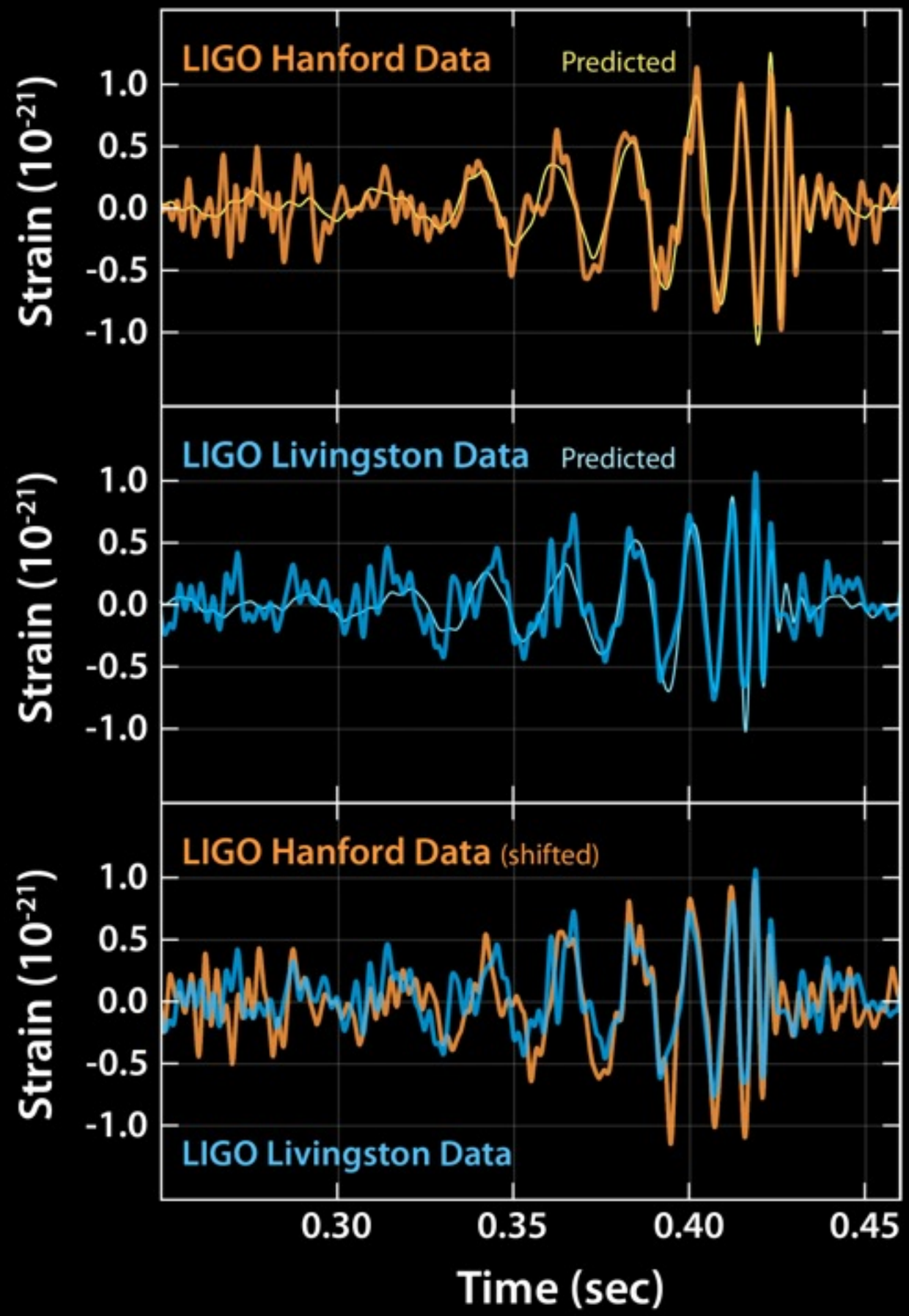
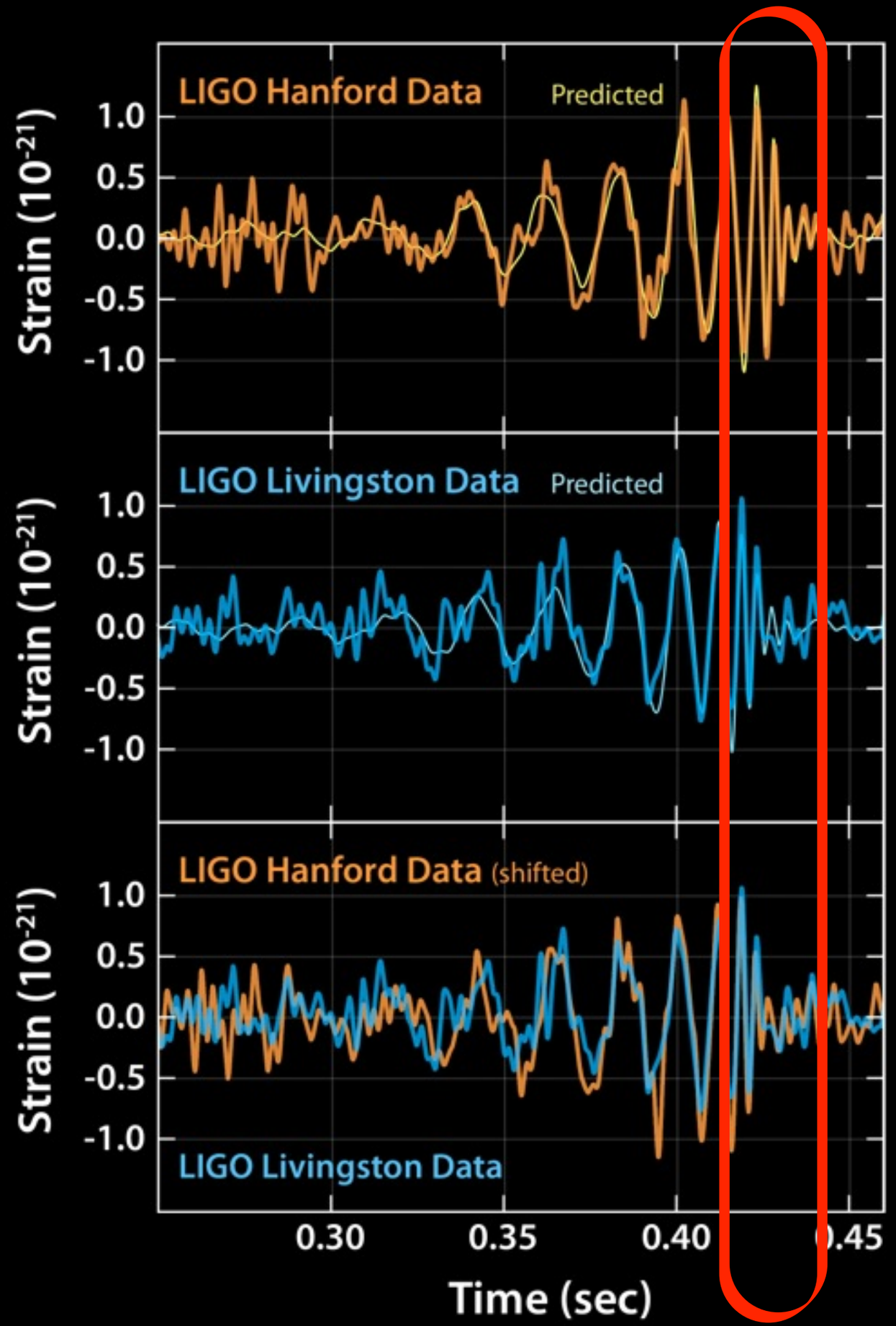
Prospects for observing multiple ringdown modes in a binary black hole merger

