Status of the Search for Black Hole Ringdowns in LIGO S4 Data

Lisa Goggin, Caltech

(for the LSC)

GWDAW 11

Potsdam, Germany

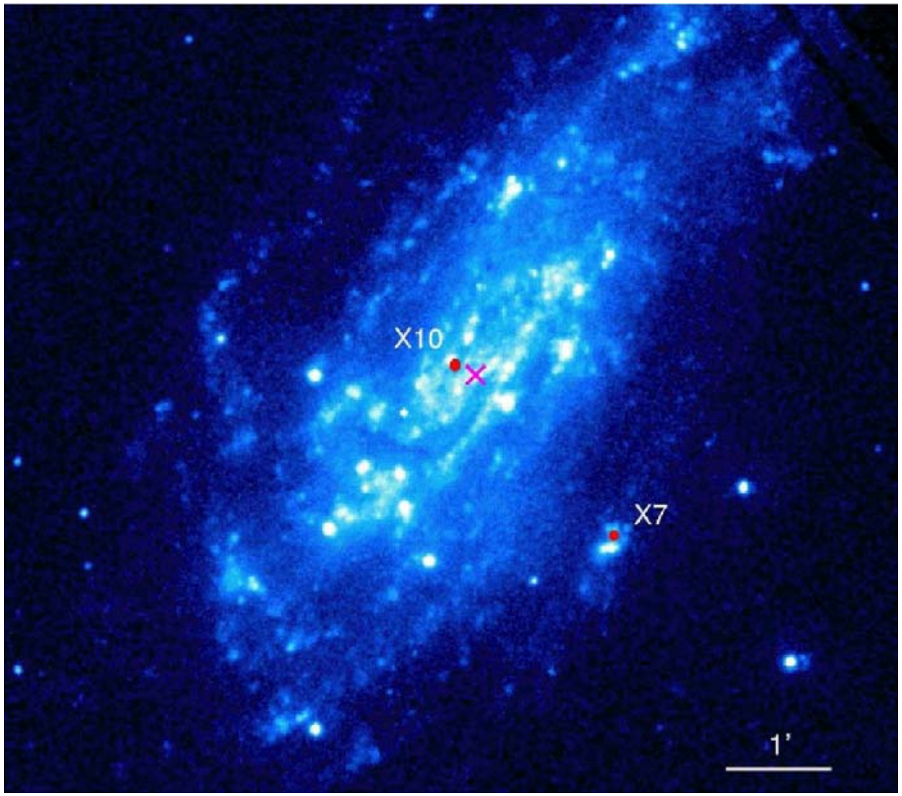
G060616-00-Z

Black Hole Perturbations

- If a newly formed black hole exists in a perturbed state, the perturbations will be radiated away as gravitational waves.
- Superposition of quasi-normal modes, each with a distinct frequency and damping time.
- Most slowly damped mode is expected to be a spheroidal harmonic of spin weight 2.
- Detection of a single mode would allow us to determine the mass and spin of the black hole, while multi-mode detection would provide a direct test of the Kerr nature of the source.
(Dorband et al, arxiv :gr-qc/060809)

Intermediate Mass Black Holes (IMBH)

- **10^2 M_{sun} < M < 10^5 M_{sun}**
- **Little evidence for their existence**
- **Observational hints from studies of**
  - **ultraluminous X-ray sources**
  - **kinematics of central regions of nearby galaxies and globular clusters**
- **Formation scenarios include**
  - **Runaway growth of a supermassive star, collapsing to a black hole**
  - **core collapse of massive young star cluster**

