バイオリンモードの周波数について

端山　和大
KAGRA Detector Characterization

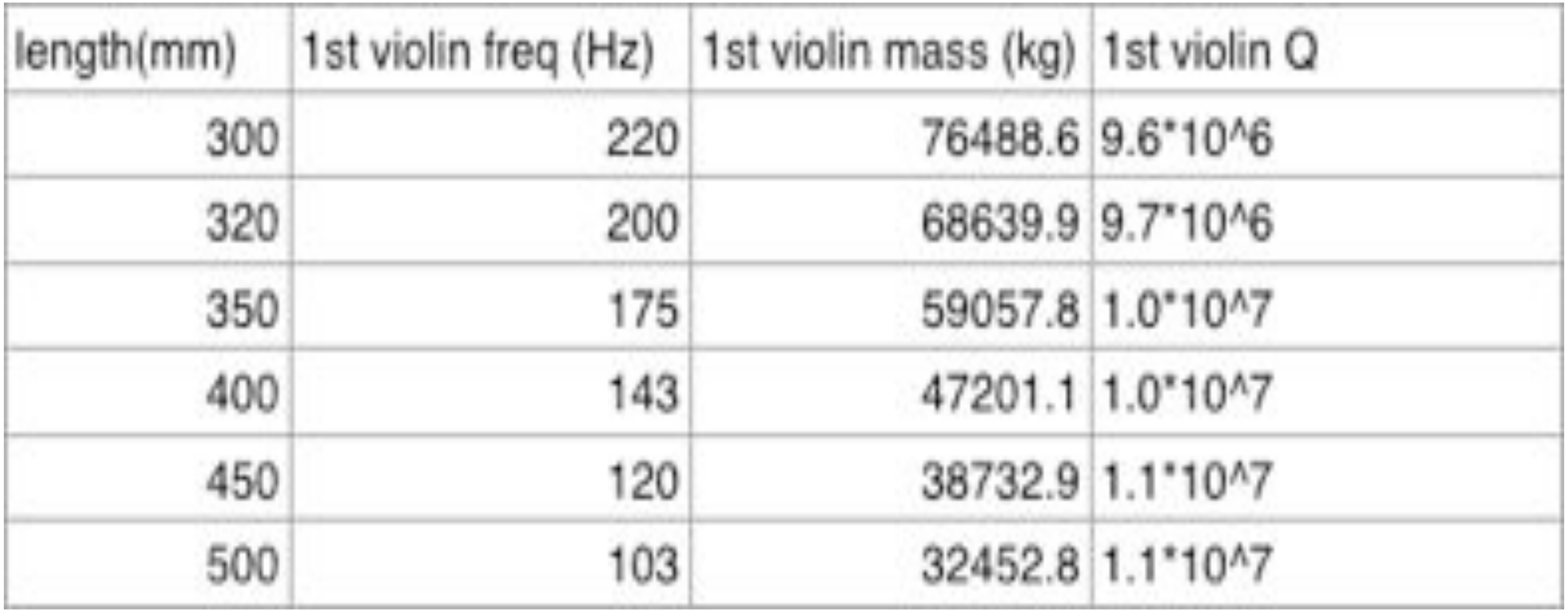
バイオリンモードスタディ資料

- 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

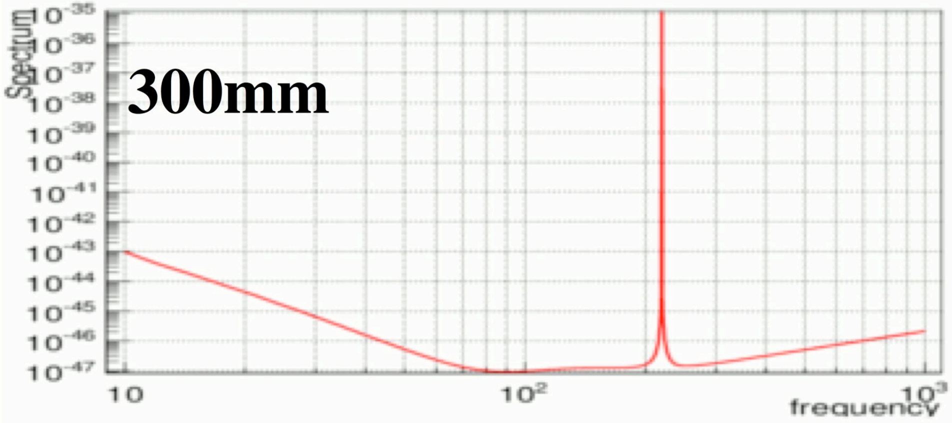
- ワイヤの長さ等によって、1次バイオリンモードの周波数が変化する。今回検討するパラメータはワイヤの長さが300mm-500mm、周波数でいうと103Hz-220Hzである。
- 1次バイオリンモードの影響のみを調べるために、公式のKAGRA感度スペクトルからラインを除去し、1次バイオリンモードのみを入れて、連星合体とリングダウンの探査距離がどのように変化するかを調べた。
- 探査距離はSNR=8で最適感度での距離、SNRの定義はLIGOのもので調べた。

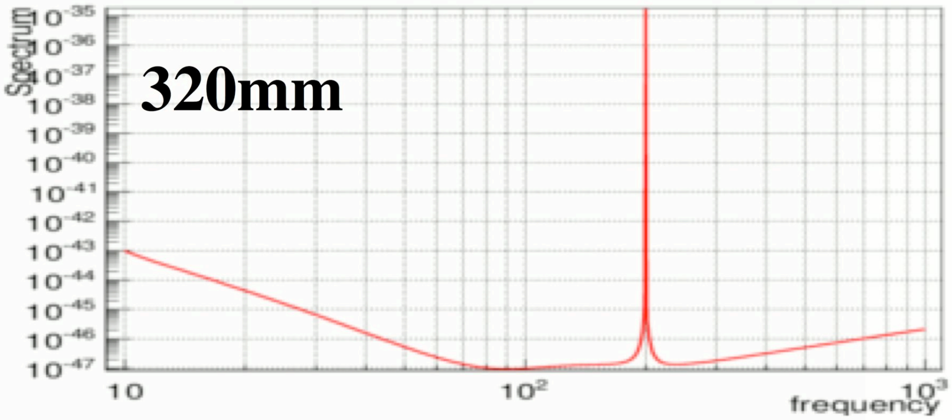
ワイヤの長さとバイオリンモードの特徴パラメータ

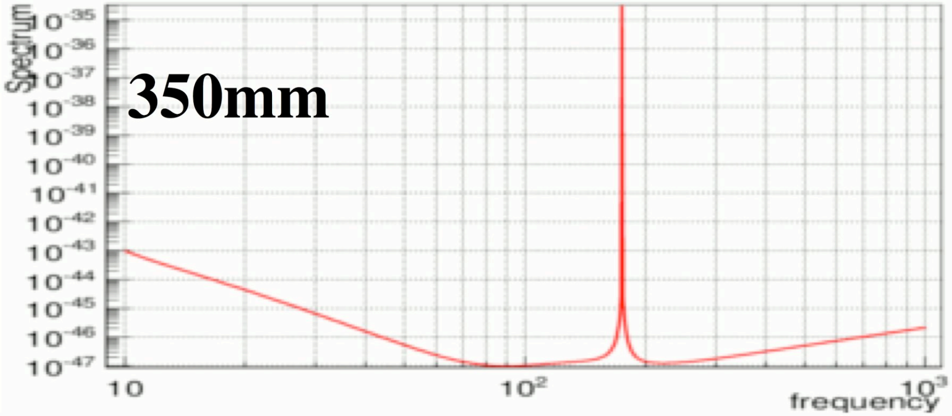


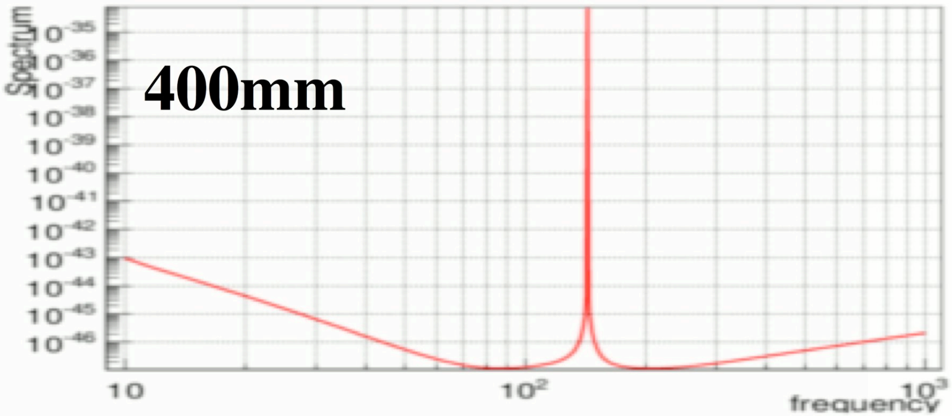
length(mm)	1st violin freq (Hz)	1st violin mass (kg)	1st violin Q
300	220	76488.6	9.6*10^6
320	200	68639.9	9.7*10^6
350	175	59057.8	1.0*10^7
400	143	47201.1	1.0*10^7
450	120	38732.9	1.1*10^7
500	103	32452.8	1.1*10^7