Albert Einstein Institute (Hannover)

Miriam Cabero Müller, Ofek Birnholtz, Chris Biwer,
Collin Capano, Badri Krishnan, Reinhard Prix

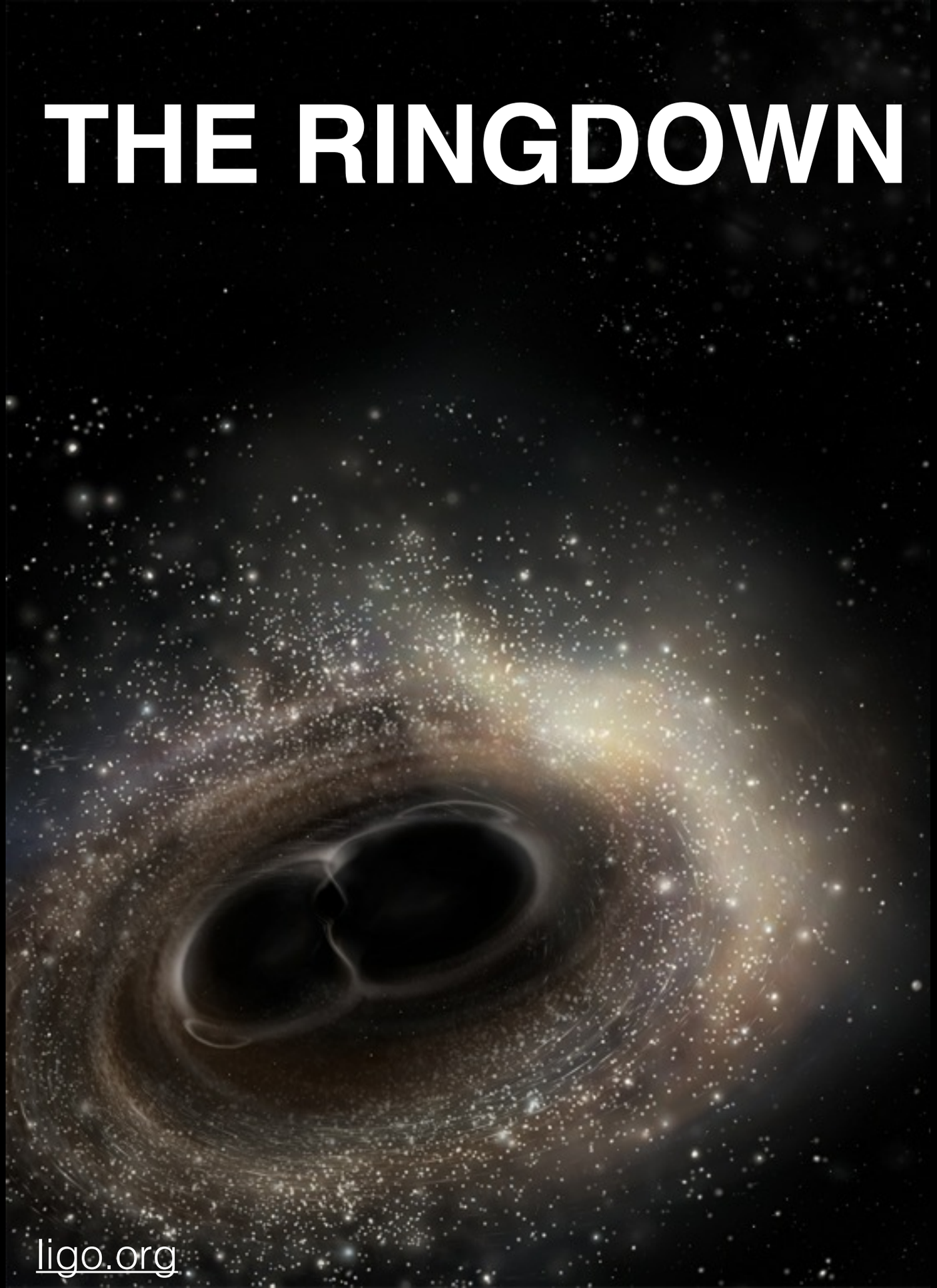


Caltech / MIT / LIGO Lab



Caltech / MIT / LIGO Lab

THE RINGDOWN

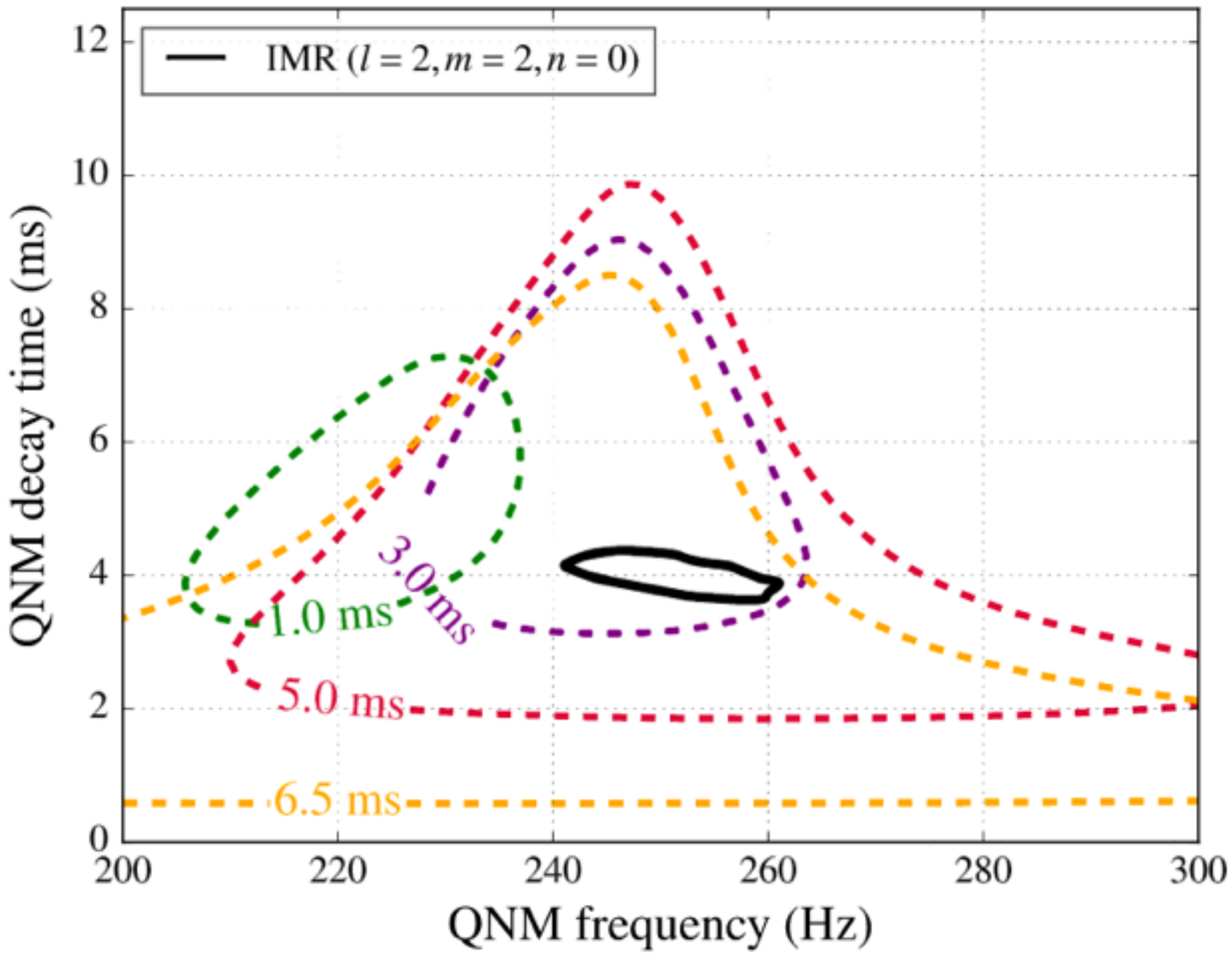


- **Final object: perturbed black hole**
- **Radiation can be expanded in quasi-normal modes (lmn)**
- **Central frequency and damping time of damped sinusoid are characteristic of mass and spin of the black hole**
- **Amplitude and phase of each mode depend on initial conditions and orientation of the source**
- **Observations of at least two modes can be used to test the no-hair theorem**