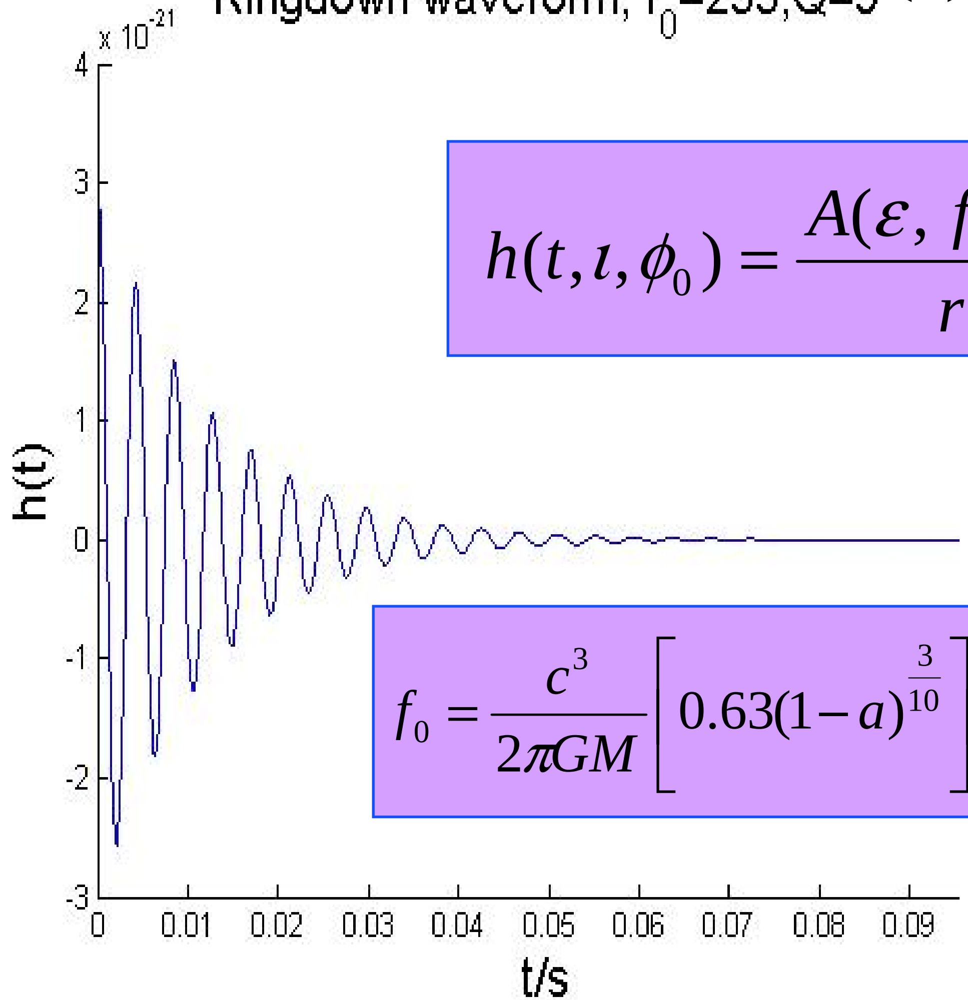


NGC 4559, XMM-Newton image, Cropper et al 2004

Detection of gravitational waves from black holes in this mass range would provide key evidence for the existence of IMBHs.

Ringdown Waveform

Ringdown waveform, f_0=235,Q=9 ⟷ M=100M_{sun}, a=0.96



$$h(t,\iota,\phi_0) = \frac{A(\varepsilon, f_0, Q)}{r} e^{-\frac{\pi f_0}{Q}t} \cos(2\pi f_0 t - \phi_0)$$