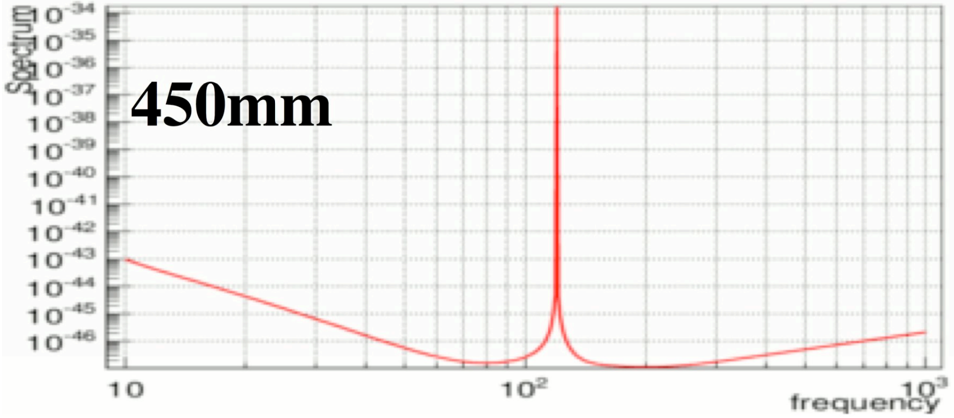
望遠鏡スペクトル

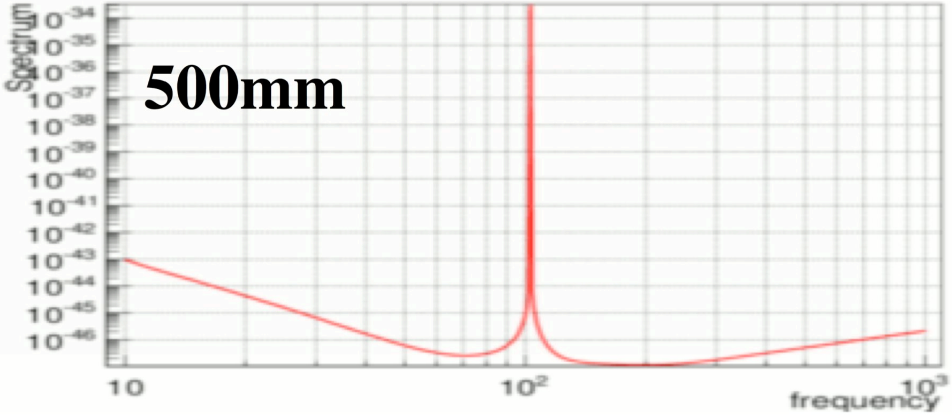

300mm


320mm


350mm


400mm

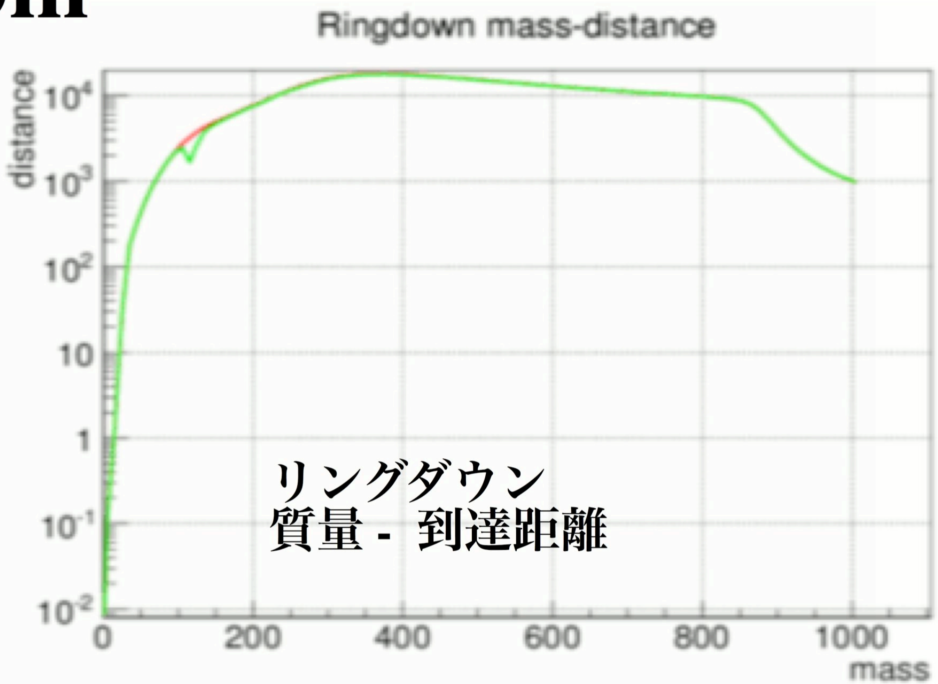

450mm


500mm

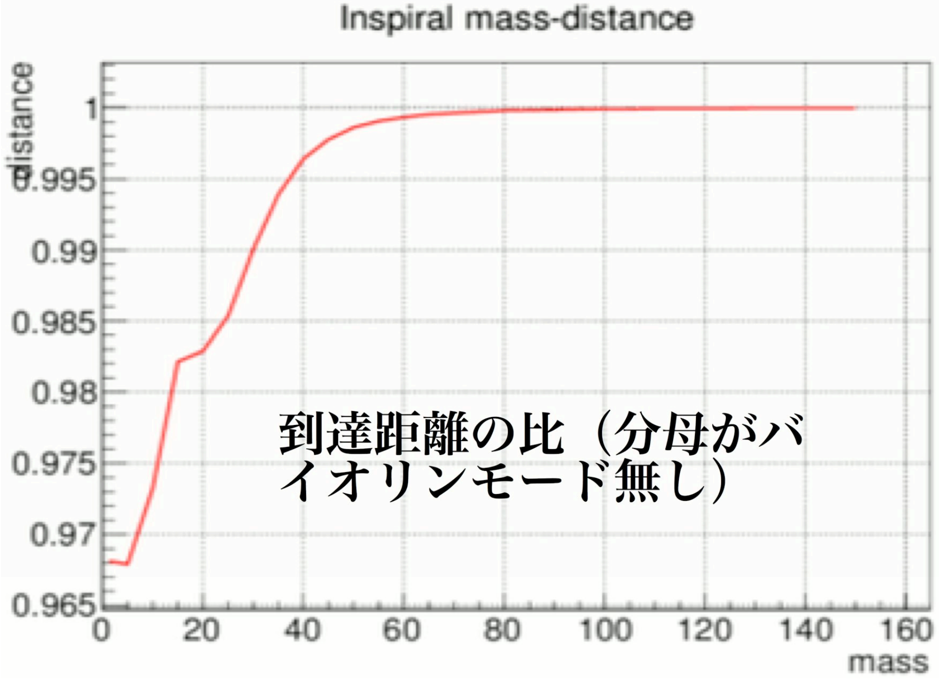
300m

連星合体
質量（等質量連星）- 到達距離

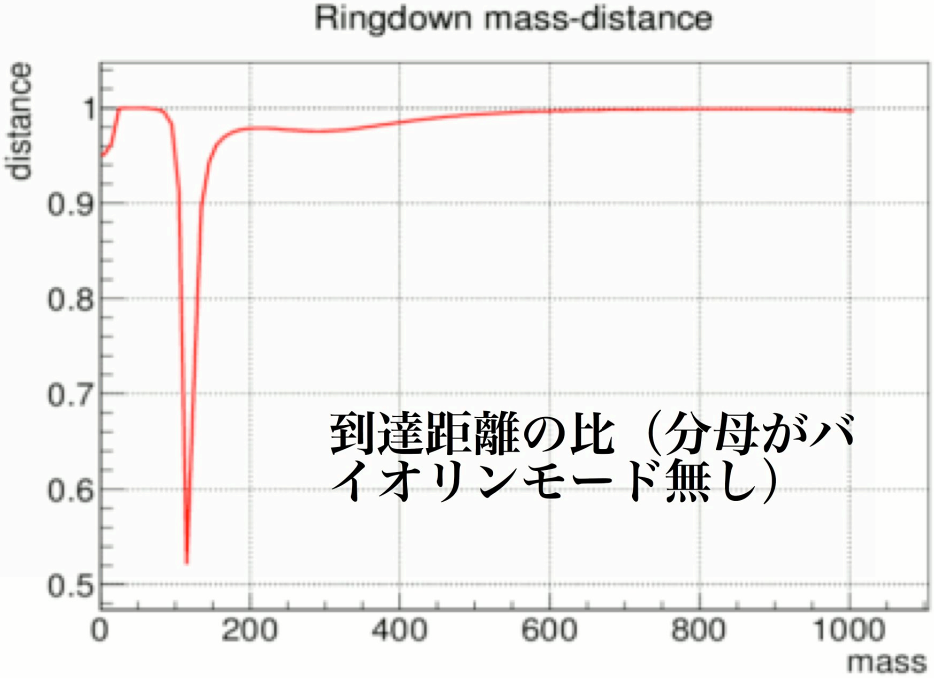
緑線：バイオリンモード有
赤線：バイオリンモード無



リングダウン
質量 - 到達距離

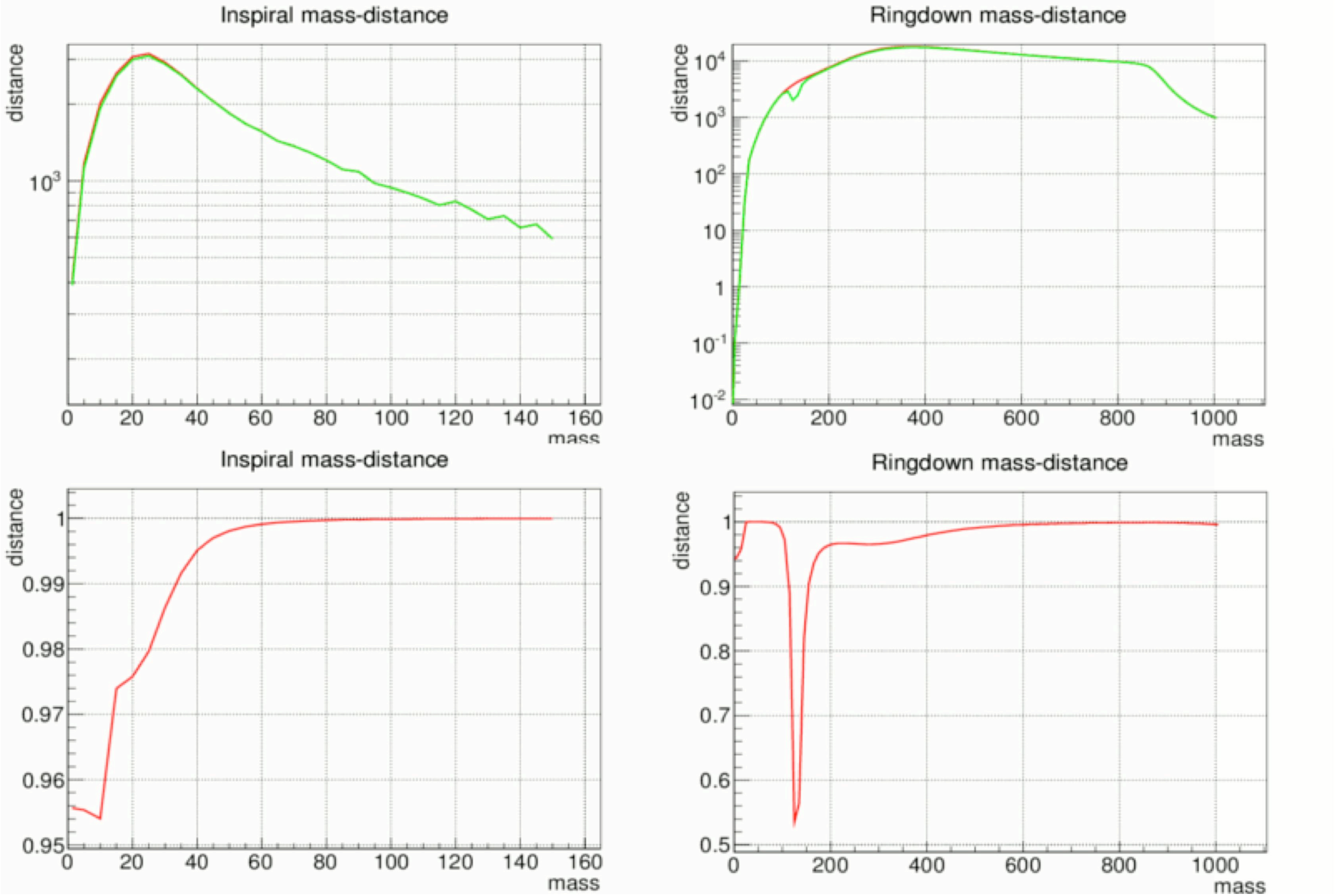


到達距離の比（分母がバイオリンモード無し）

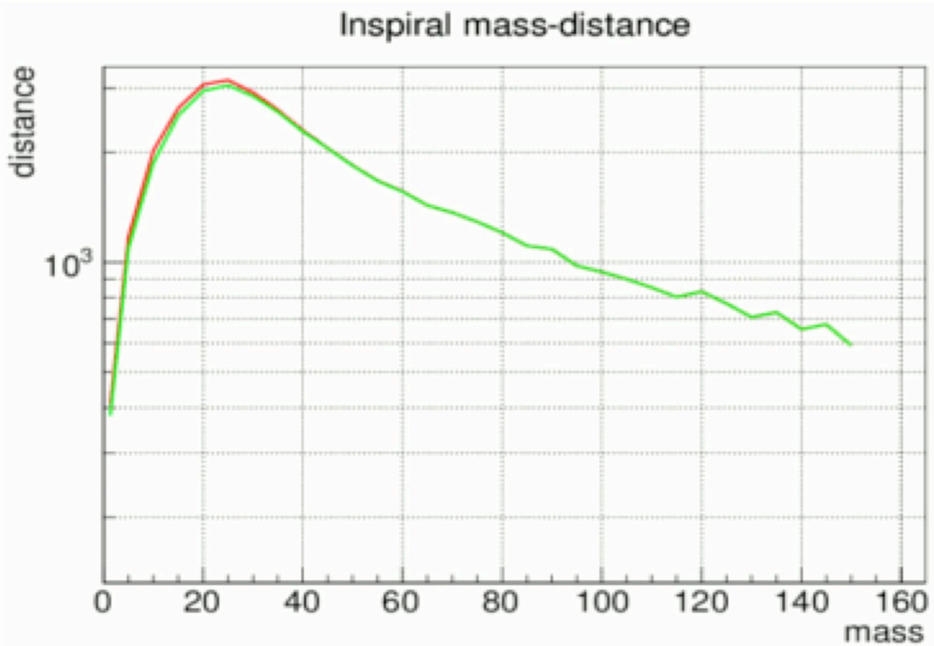


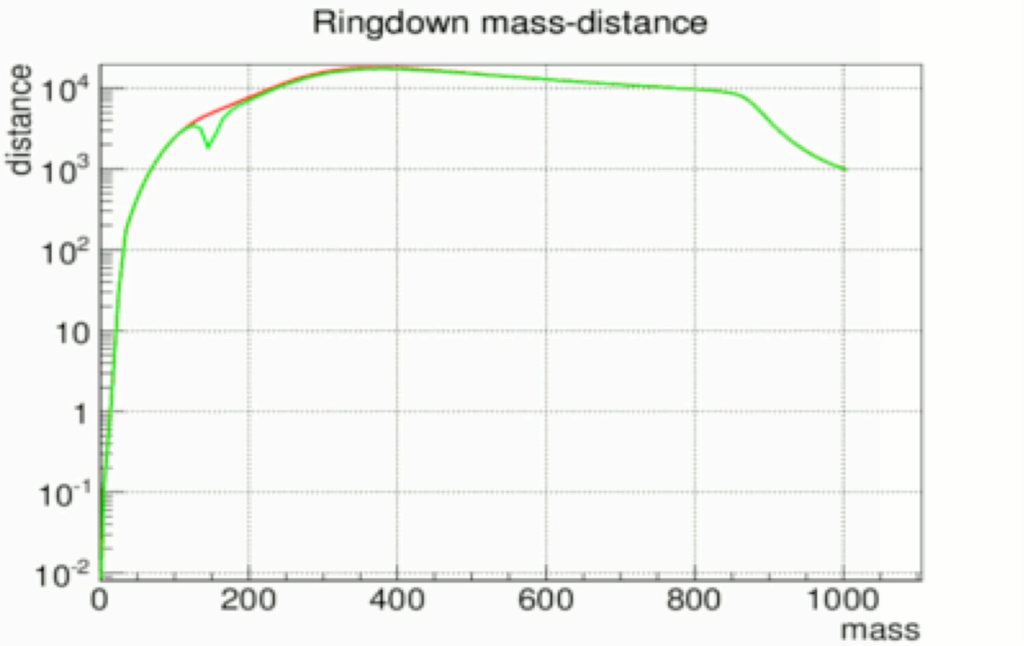
到達距離の比（分母がバイオリンモード無し）

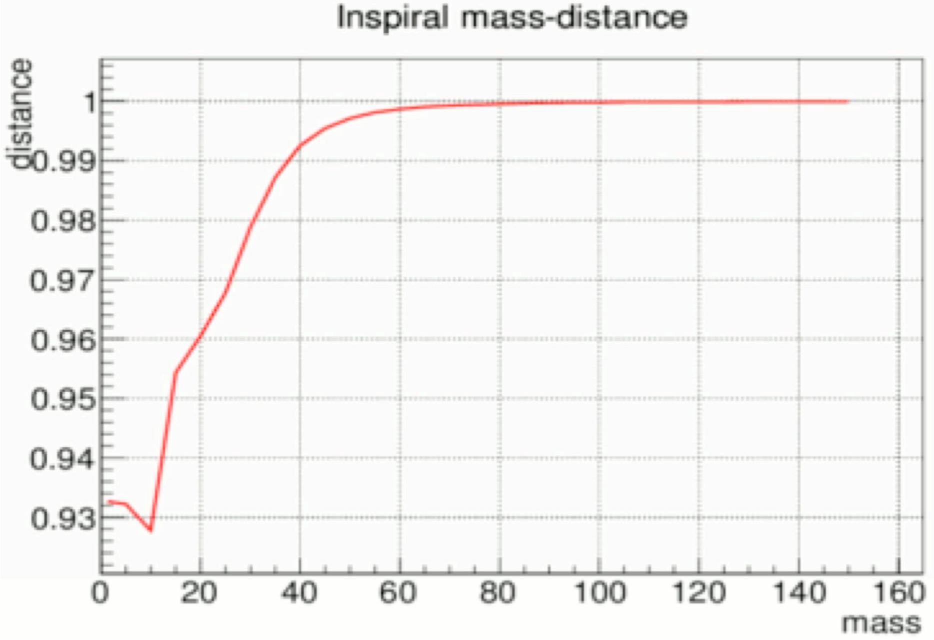
320mm

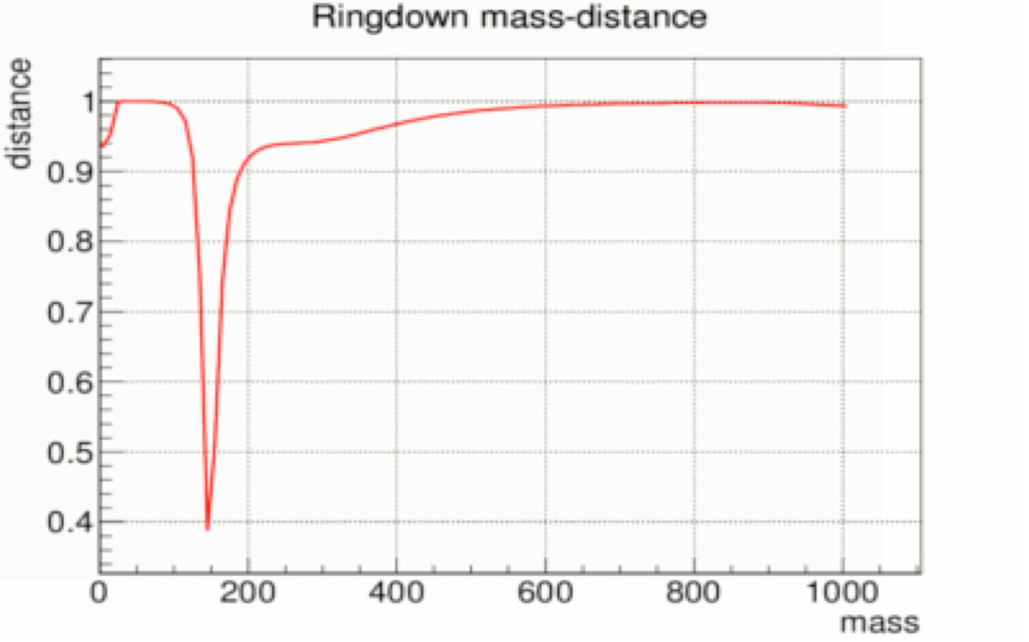

Inspiral mass-distance
distance
10^3
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
mass
Inspiral mass-distance
distance
1
0.99
0.98
0.97
0.96
0.95
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
1
0.9
0.8
0.7
0.6
0.5
0
200
400
600
800
1000
mass