Tests of General Relativity

$$h(t \geq t_0) = Ae^{-(t-t_0)/\tau} \cos[2\pi f_0(t-t_0) + \phi_0]$$

- $t_0 = t_M + 3$ ms: SNR $\simeq 8.5$
- $t_0 = t_M + 5$ ms: SNR $\simeq 6.3$
- $t_0 = t_M + 6.5$ ms: SNR $\simeq 4.8$



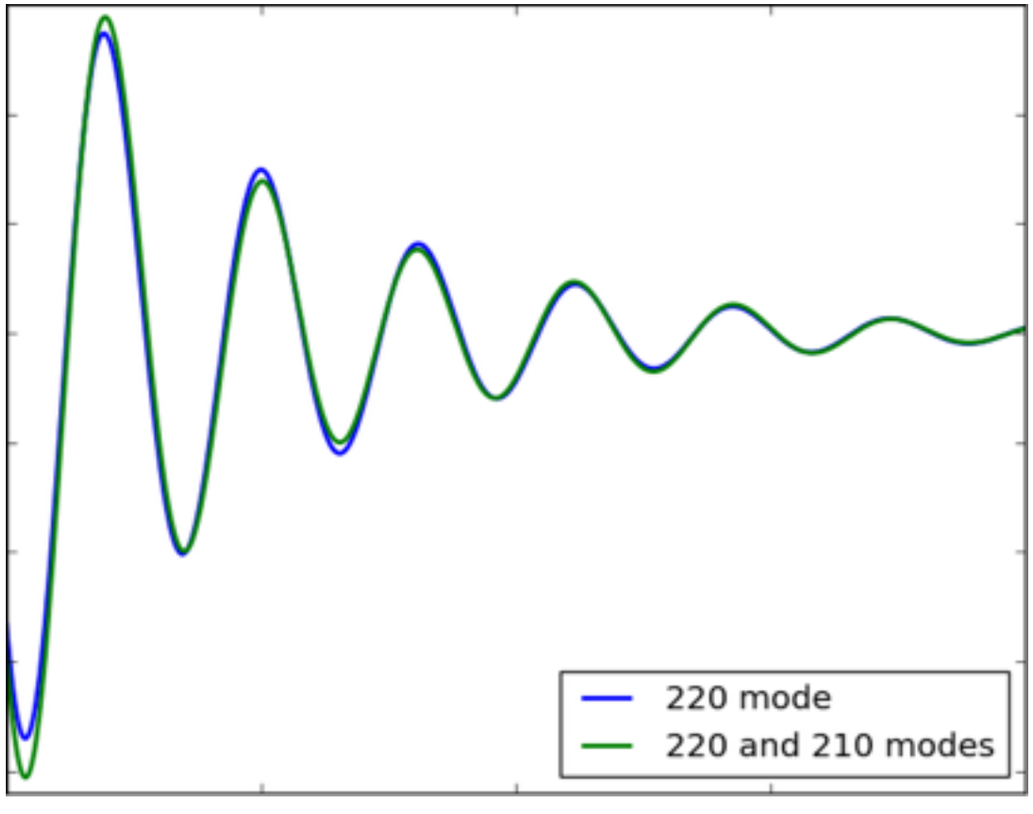
LVC, PRL 116, 221101 (2016)