$$f_0 = \frac{c^3}{2\pi GM}\left[0.63(1-a)^{\frac{3}{10}}\right]$$

Amount of mass emitted as gw's,

ε = 1%

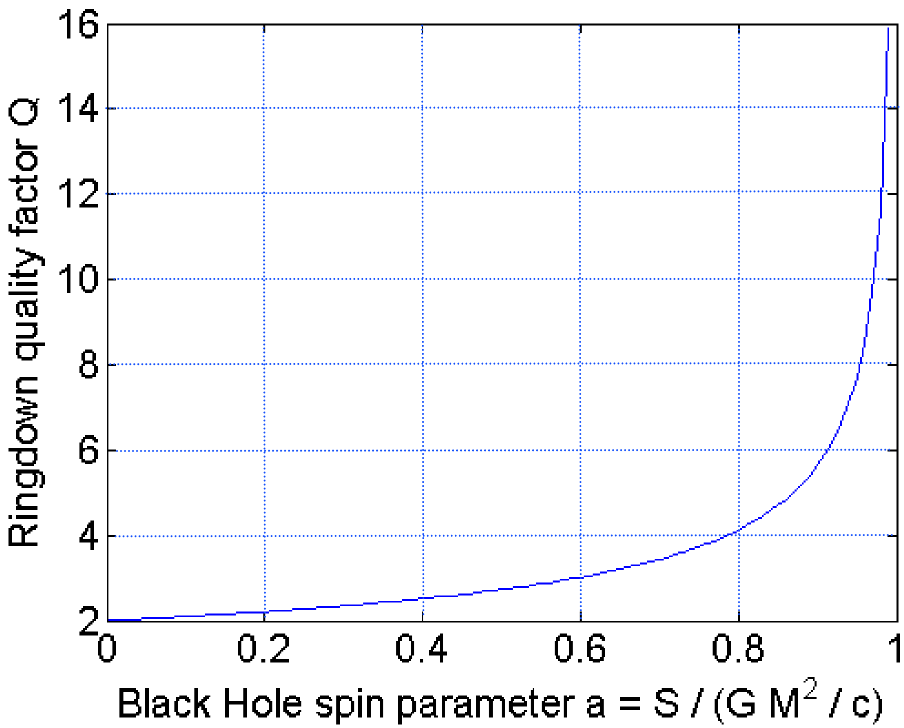
$$Q \approx 2(1-a)^{-\frac{9}{20}}$$

$$a = S\frac{c}{GM^2} \qquad 0 \leq a \leq 1$$

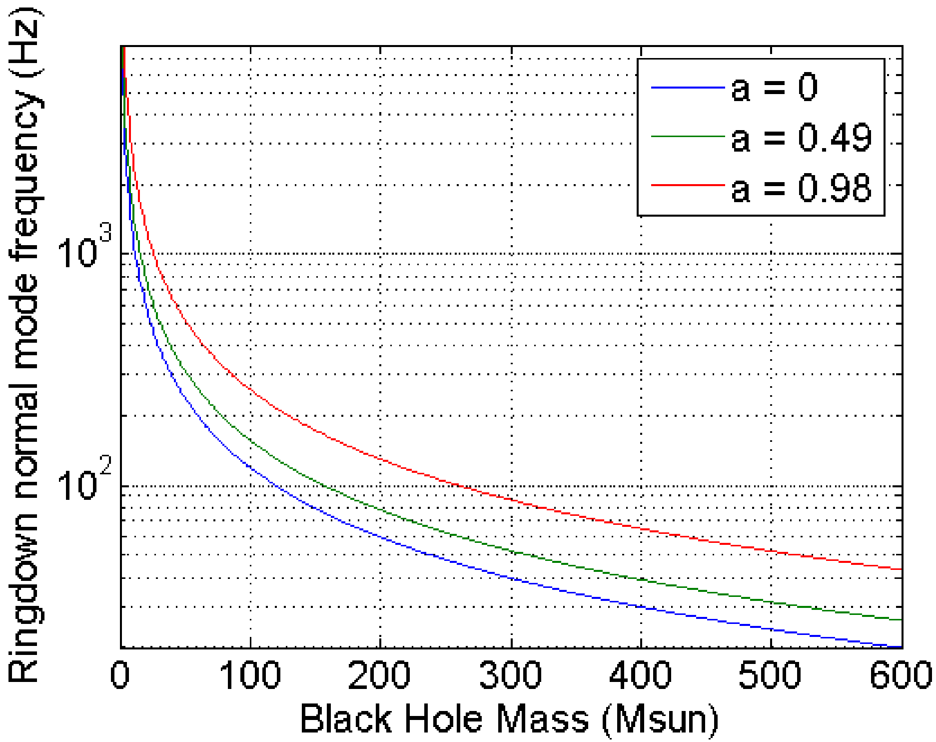
(Echeverria, 1989)

Waveform parameters ↔ Astrophysical quantities

- For the Y_2^2 mode, f_0 & Q are unique and invertible functions of mass and spin