350mm

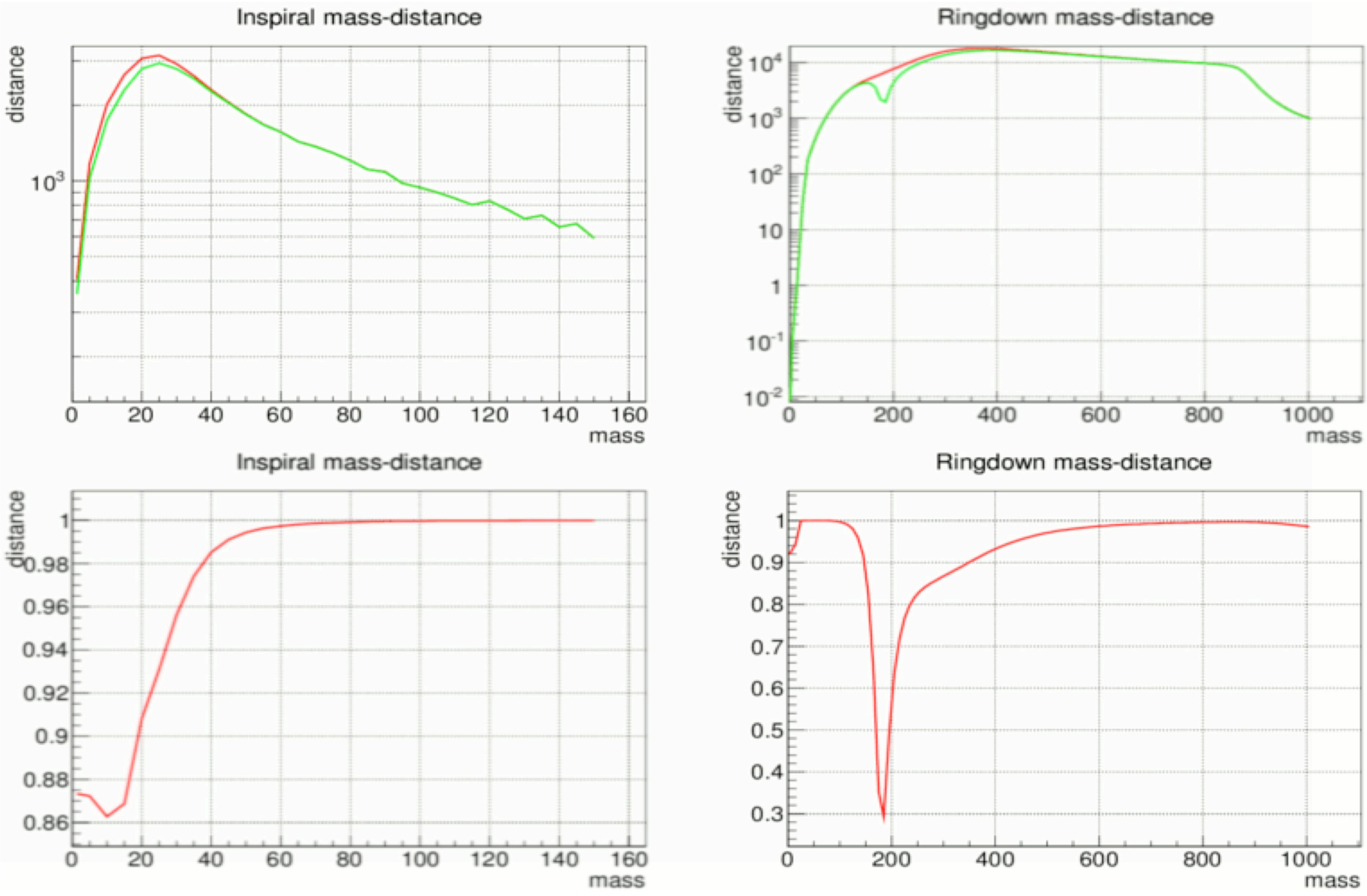

Inspiral mass-distance
distance
10^3
0
20
40
60
80
100
120
140
160
mass


Ringdown mass-distance
distance
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
mass

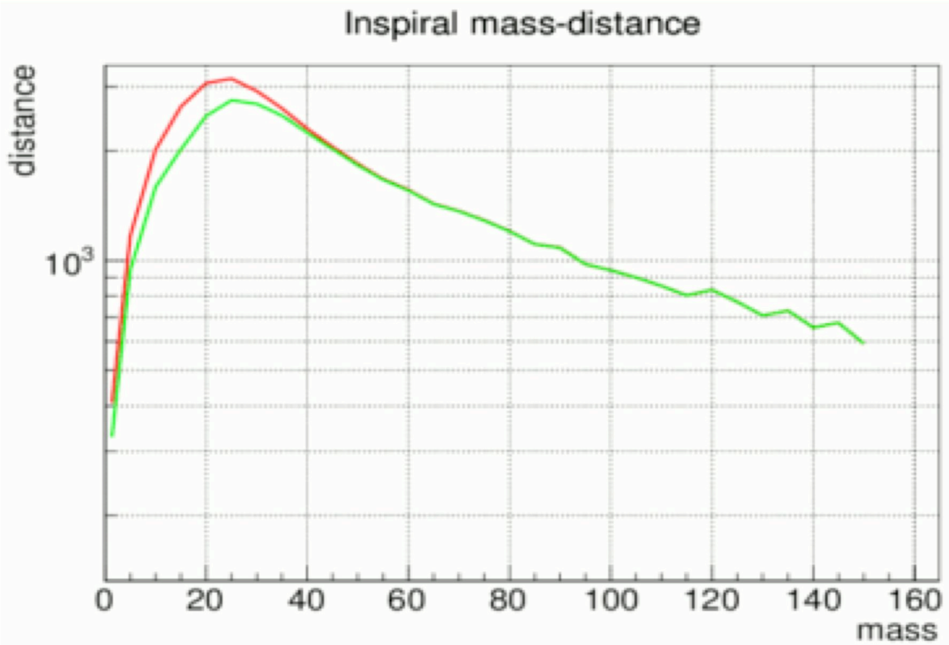

Inspiral mass-distance
distance
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0
20
40
60
80
100
120
140
160
mass

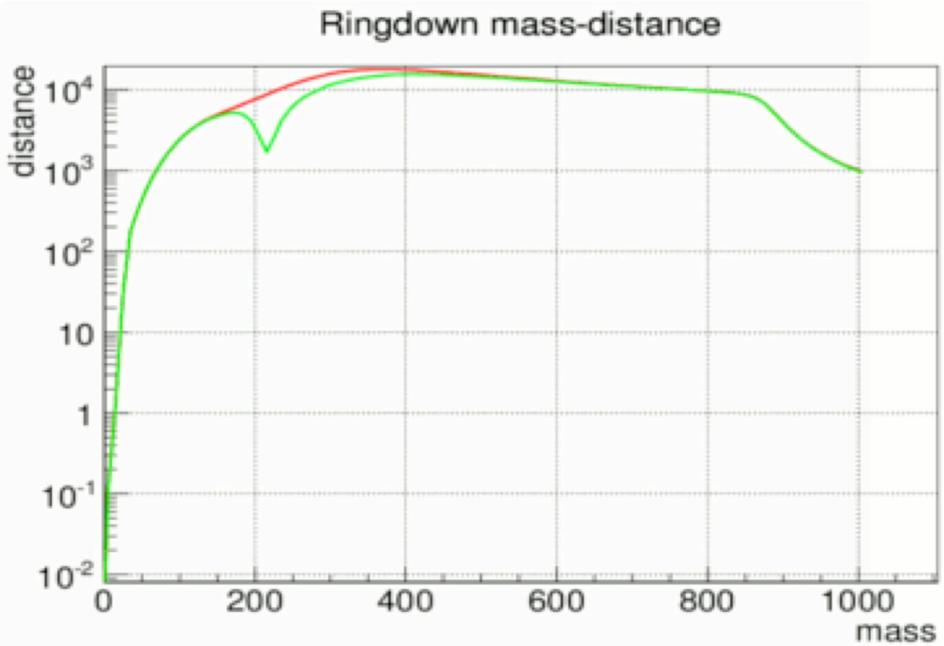

Ringdown mass-distance
distance
1
0.9
0.8
0.7
0.6
0.5
0.4
0
200
400
600
800
1000
mass

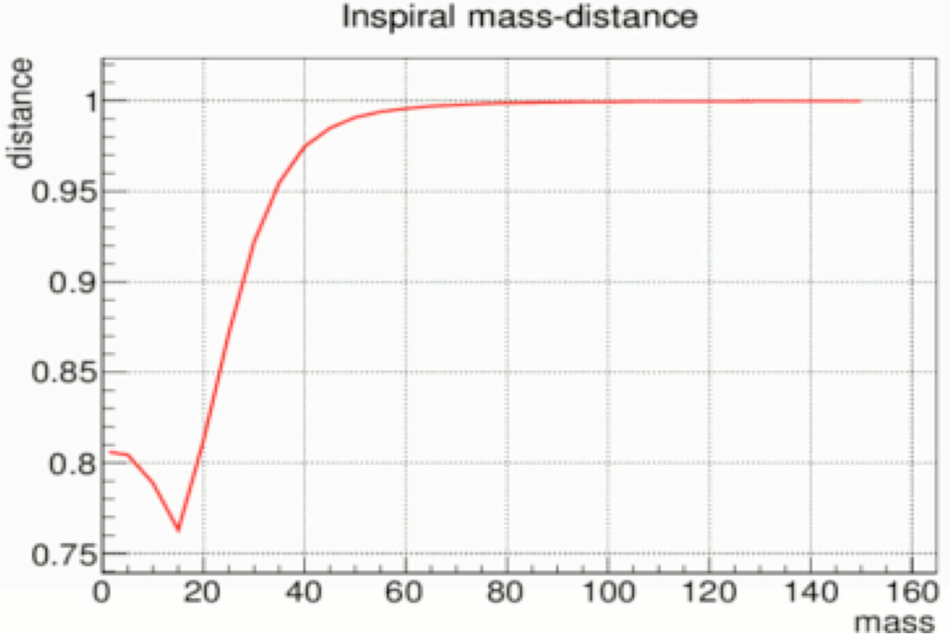
400mm

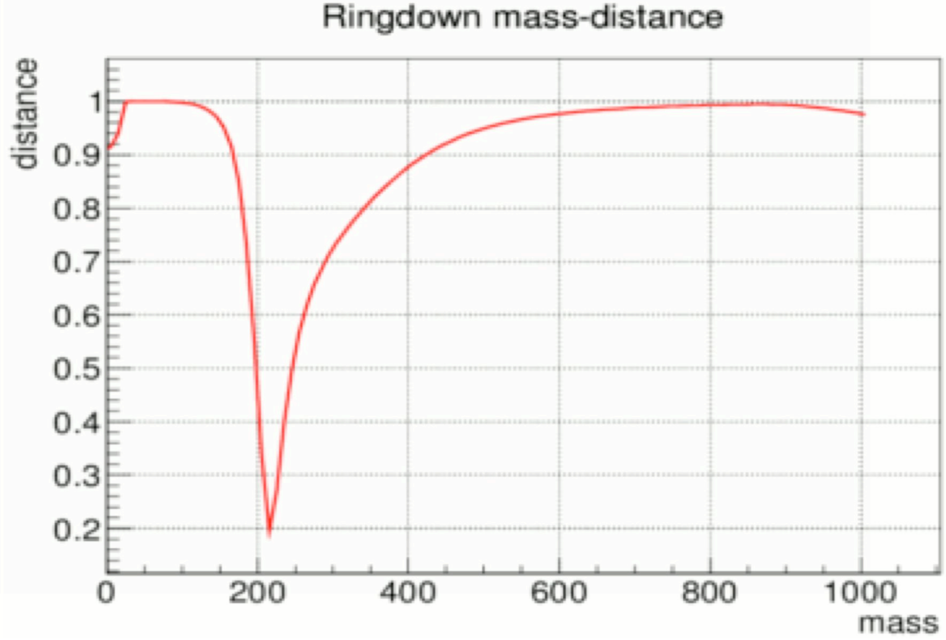

Inspiral mass-distance
distance
10^3
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
mass
Inspiral mass-distance
distance
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
200
400
600
800
1000
mass

450mm

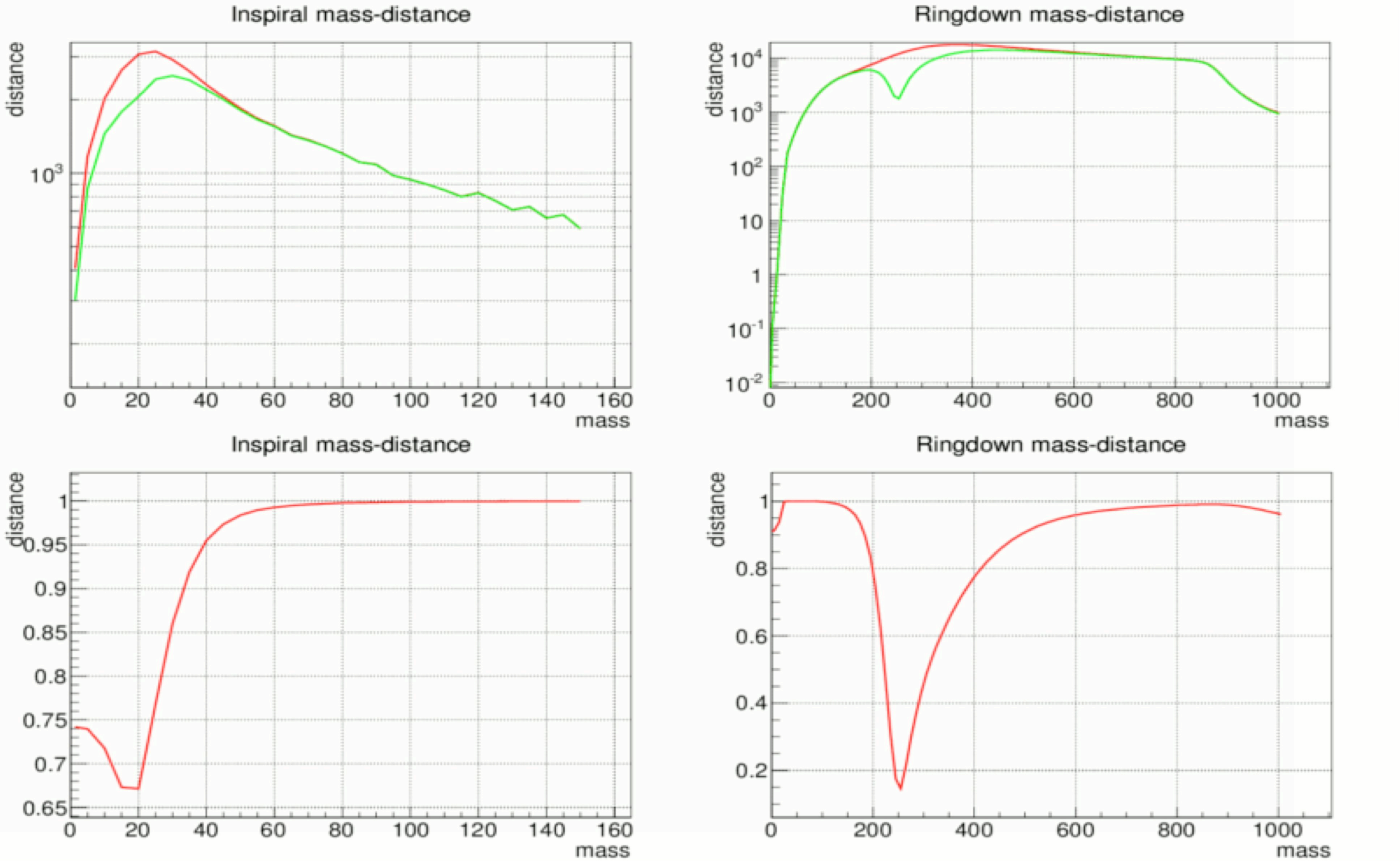

Inspiral mass-distance
distance
10^3
0
20
40
60
80
100
120
140
160
mass


Ringdown mass-distance
distance
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
200
400
600
800
1000
mass


Inspiral mass-distance
distance
1
0.95
0.9
0.85
0.8
0.75
0
20
40
60
80
100
120
140
160
mass


Ringdown mass-distance
distance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
200
400
600
800
1000
mass