Identifying the ringdown

Parameter estimation

PyCBC MCMC

Ringdown GR model



https://github.com/ligo-cbc/pycbc/

E. Berti et al., PRD 73, 064030 (2006)

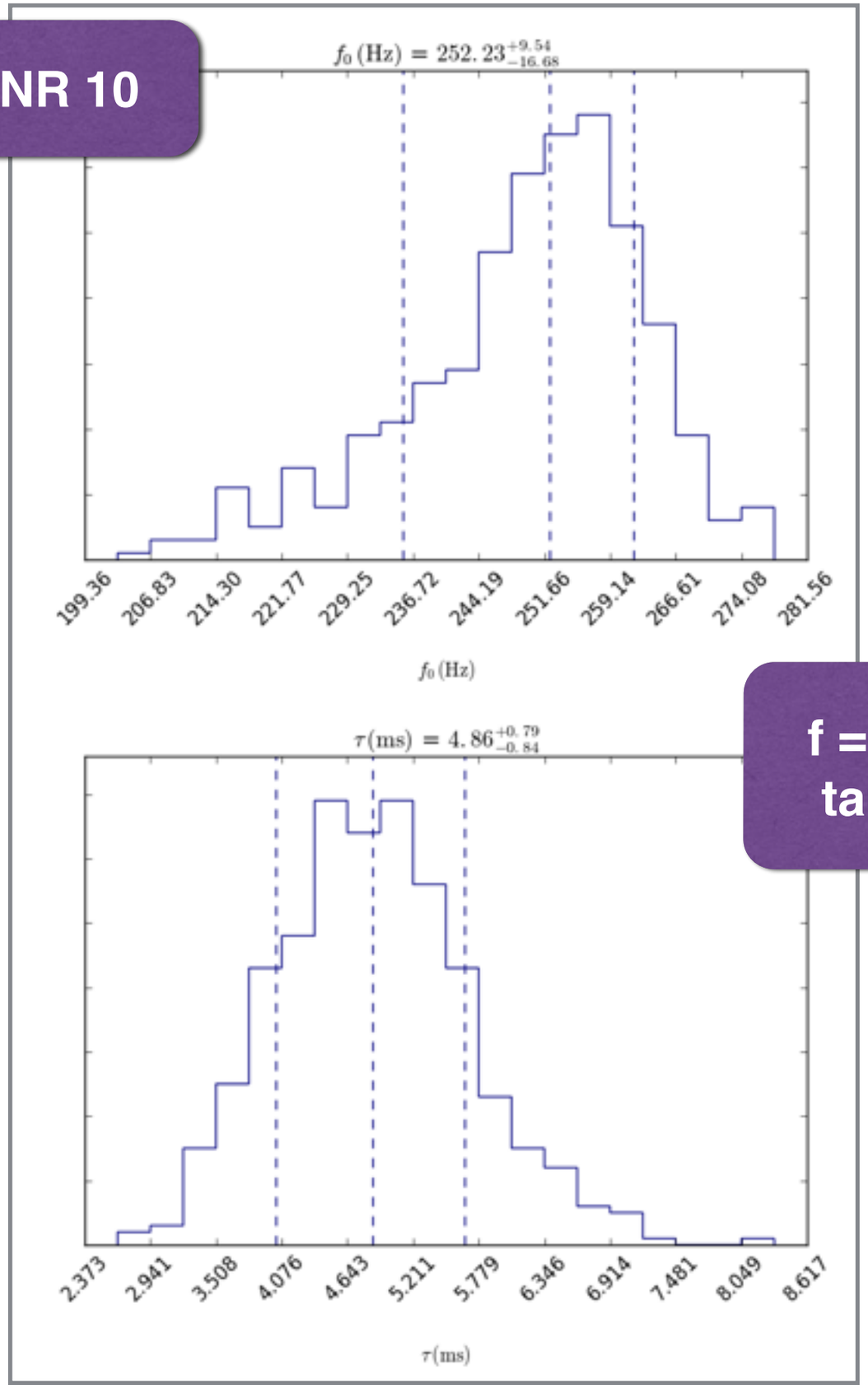
First tests