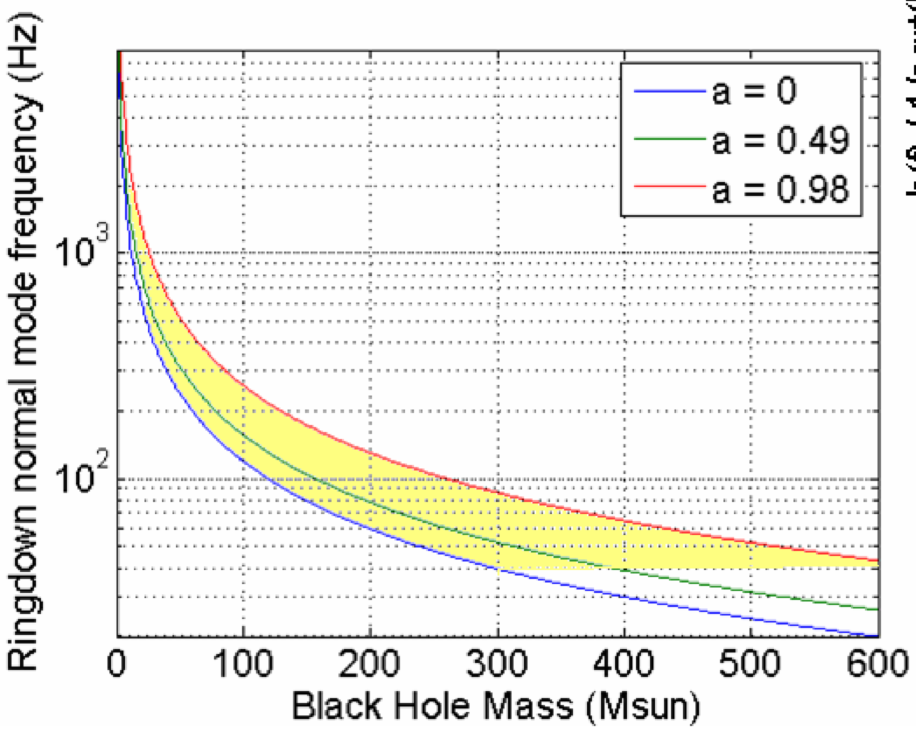
$$Q \approx 2(1-a)^{-\frac{9}{20}}$$

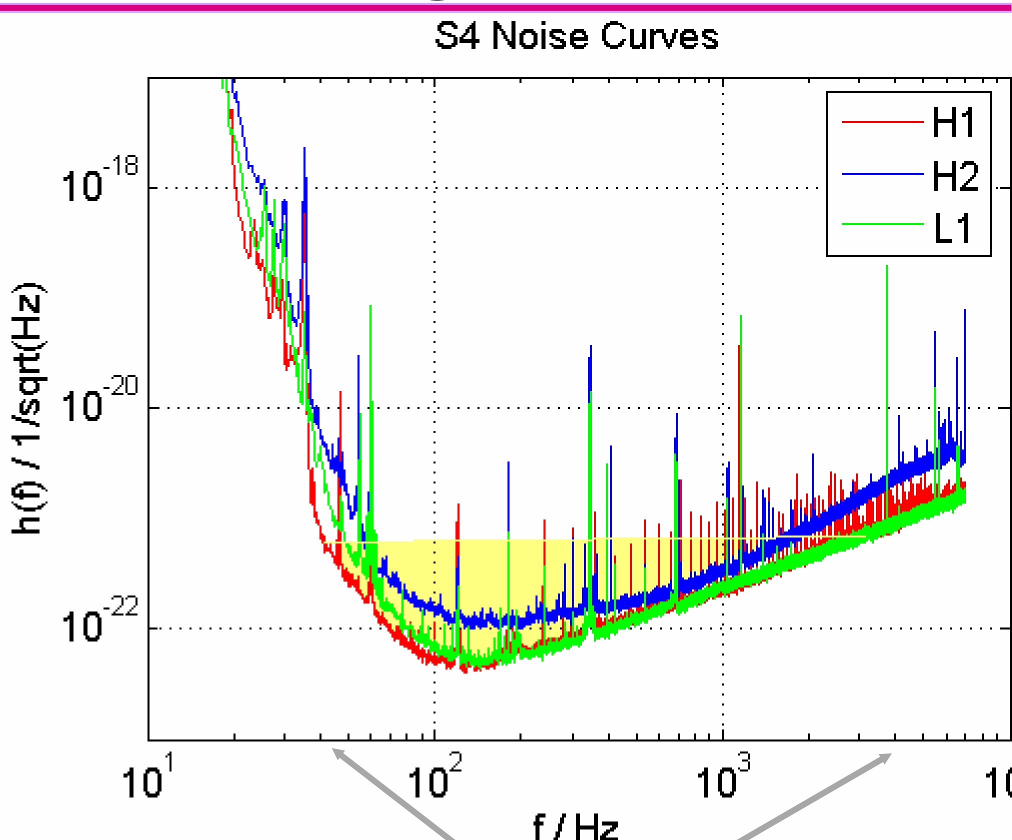


$$f = \frac{c^3}{2\pi GM}\left[0.63(1-a)^{\frac{3}{10}}\right]$$

Frequency & Mass Ranges

- For the Y_2^2 mode, f_0 & Q are unique and invertible functions of mass and spin

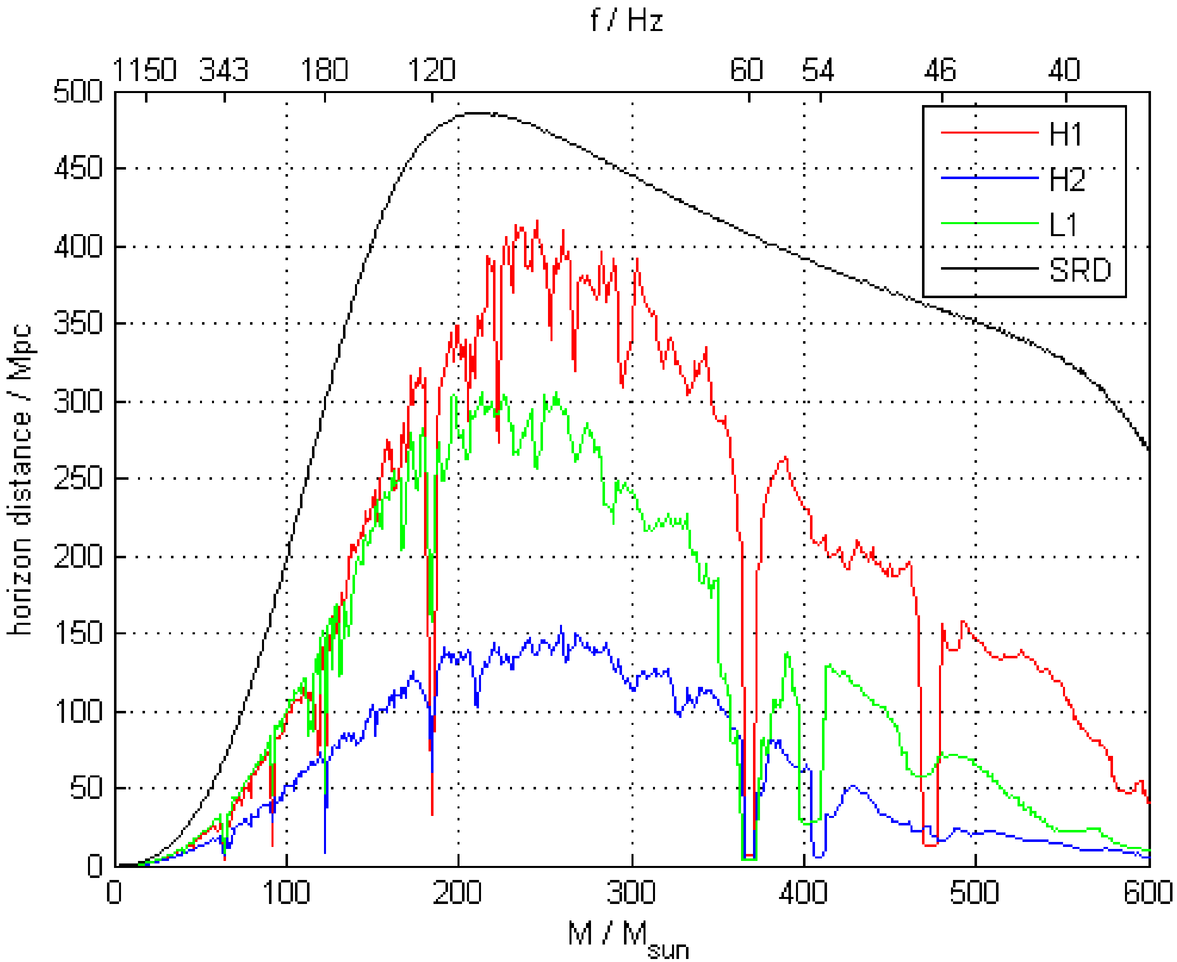




Sensitive between 40Hz and 4kHz

IMBH range

S4 Search



(based on average noise spectra)