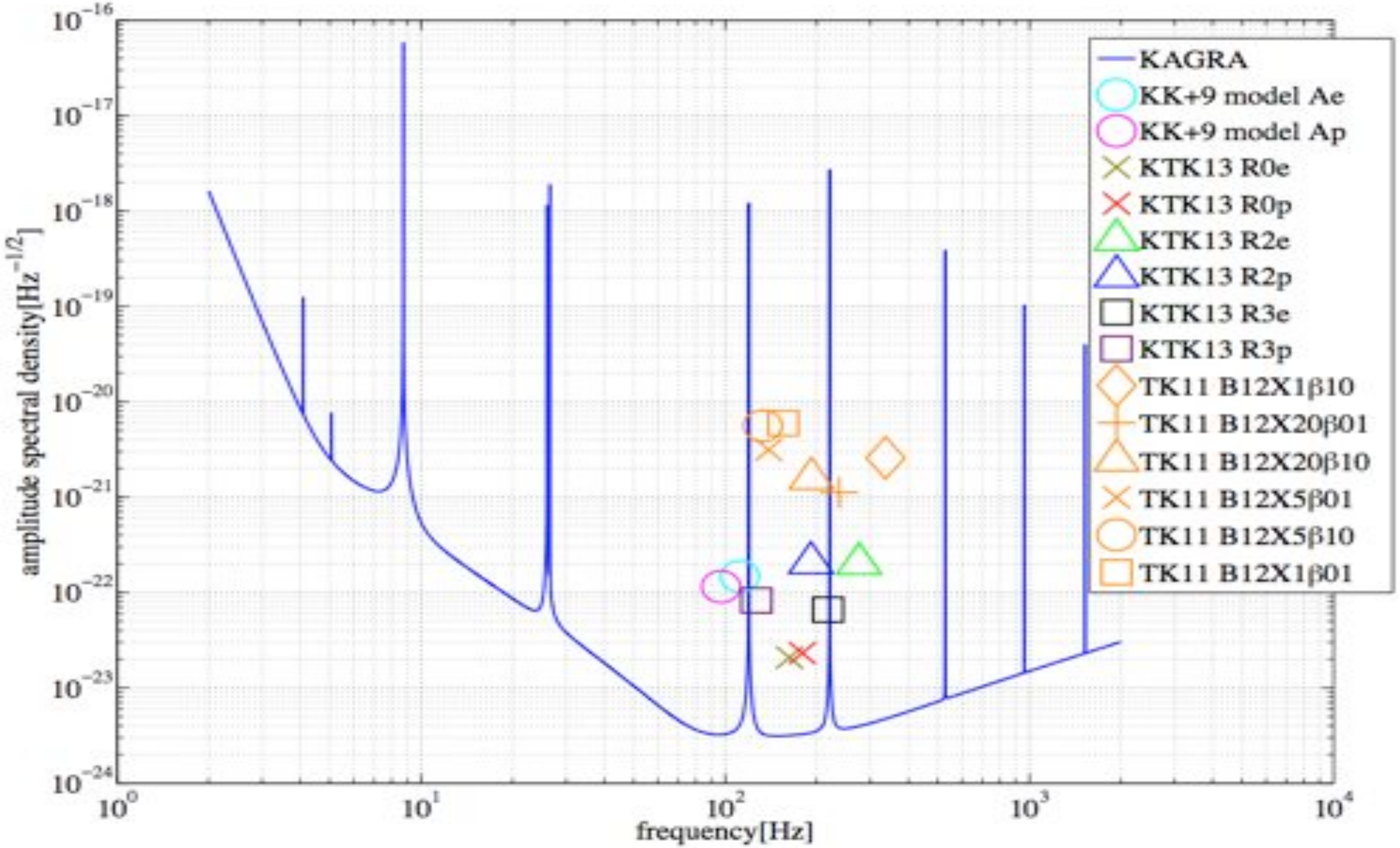
500mm


Inspiral mass-distance
distance
10^3
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
10^4
10^3
10^2
10
1
10^-1
10^-2
0
200
400
600
800
1000
mass
Inspiral mass-distance
distance
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0
20
40
60
80
100
120
140
160
mass
Ringdown mass-distance
distance
1
0.8
0.6
0.4
0.2
0
200
400
600
800
1000
mass

バースト重力波について

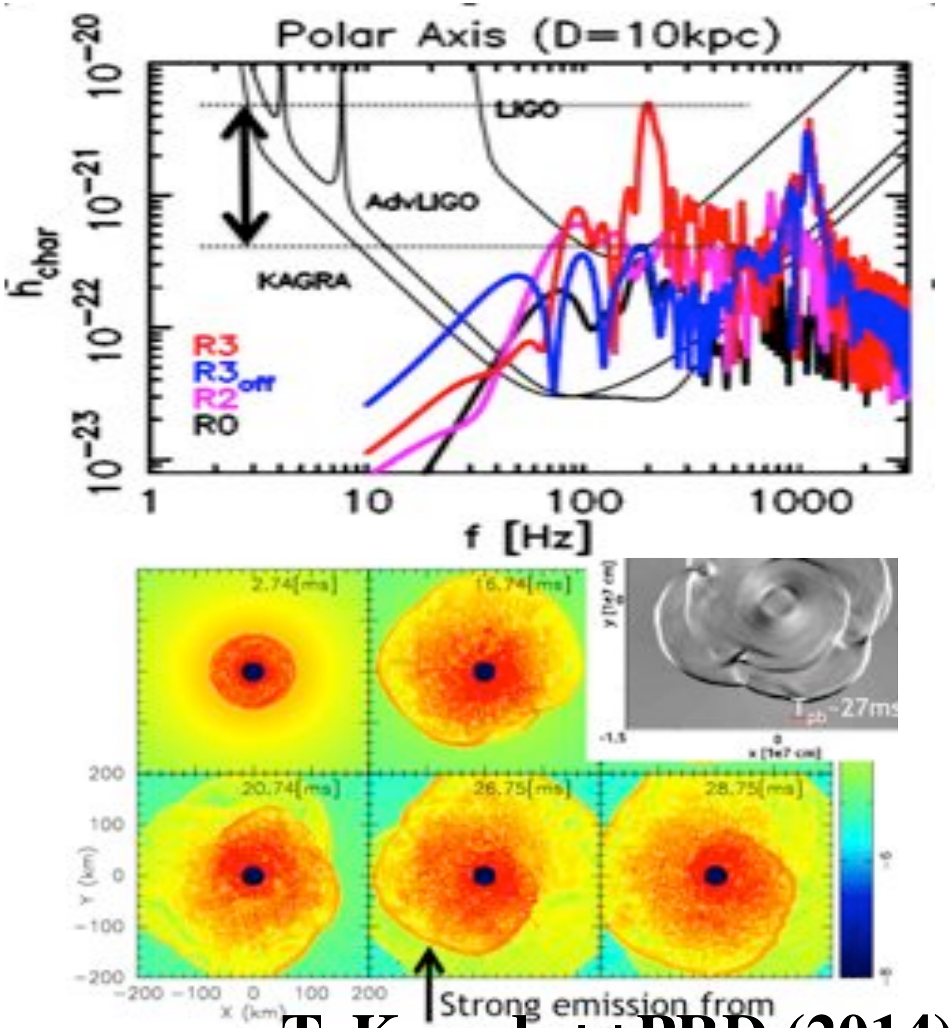
- バースト性重力波は広範囲の周波数に広がるため、結局全周波数帯で感度が良いことが望まれる。そのため、検出という視点から見ると、ある特定の周波数というよりも、裾、分裂したバイオリンモードがなるべく観測周波数に無いがよいので汚れる領域が一番小さくなる高周波の方が良いことになる。
- KAGRAの場合、特に100-200Hzの感度が良くなるため、超新星爆発からの重力波シミュレーションを見てみると、検出特徴周波数は100-200Hzになる。
-

超新星爆発からの重力波

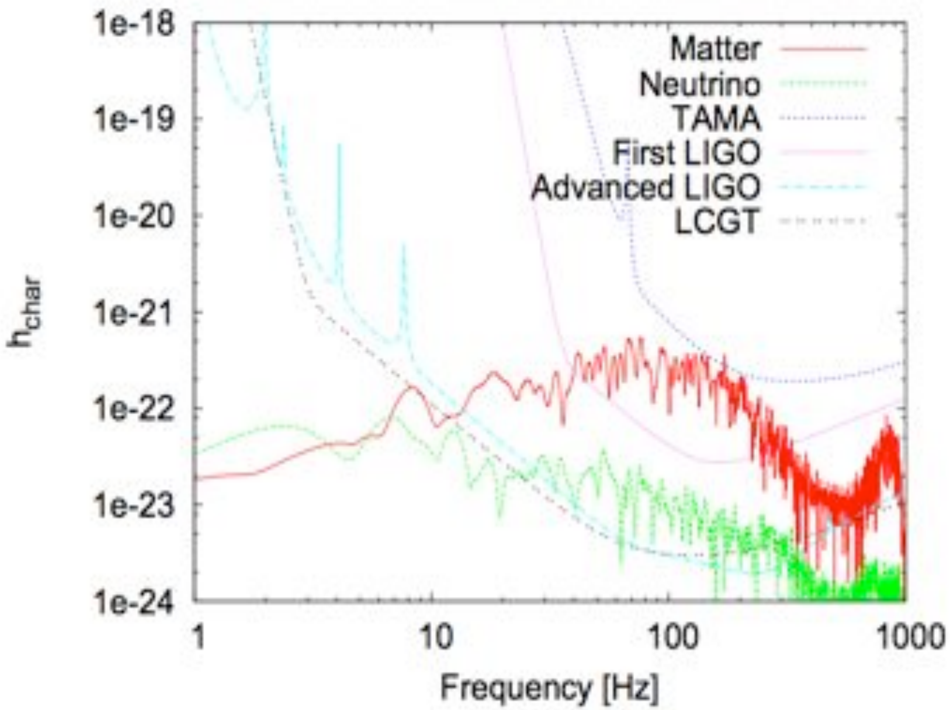


超新星爆発からの重力波

- 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。

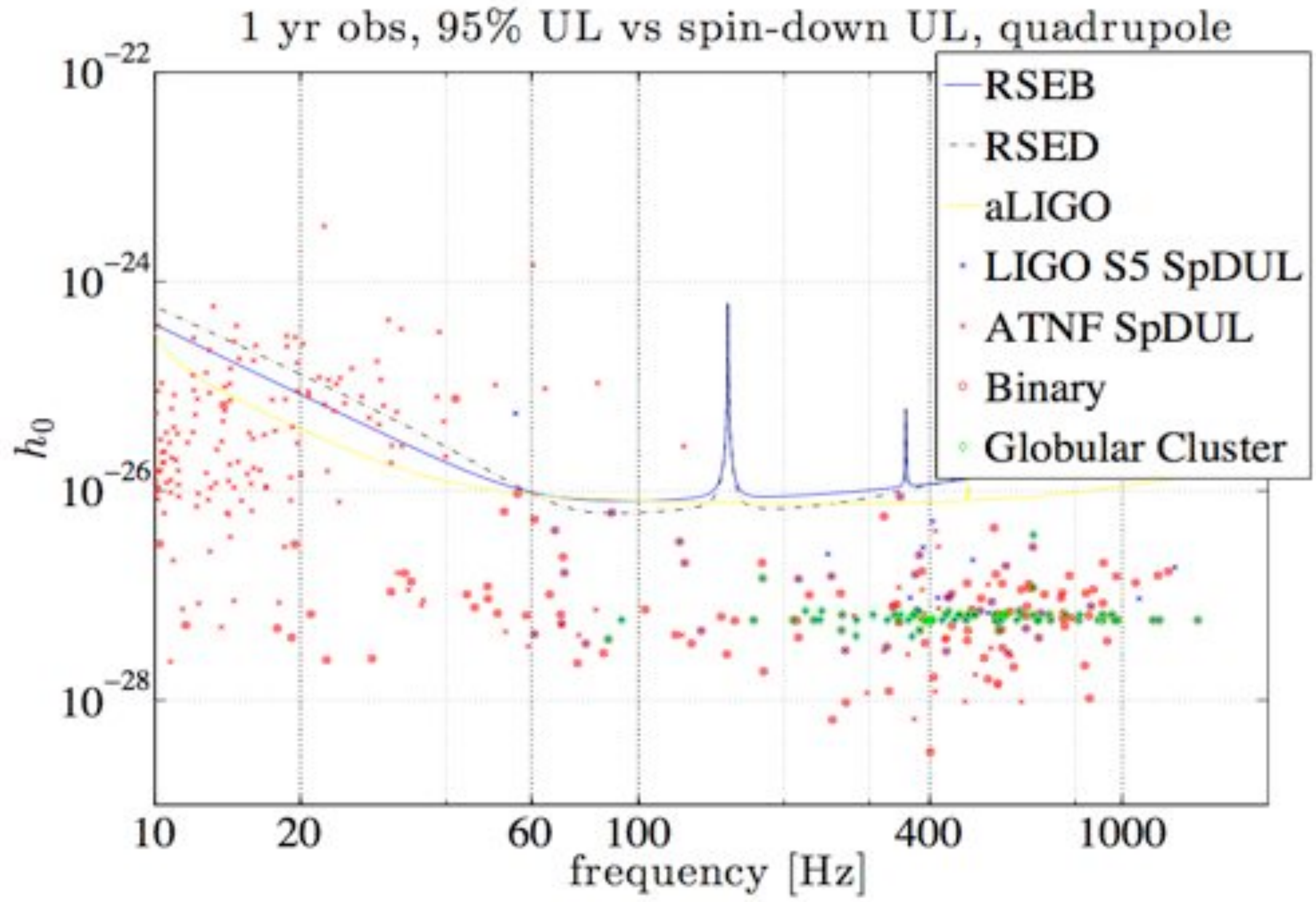


T. Kuroda++PRD (2014)



Kotake+ApJ (2009)

パルサーについて


1 yr obs, 95% UL vs spin-down UL, quadrupole
10^{-22}
10^{-24}
10^{-26}
10^{-28}
h_0
10
20
60
100
400
1000
frequency [Hz]
RSEB
RSED
aLIGO
LIGO S5 SpDUL
ATNF SpDUL
Binary
Globular Cluster

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）

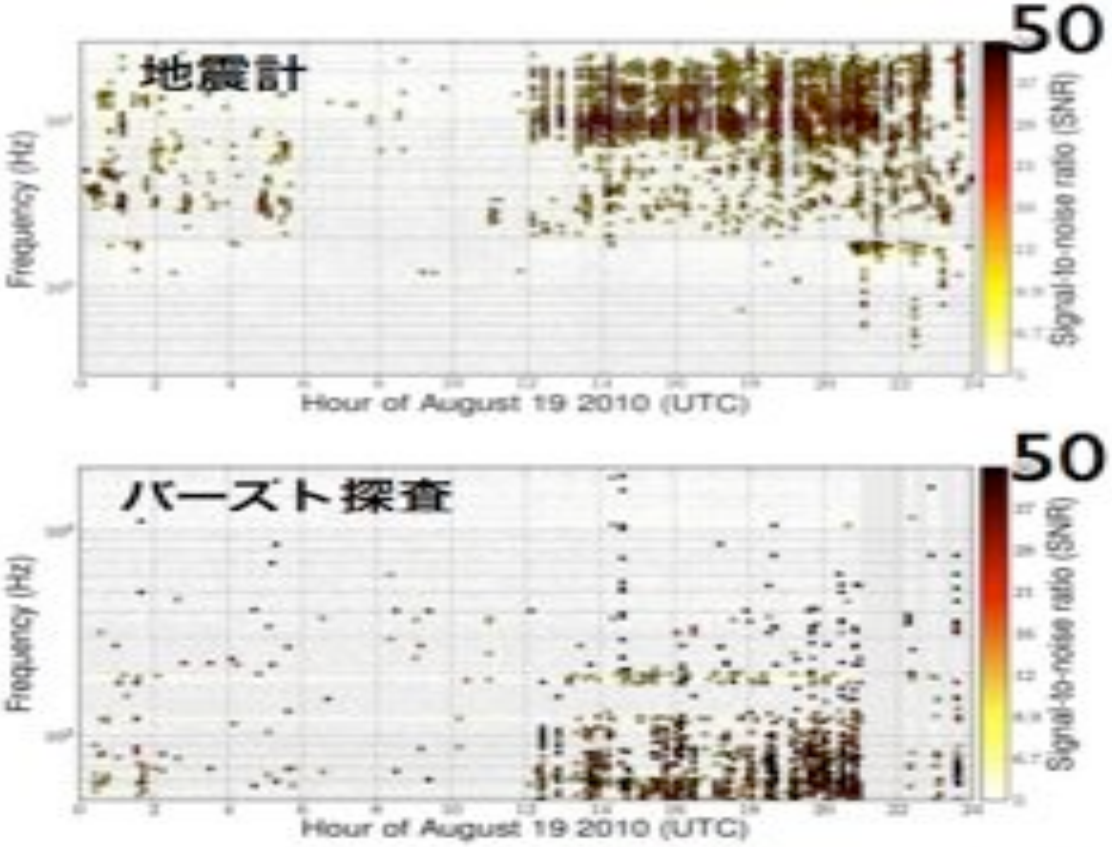
一般論としては、スイートスポットの100Hz-200Hzにバイオリンを置くのは非常によくないと思いますが、
置かざるを得ないなら、パワーラインの120Hz（のちょっと下で110Hz-120Hzあたり）や180Hzと重ねてしまって使えなくなるバンドを少なくするとかできないでしょうか？？？（伊藤）