Parameter estimation with only a damped sinusoid

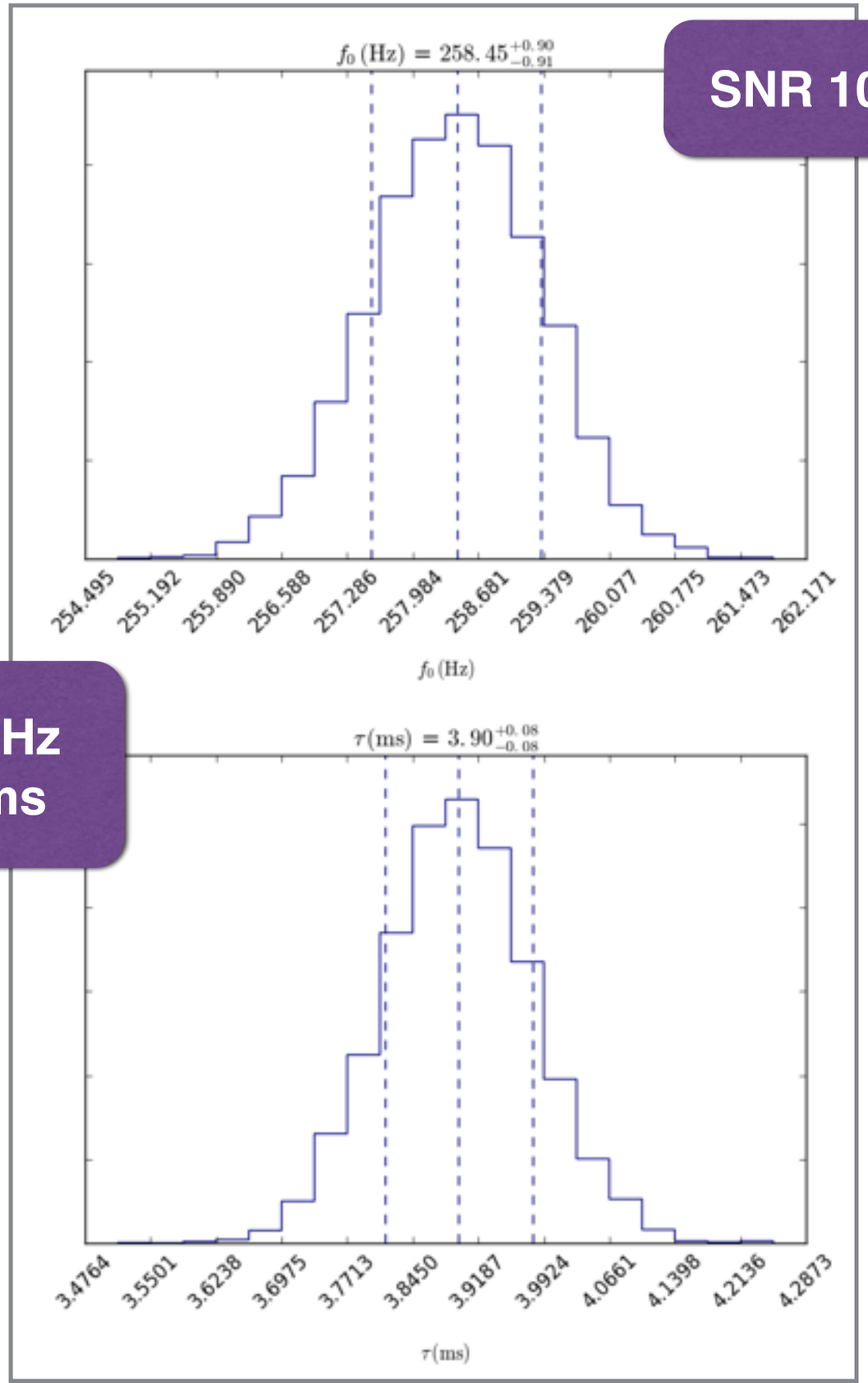
- Create fake strain using PSD of O1 run
- Add injection using ringdown-only waveform
- SNR of injection determined by amplitude
- Coherent analysis (two detectors)