- Optimally oriented source
- Single detector signal-to-noise ratio = 8
- Spin a = 0.9

For $M=230M_{sun}$, sensitive to black hole ringdowns at a distance of

H1: 400 Mpc

H2: 150 Mpc

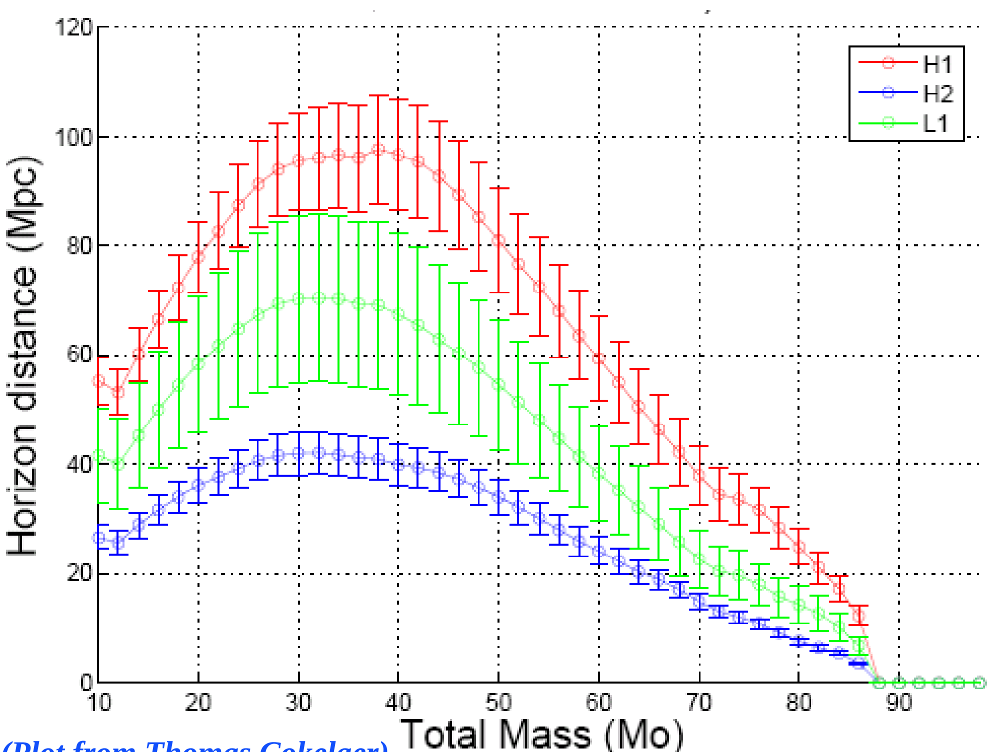
L1: 300 Mpc

Binary Coalescence

• Ringdowns are produced during the final stage of binary coalescence

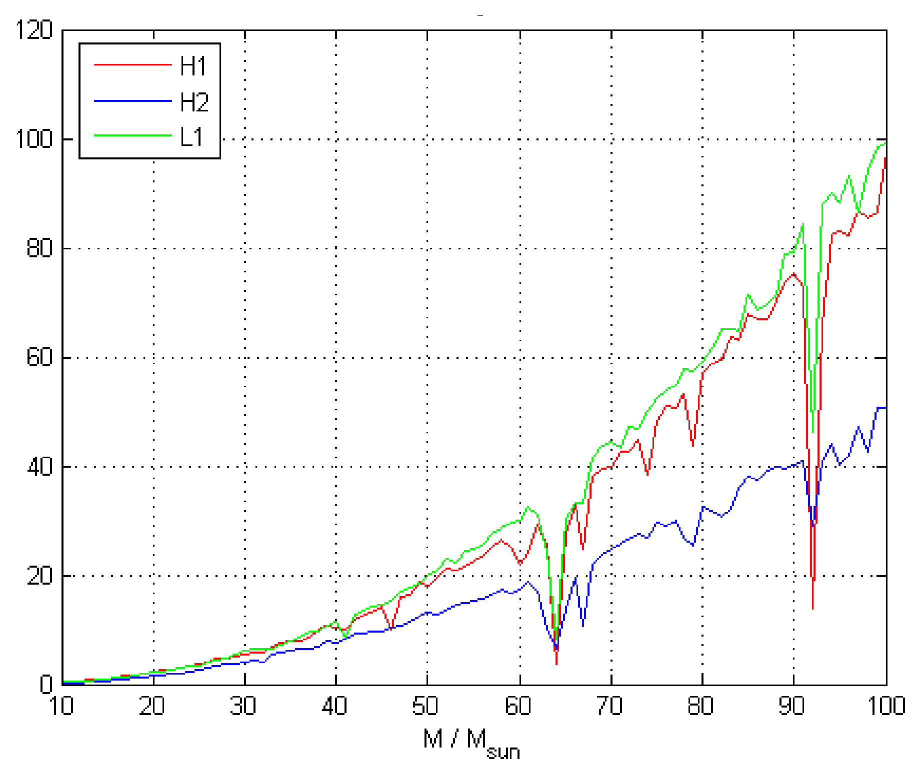
• There is an overlap between the mass range of the binary black hole (BBH) inspiral search and the ringdown search