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

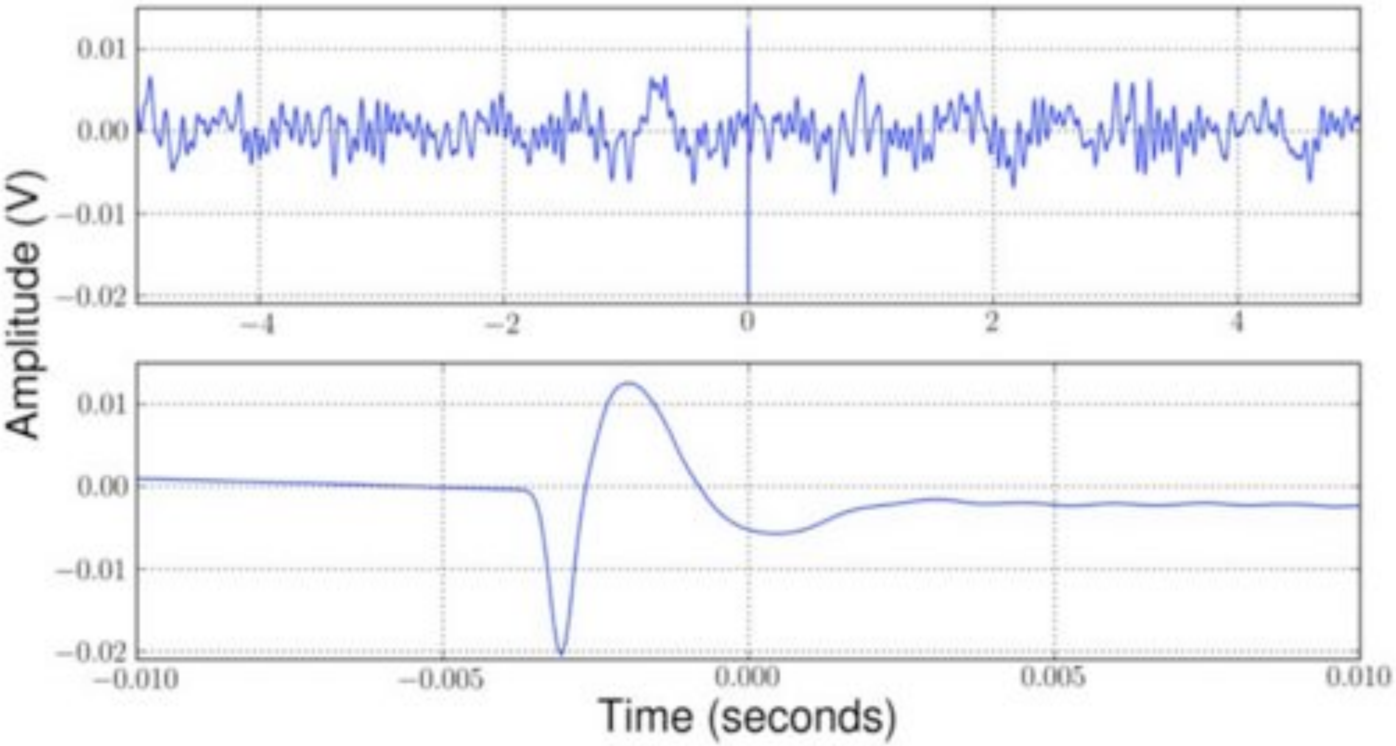
- **SNR~50のイベントが1日のうちに多数出現**



LIGO-P1000142

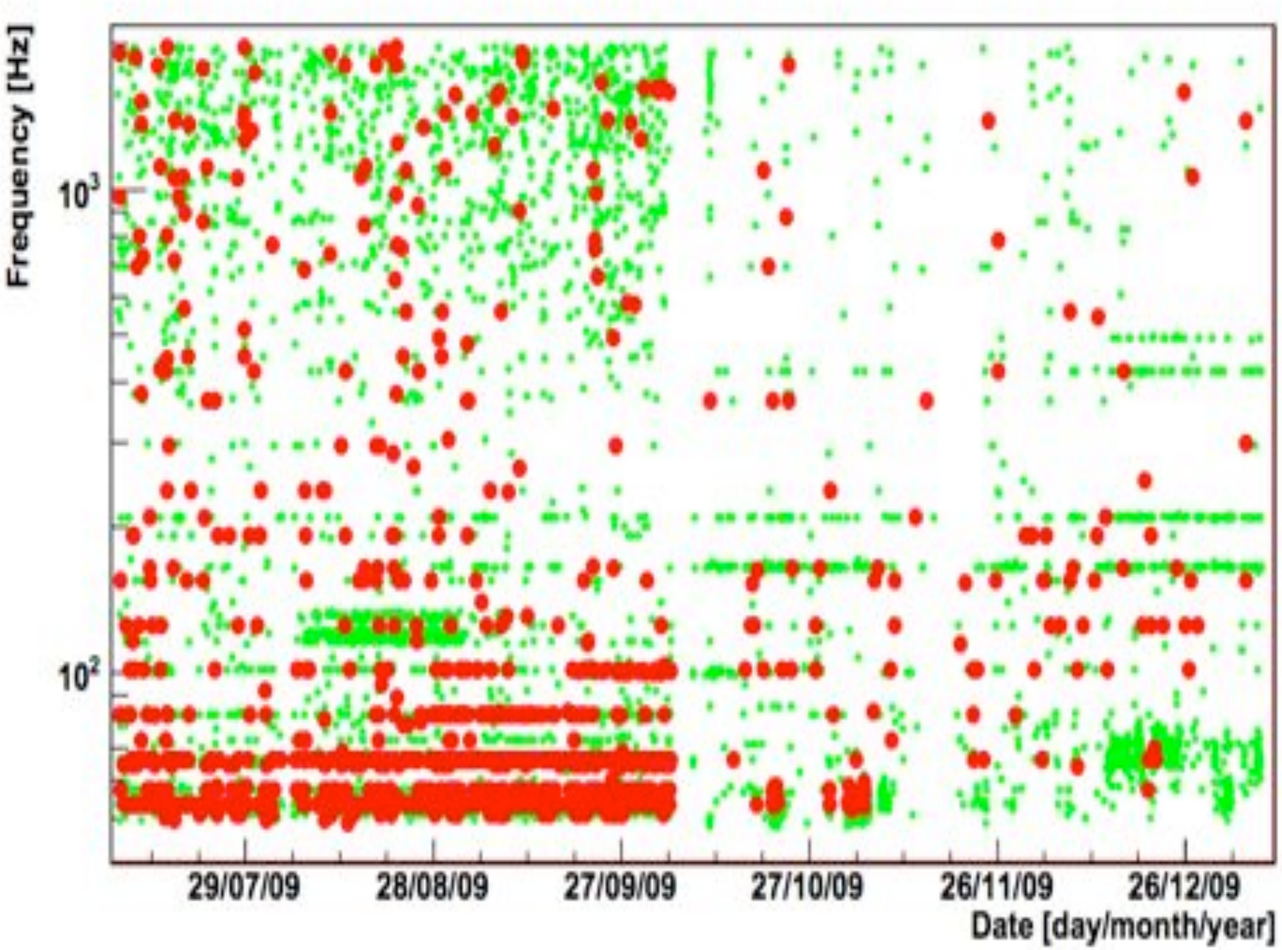
S6 unknown spike glitch

- バースト探査でSNR ~ 200-20000



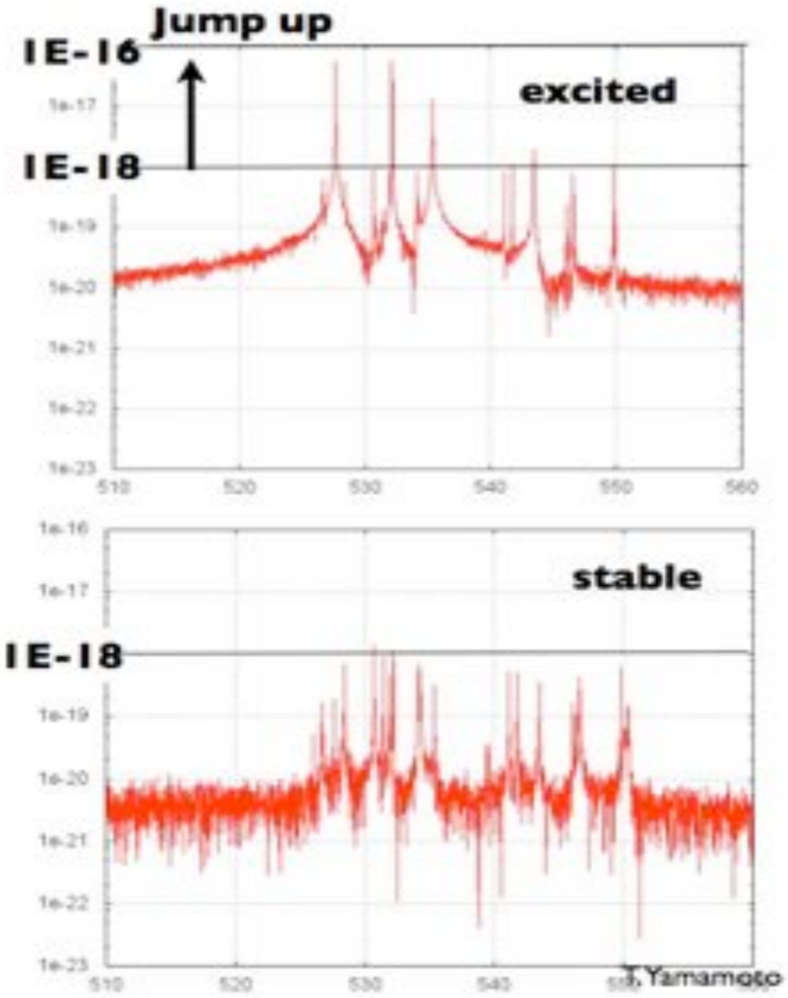
LIGO-P1000142

Virgoでのグリッチイベント

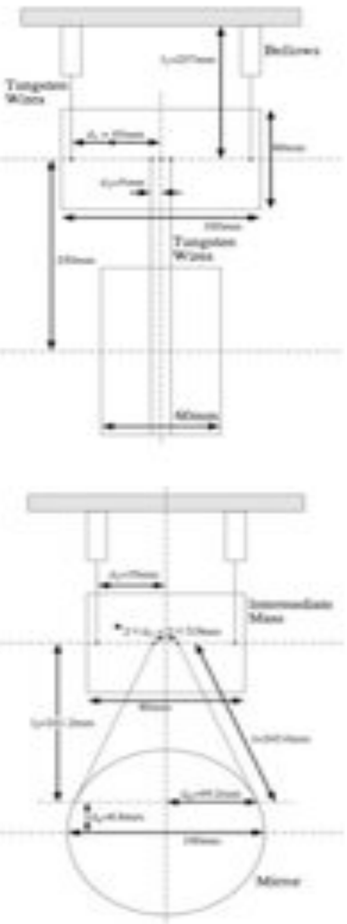


SNR>5のイベント
が毎秒1.8個

TAMAバイオリンモードの励起



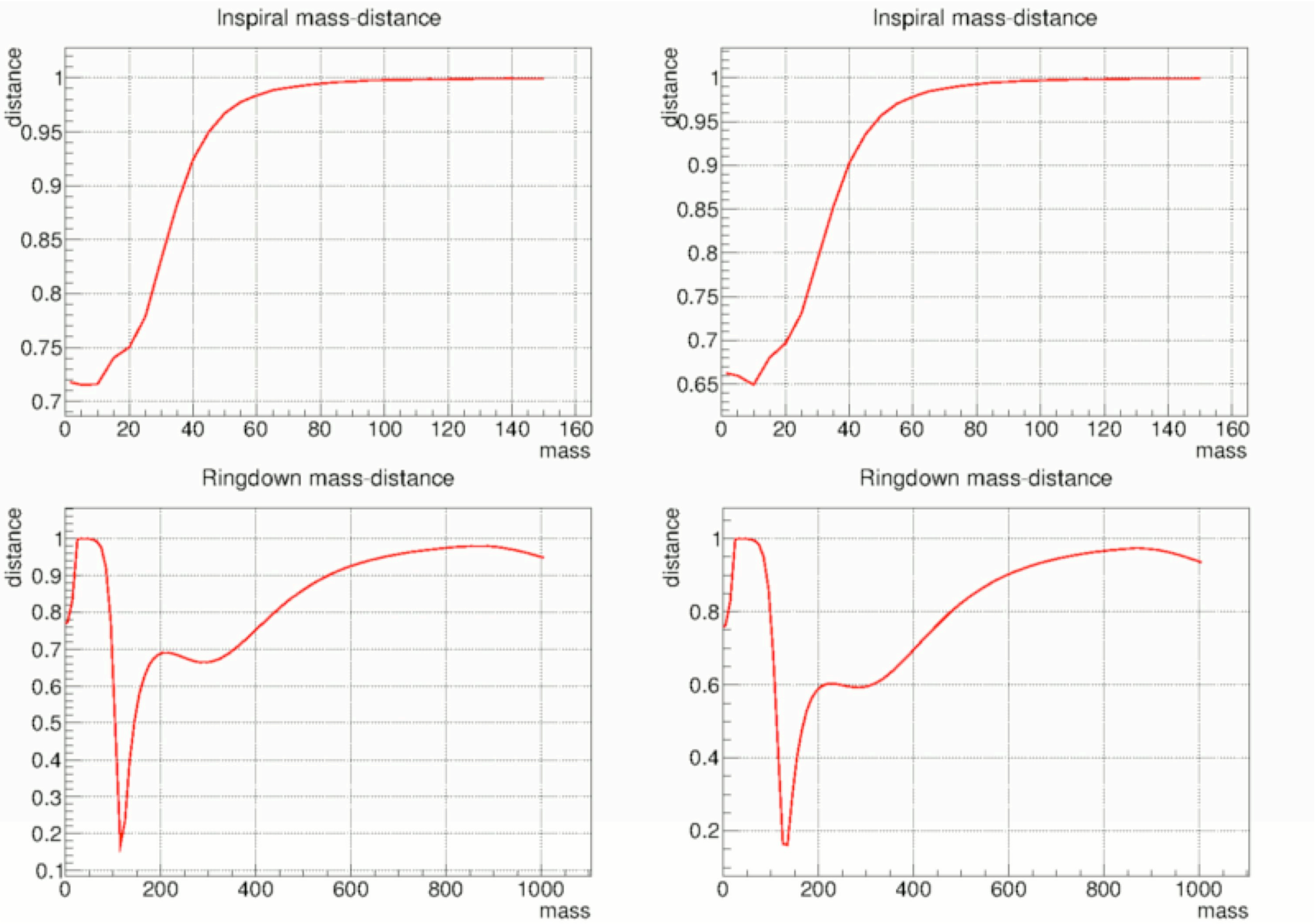
T.Yamamoto



