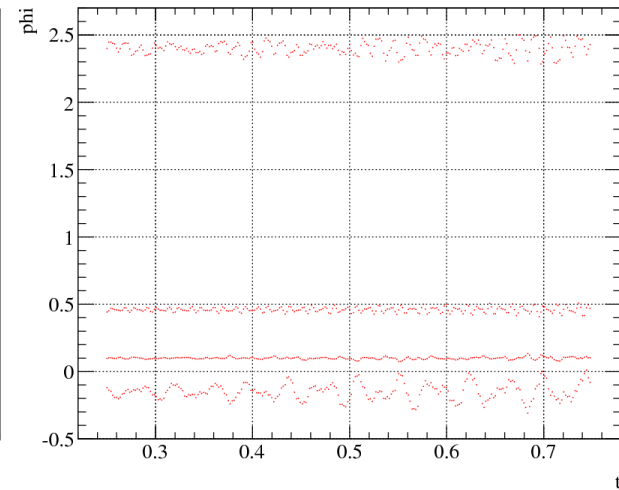
Amplitude



Frequency



Initial phase



While frequencies were well reconstructed, some of the amplitudes were not, which are caused by signal-signal interference.

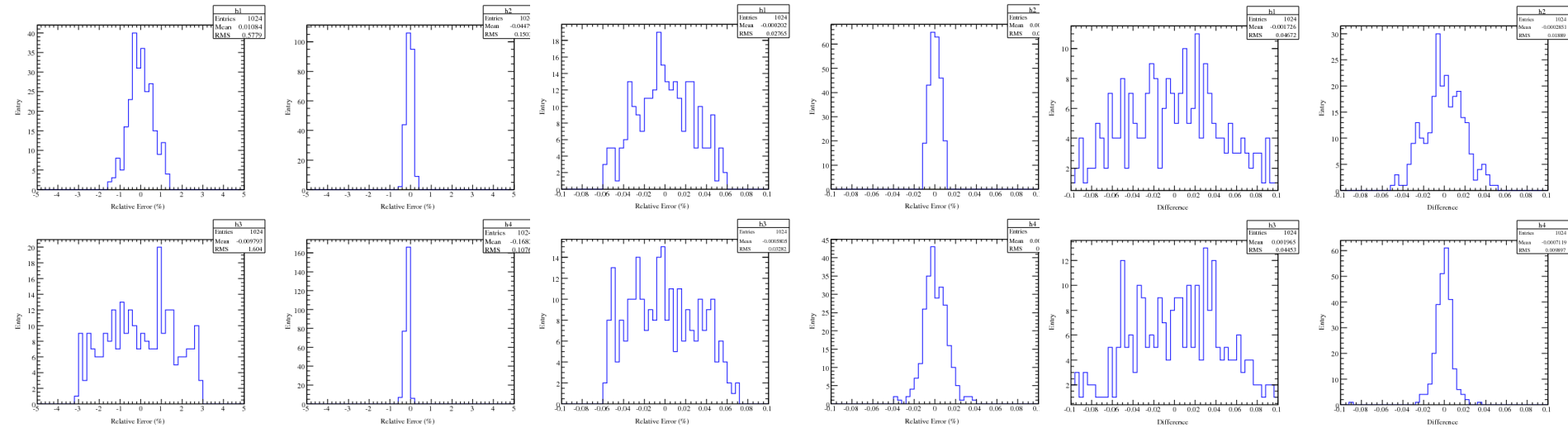
What is already clear: when there are multiple signals within the same duration, the minimum of the cost function does not always correspond to the true amplitude value, and the solution shift a little bit.

Result (resolution)

Amplitude

Frequency

Initial phase



Frequencies were reconstructed within 0.1%,
while amplitudes 3%.