Inspiral phase (S4 BBH search)

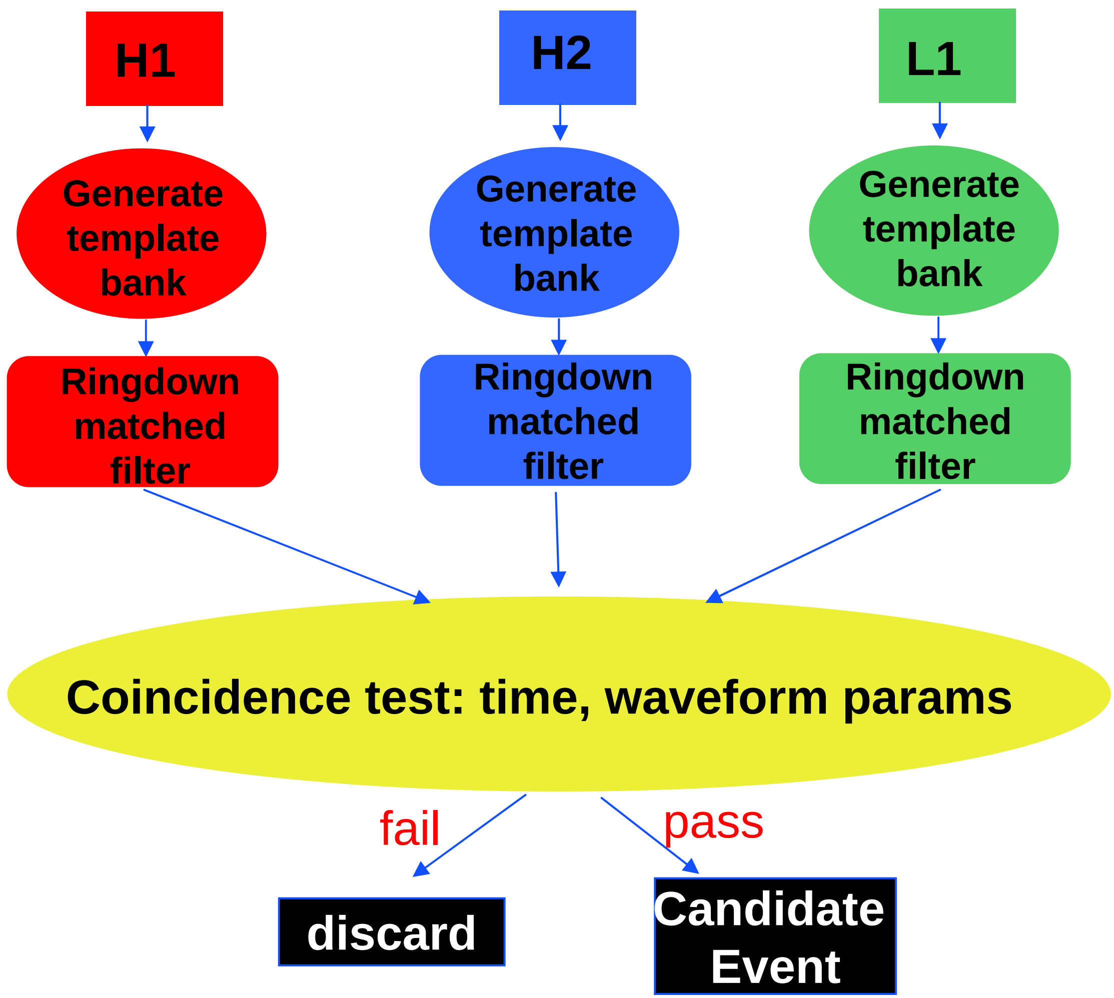


(Plot from Thomas Cokelaer)