K.Yamamoto M. thesis

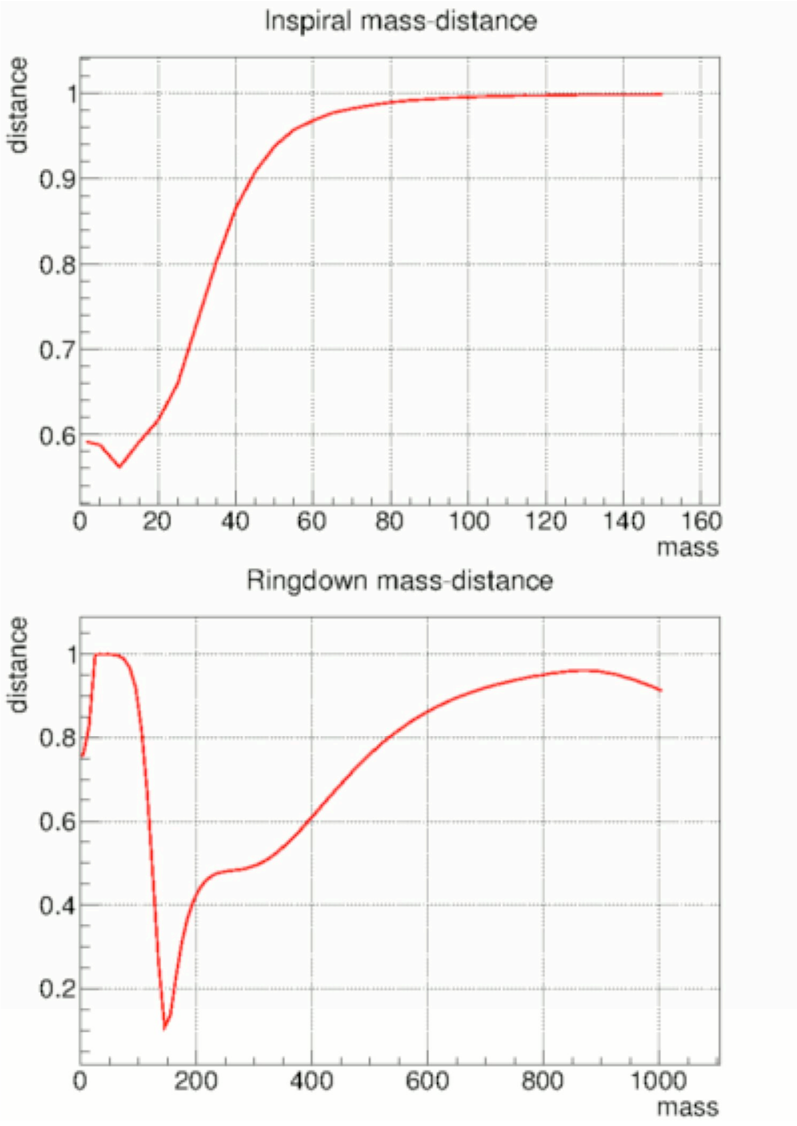
バイオリンモードが5倍励起された場合

300mm **320mm**

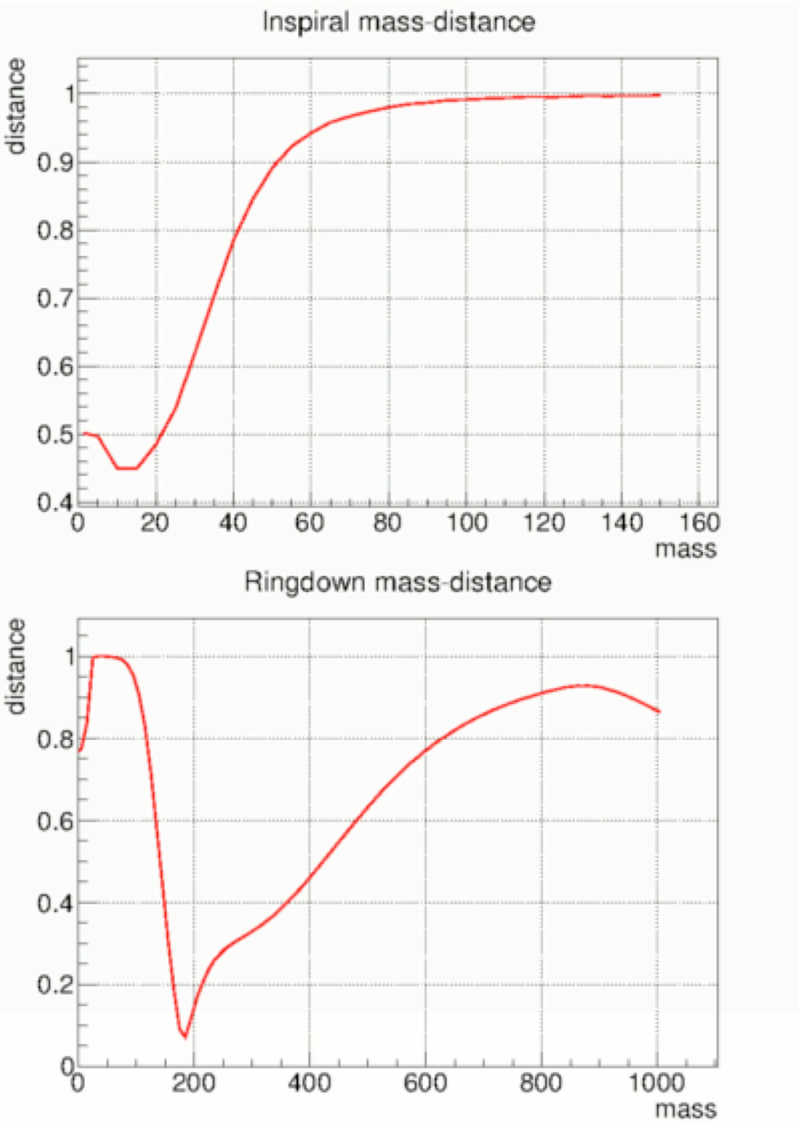


バイオリンモードが5倍励起された場合

350mm

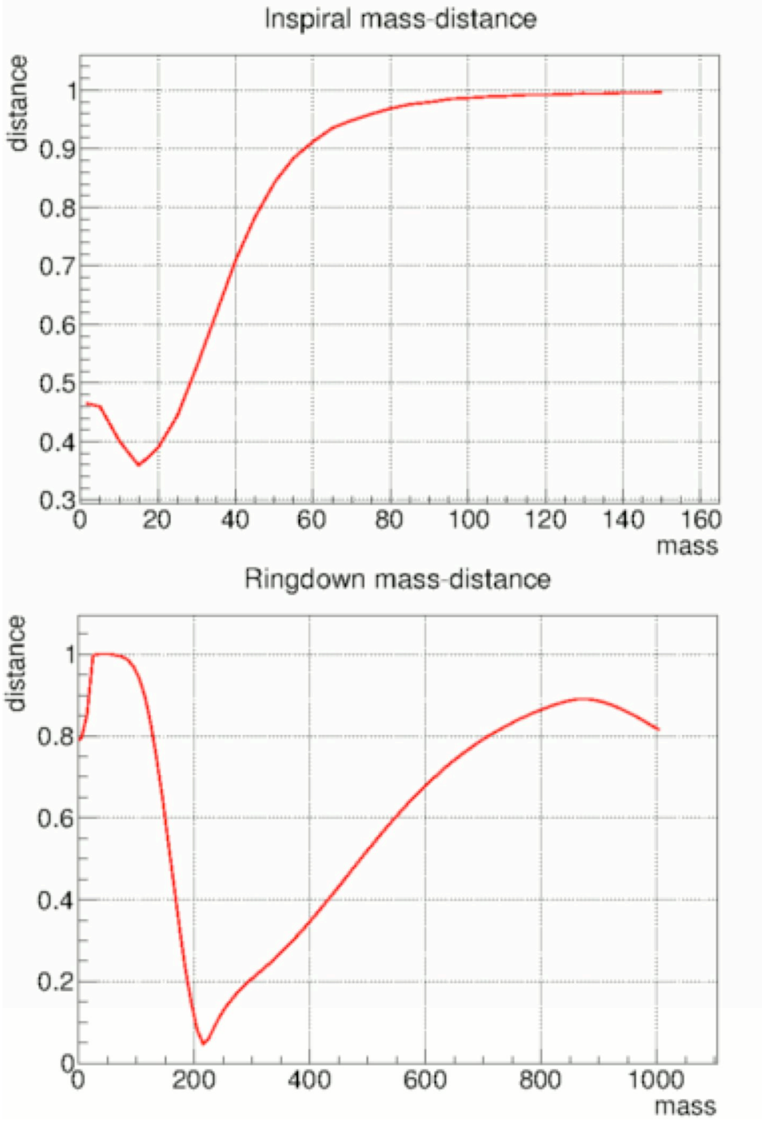


400mm

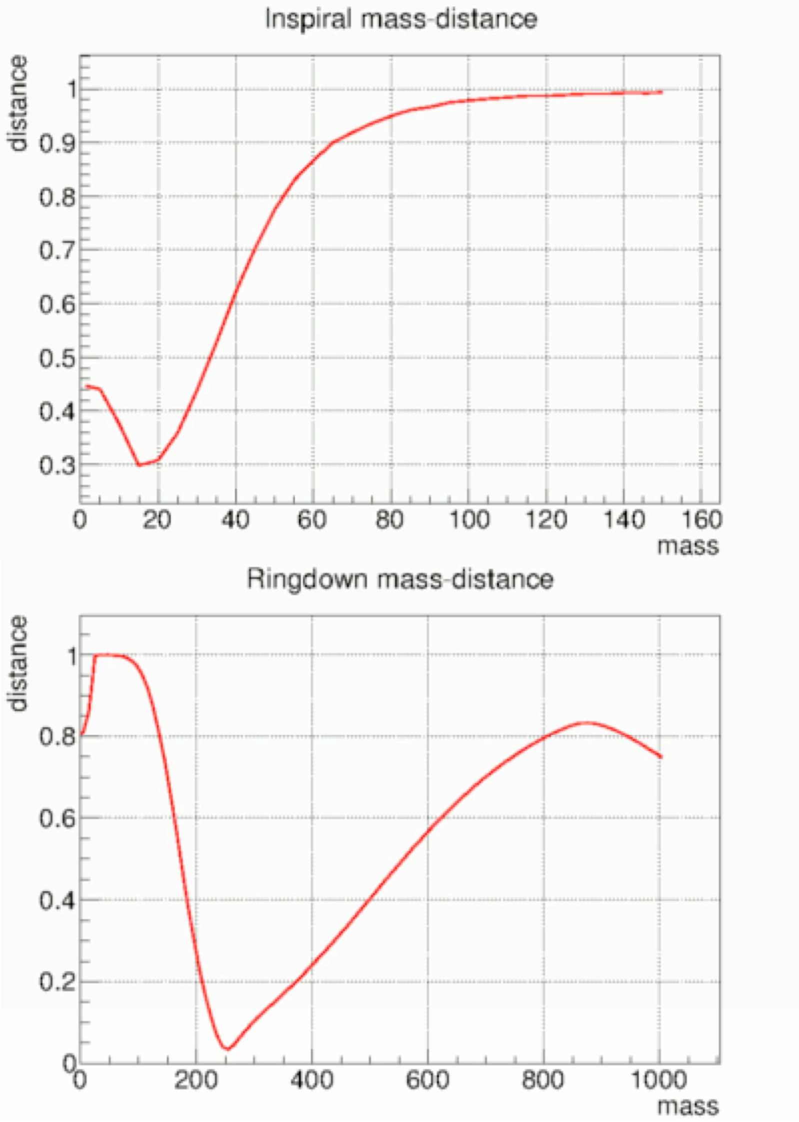


バイオリンモードが5倍励起された場合

450mm



500mm



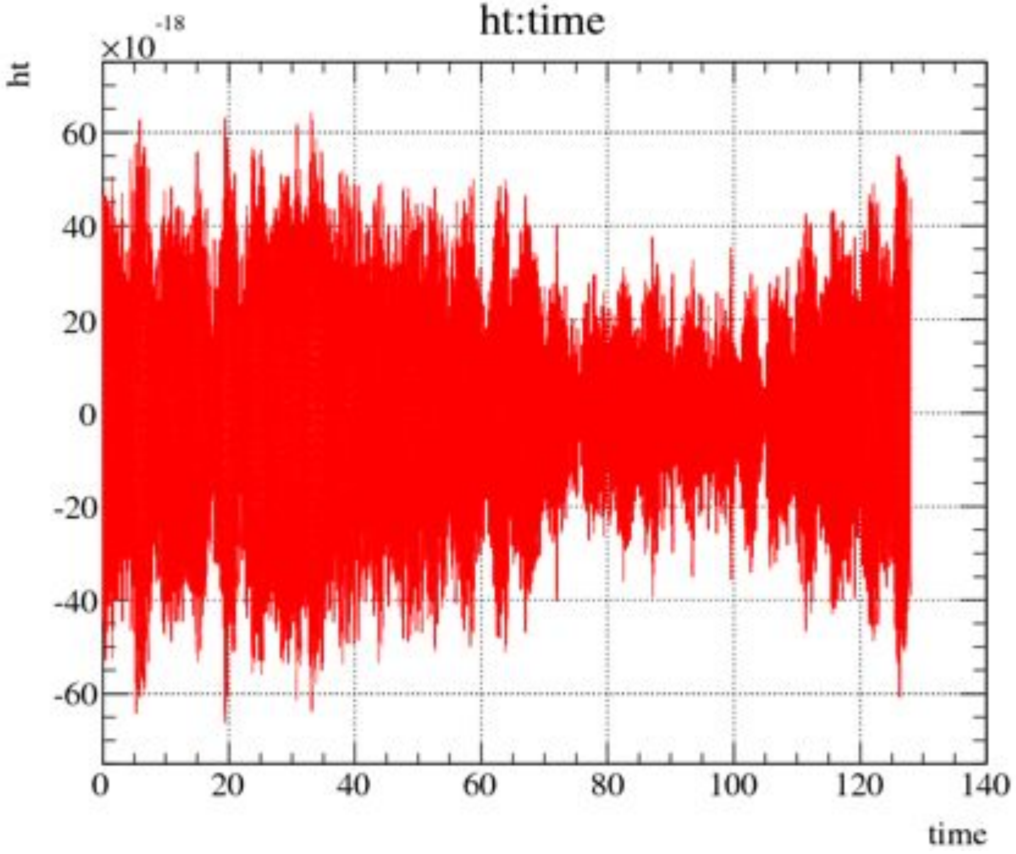
Line characterization

6 Oct. 2014

K. Ueno (Osaka Univ.)

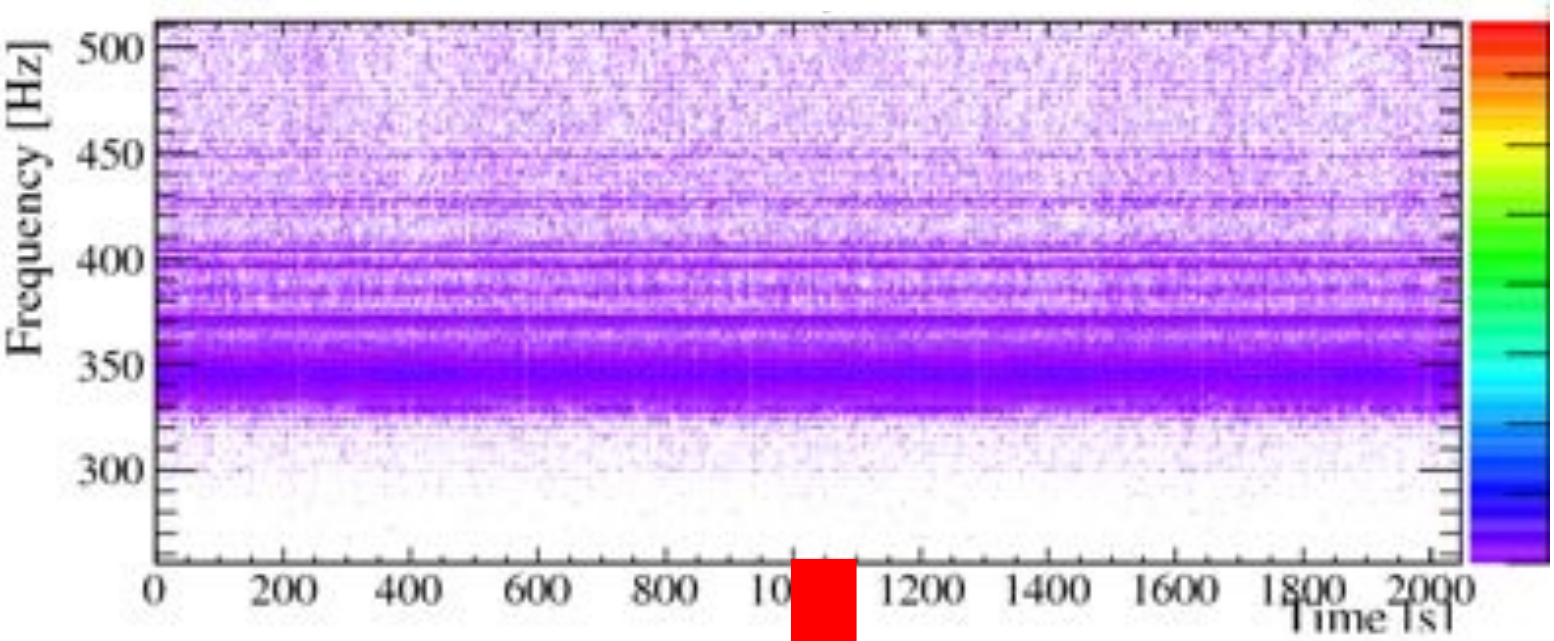
S6 data (example)

- I analyzed LIGO S6 data
  L-L1_LDAS_C02_L2-959200000-128.gwf

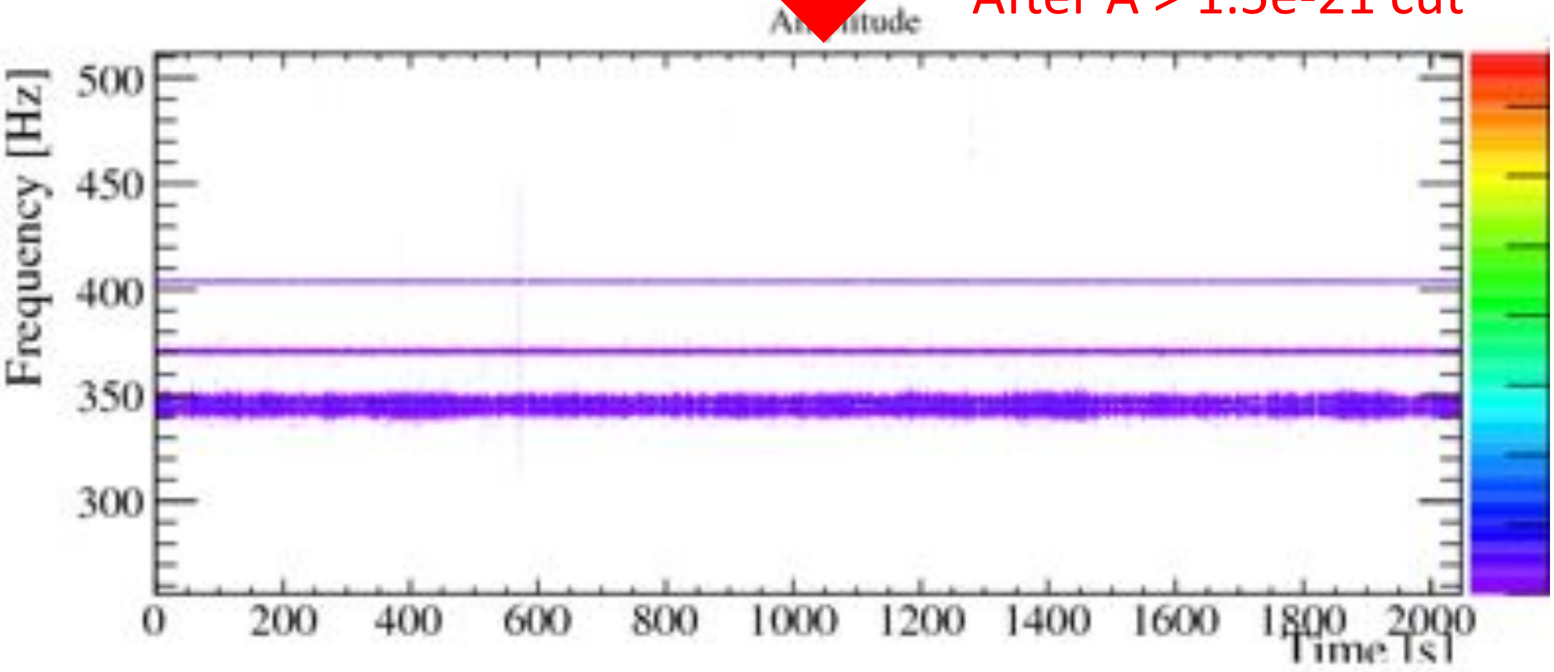


  - T = 128 s
  - fs = 16384 Hz

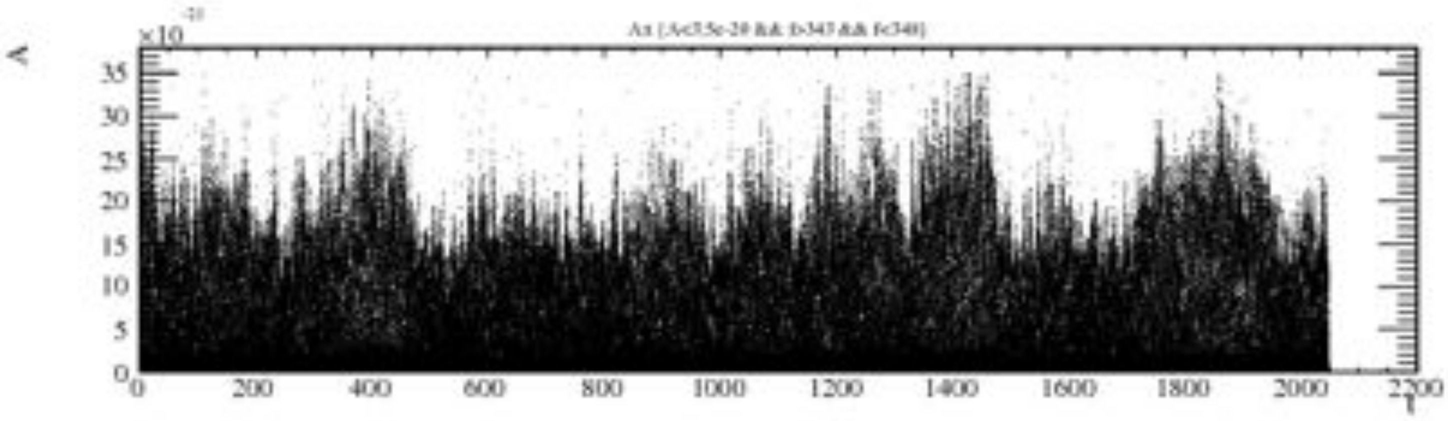
fs=1024Hz; frame=256; shift=16; #spectrum=20