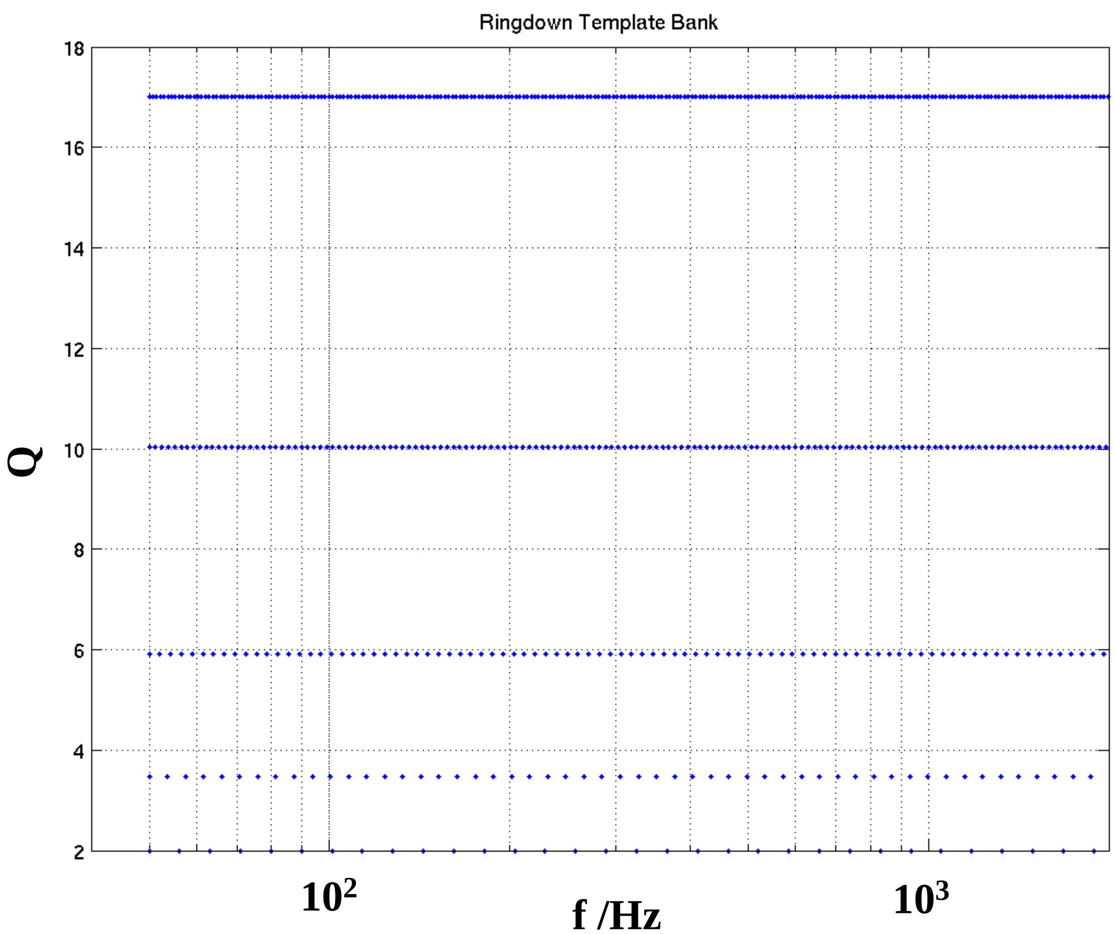
Ringdown phase (S4)



Overview of Ringdown Analysis Pipeline



Template Bank



$$ds^2 \approx \frac{1}{8}\frac{dQ^2}{Q^2} - \frac{1}{4}\frac{dQ}{Q}\frac{df}{f} + Q^2\frac{df^2}{f^2}$$

J. D. E. Creighton ‘99

$$40 \leq f \leq 4000 Hz$$

$$2 \leq Q \leq 20$$

- **N~700**
- **mismatch = 0.03**

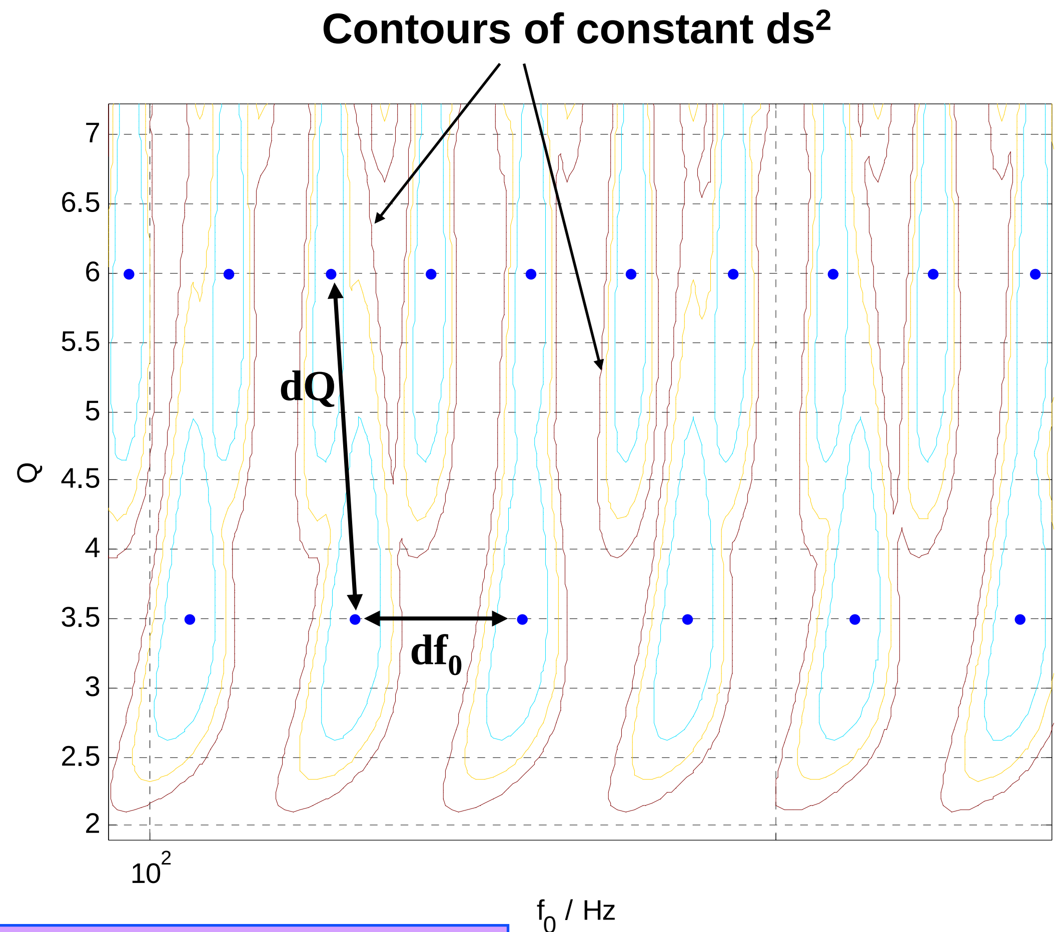
$$h(t-t_0) = e^{-\frac{\pi f_0}{Q}t}\cos(2\pi f_0 t)$$