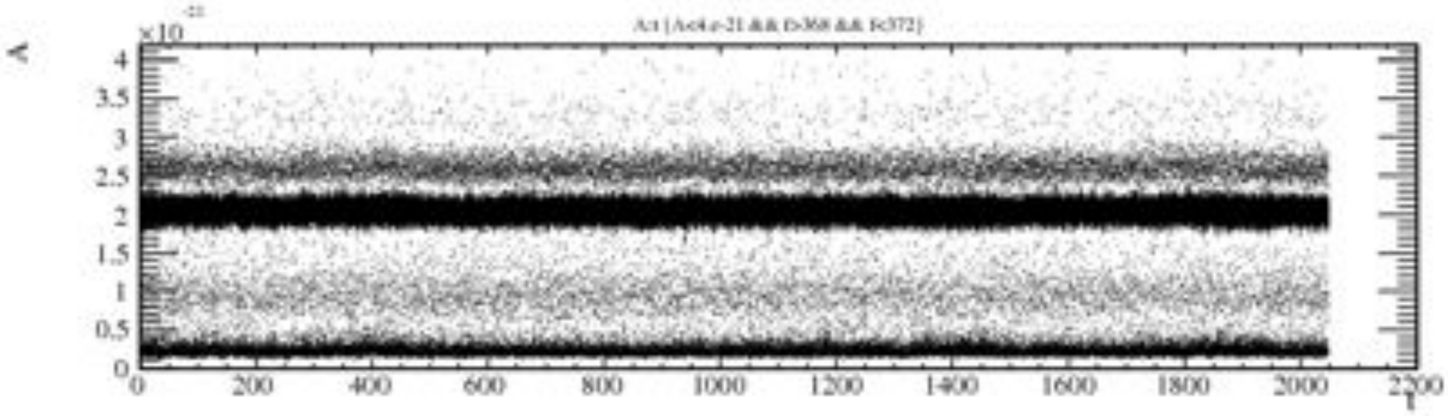
After A > 1.5e-21 cut



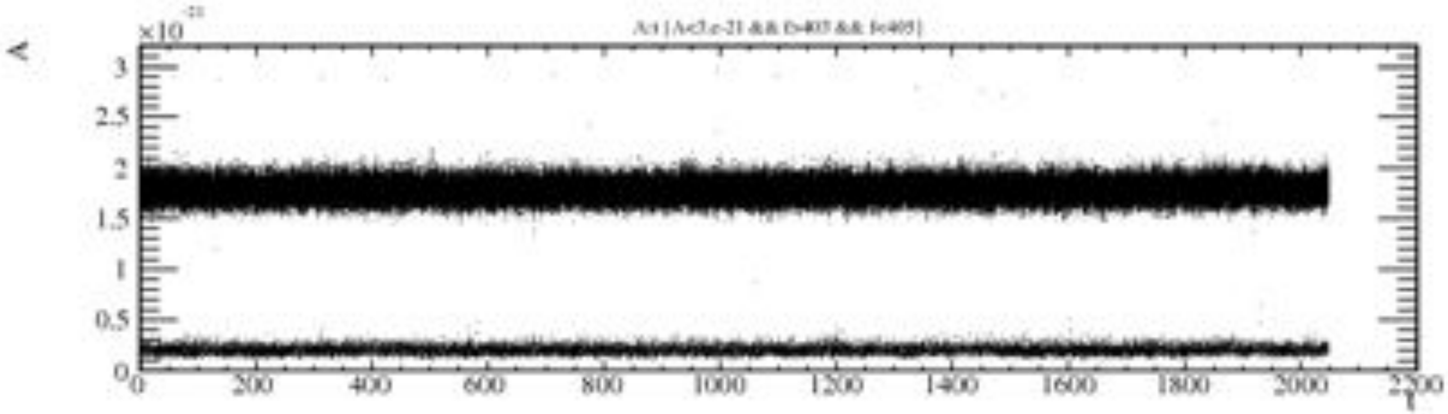
Time variation of amplitudes



~ 345 Hz

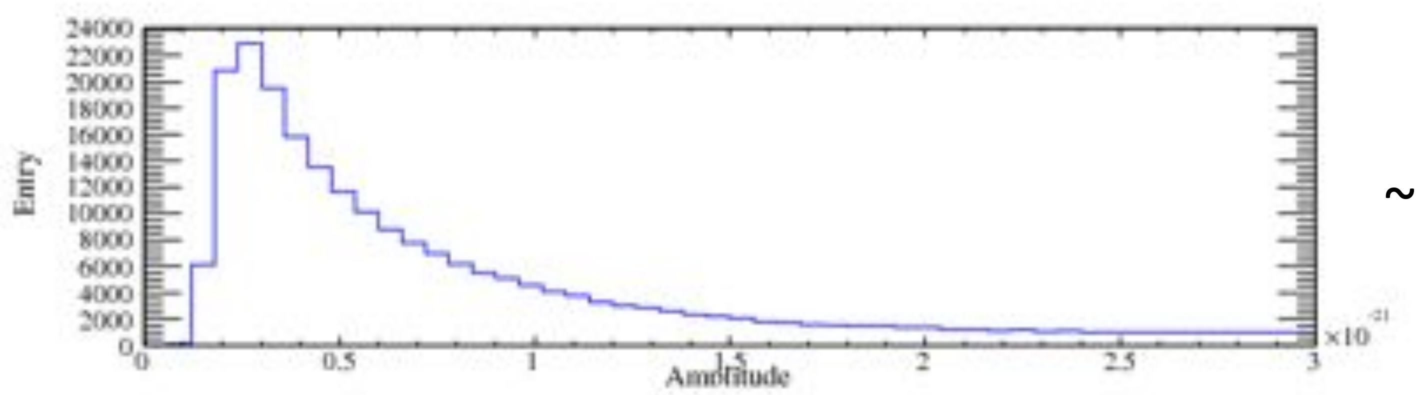


~370 Hz

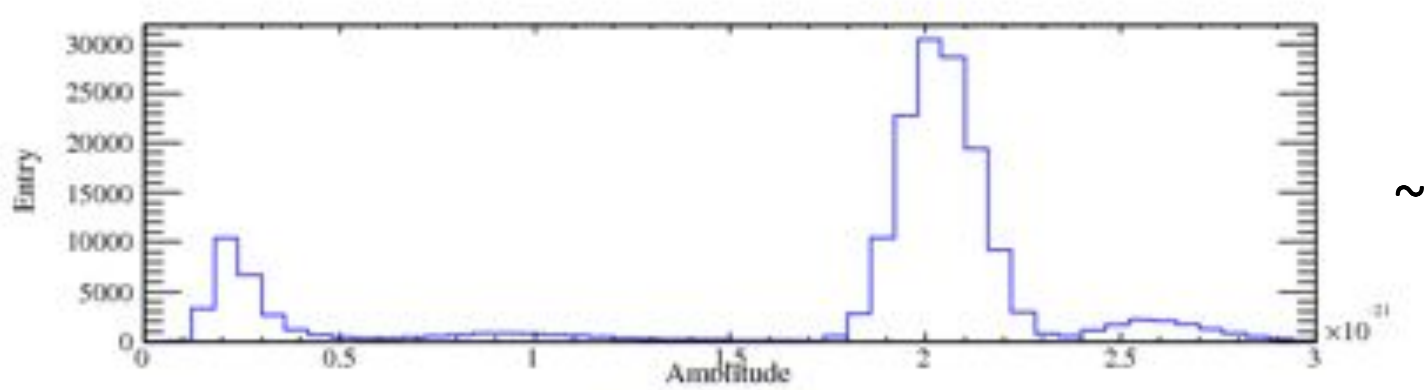


~403 Hz

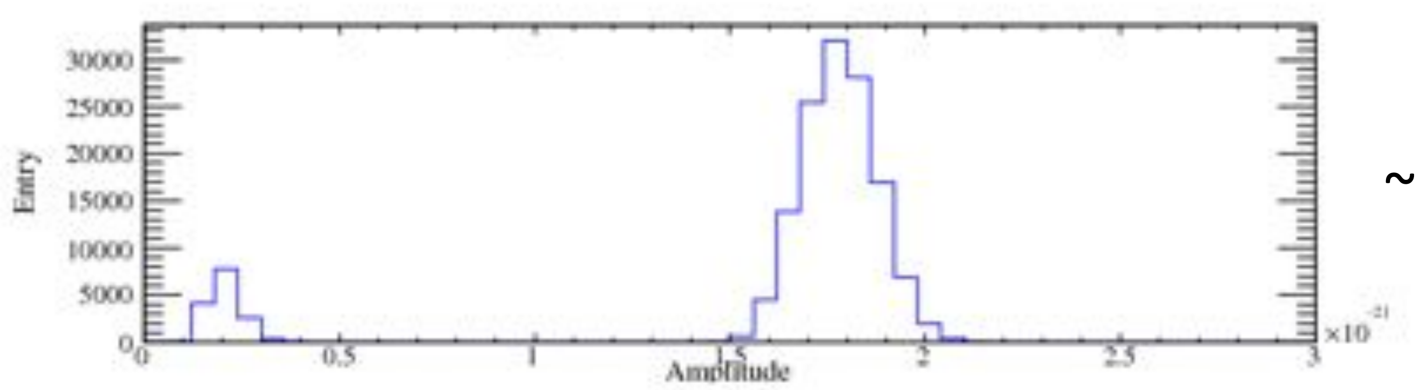
Amplitude distribution



~ 345 Hz

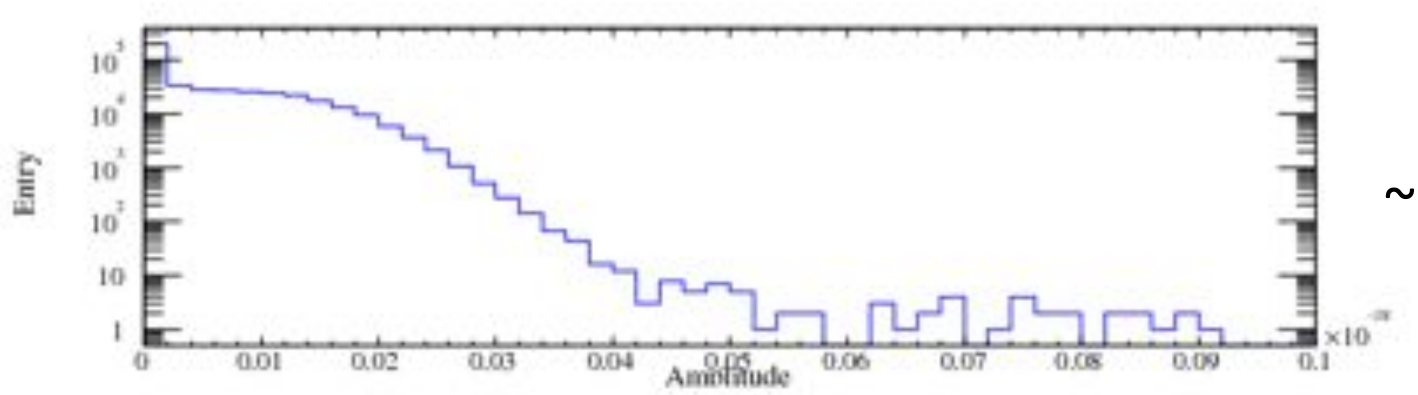


~370 Hz

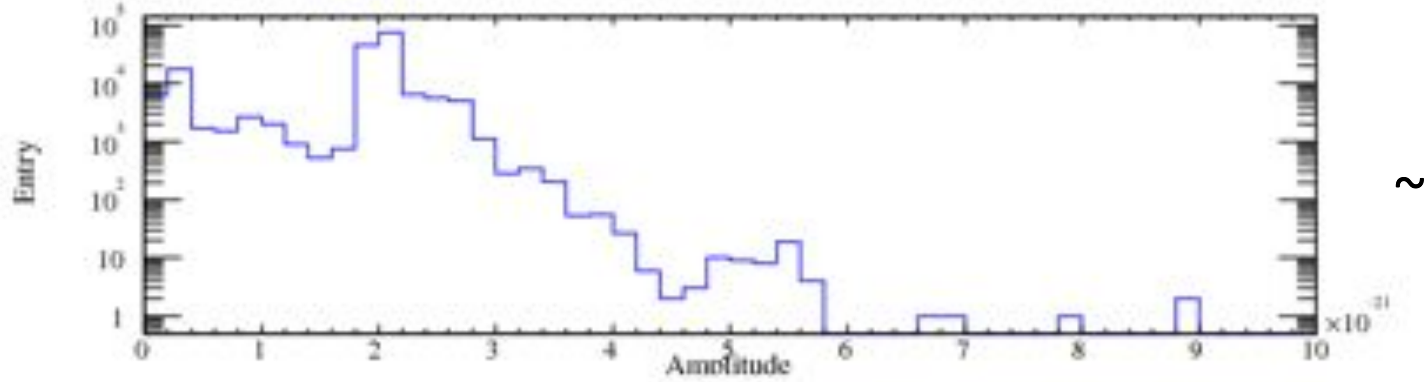


~403 Hz

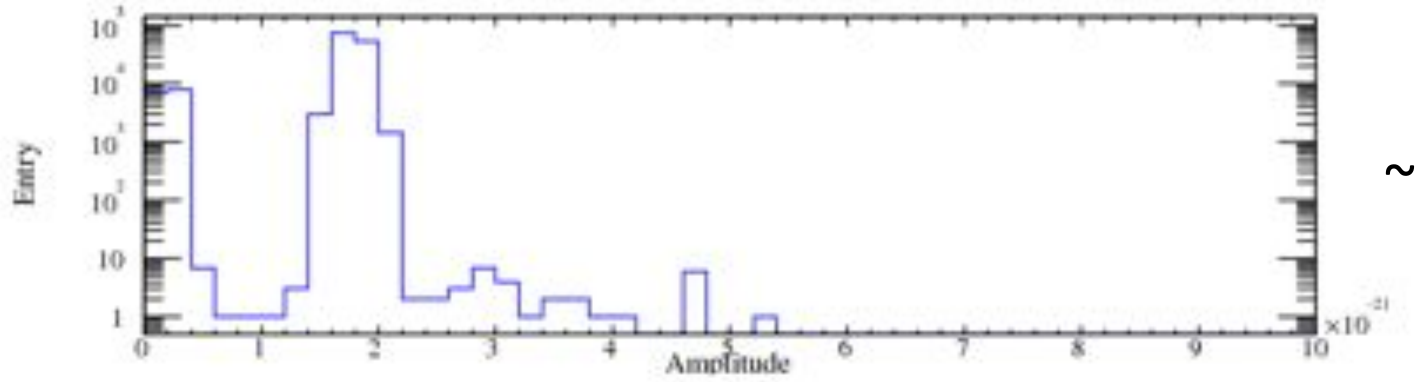
Amplitude distribution (logy)



~ 345 Hz



~370 Hz



~403 Hz

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,

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

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 〜 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.

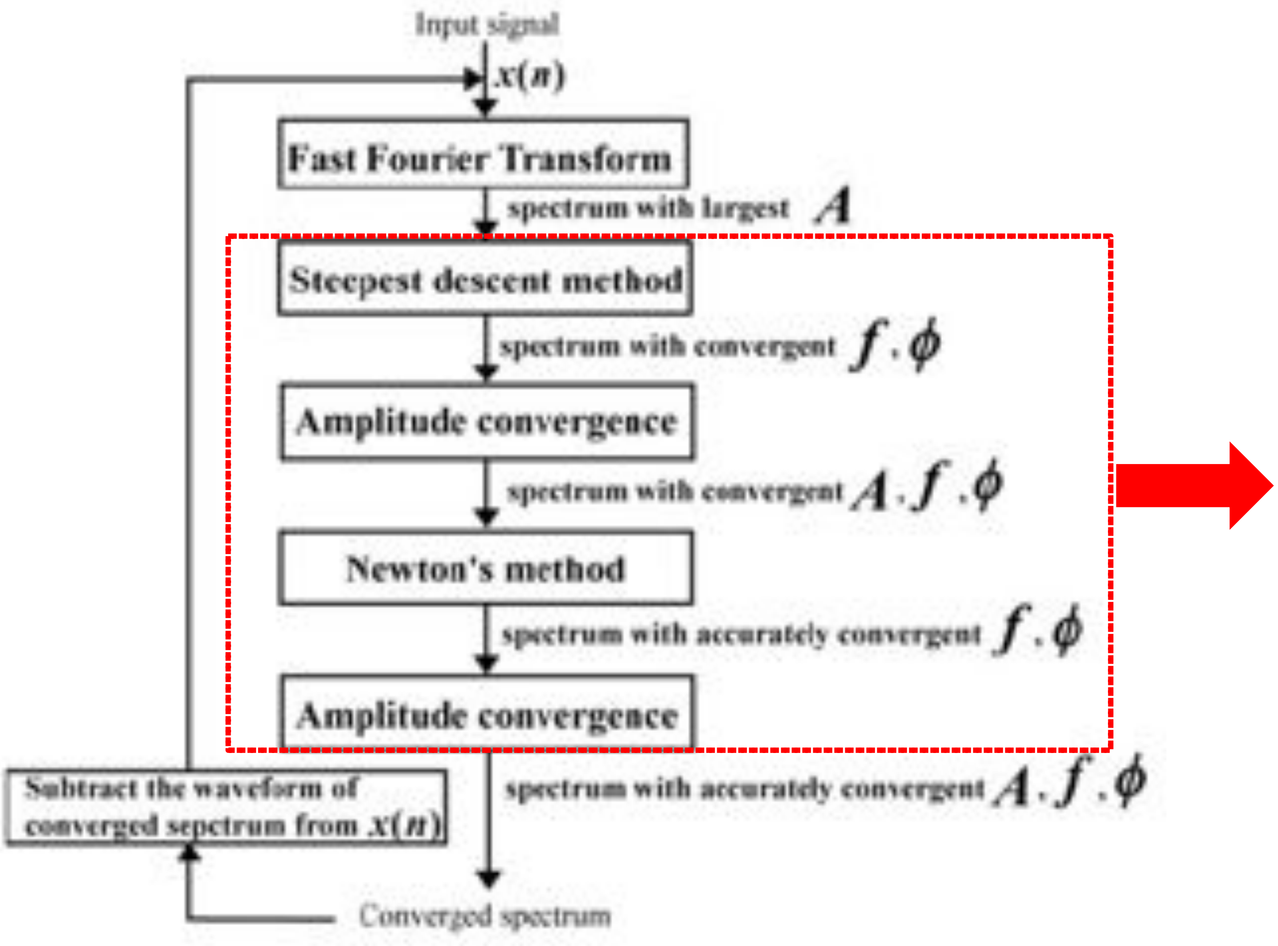
- So I tried to implement this method from the scratch. But when I followed the paper faithfully, the solutions were found not to be stable and soon diverge.

- 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

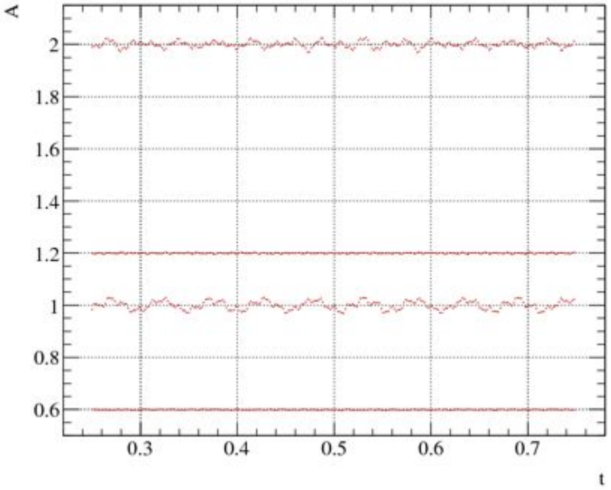
Test Example

- 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.

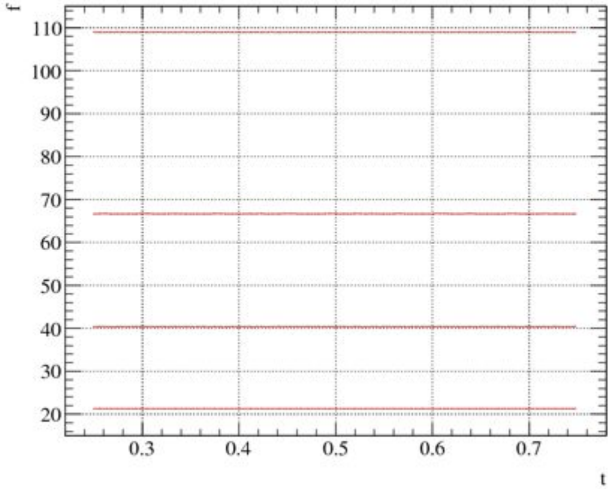
Amplitude	Frequency [Hz]	Initial phase [rad]
2.0	66.7	-0.15
1.2	109.0	0.46
1.0	40.4	2.40
0.6	21.3	0.10

Result (absolute)

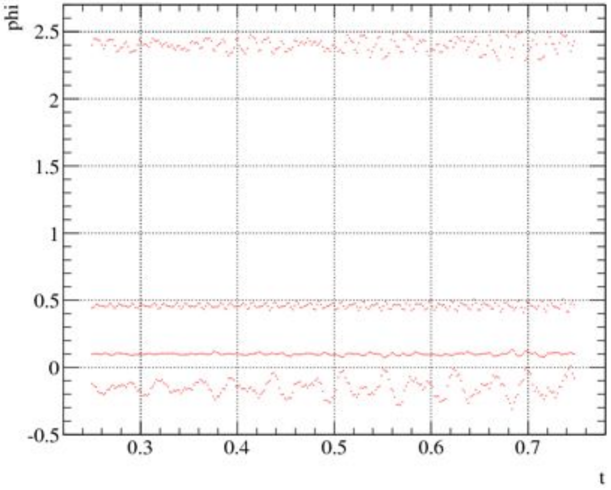
Amplitude



Frequency



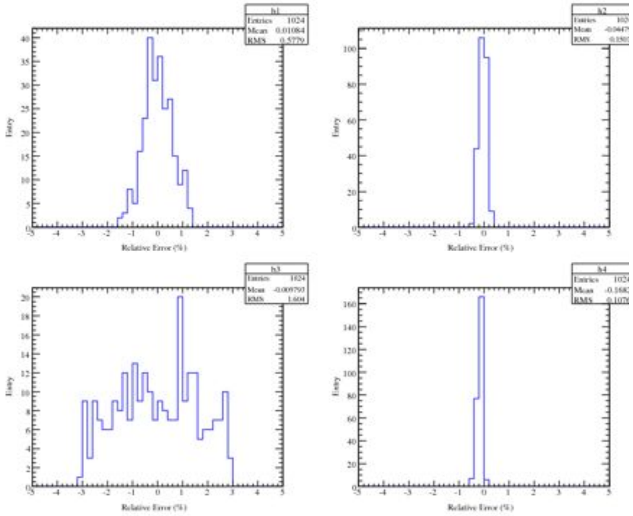
Initial phase



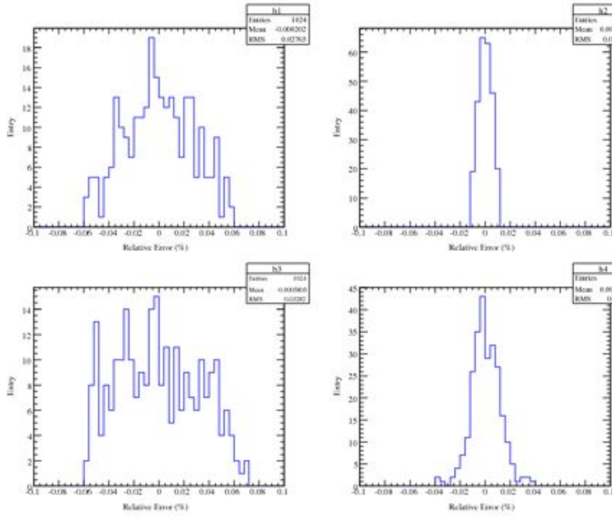
While frequencies were well reconstructed, some of the amplitudes were not, which are caused by signal-signal interference.
What is already clear: when there are multiple signals within the same duration, the minimum of the cost function does not always correspond to the true amplitude value, and the solution shift a little bit.

Result (resolution)

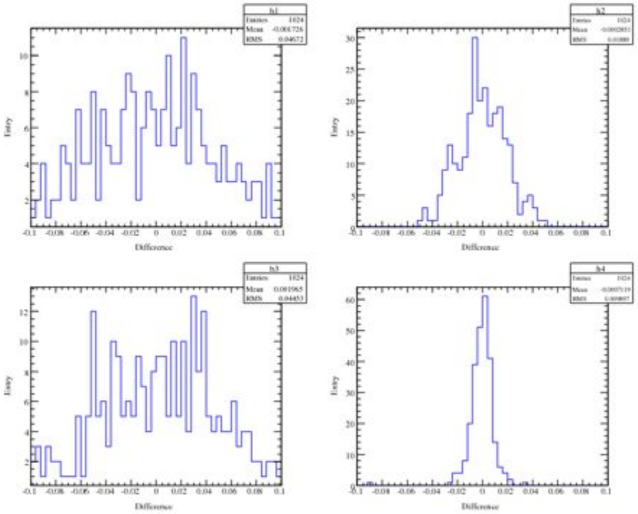
Amplitude



Frequency



Initial phase



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