Coincidence Test

- Template bank is not uniform in f and Q.

- Rather than looking at f and Q separately, look at both parameters together via metric.

- Can plot contours of constant ds^2.

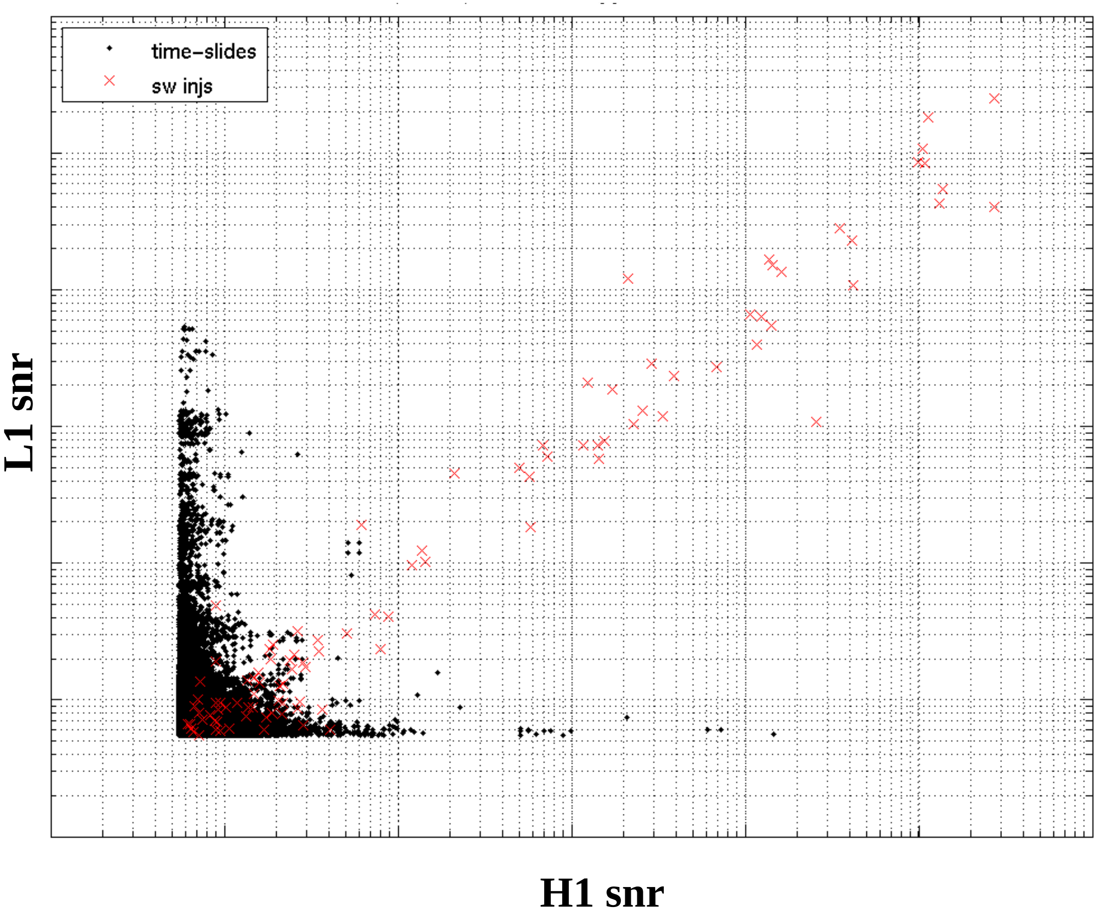


If contours overlap => coincidence

Tuning Considerations

- injecting ringdown signals into the data stream
- how well do we recover the injected parameters for single ifo?
- how do these parameters differ between interferometers?
- look at the rate of false coincidences by sliding data sets in time.

H1L1 coincident triggers: injections, timeslides



(Example of coincidences found with a particular choice of tuning parameters, - these are not final)

Next for this Search

- Complete tuning of the coincidence test
- Open the box on the analysis in early January

Future Ringdown Searches

- Run the search on S5 data
- Inspiral – Merger – Ringdown search