First tests

SNR 10



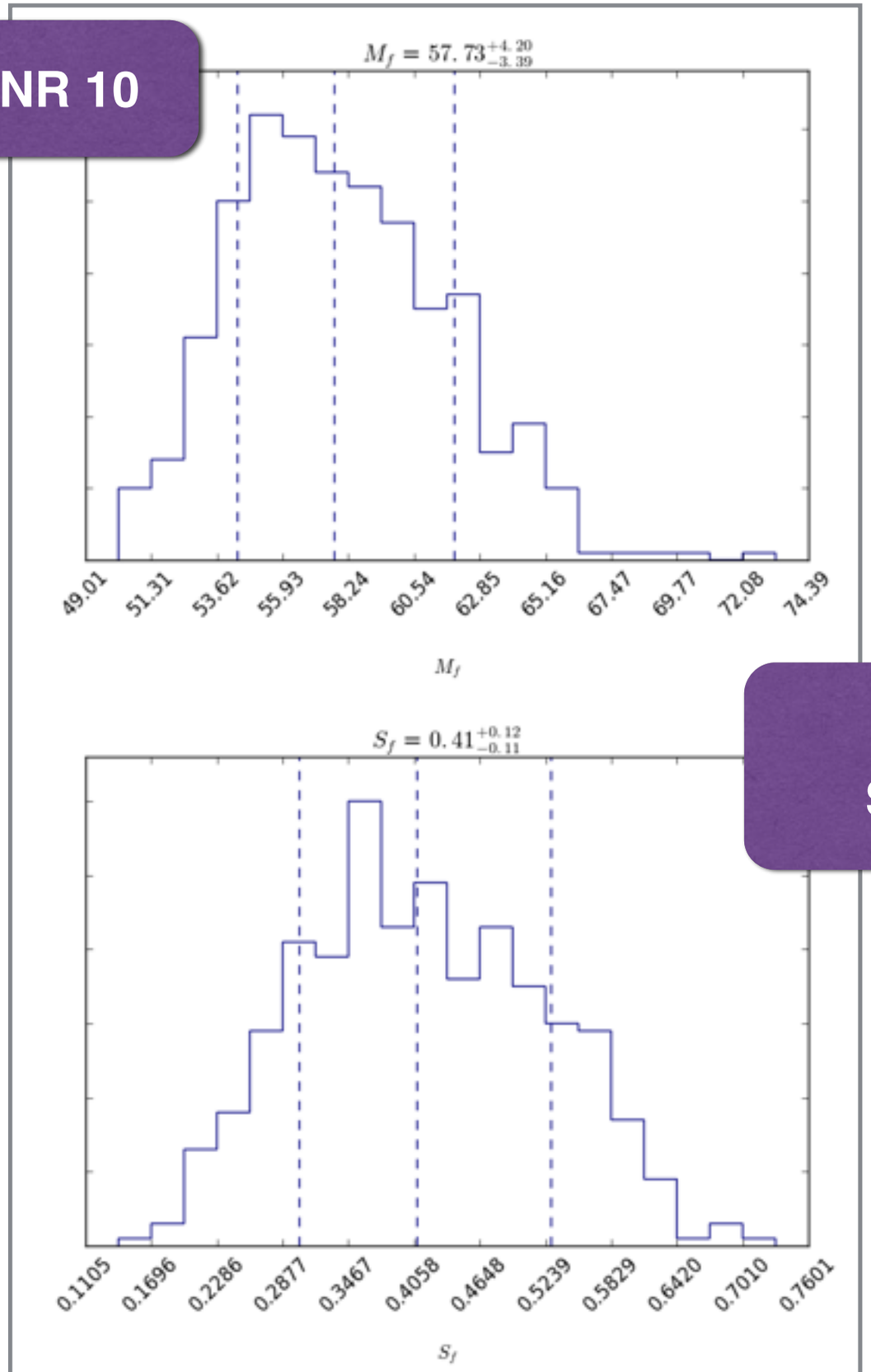
SNR 100



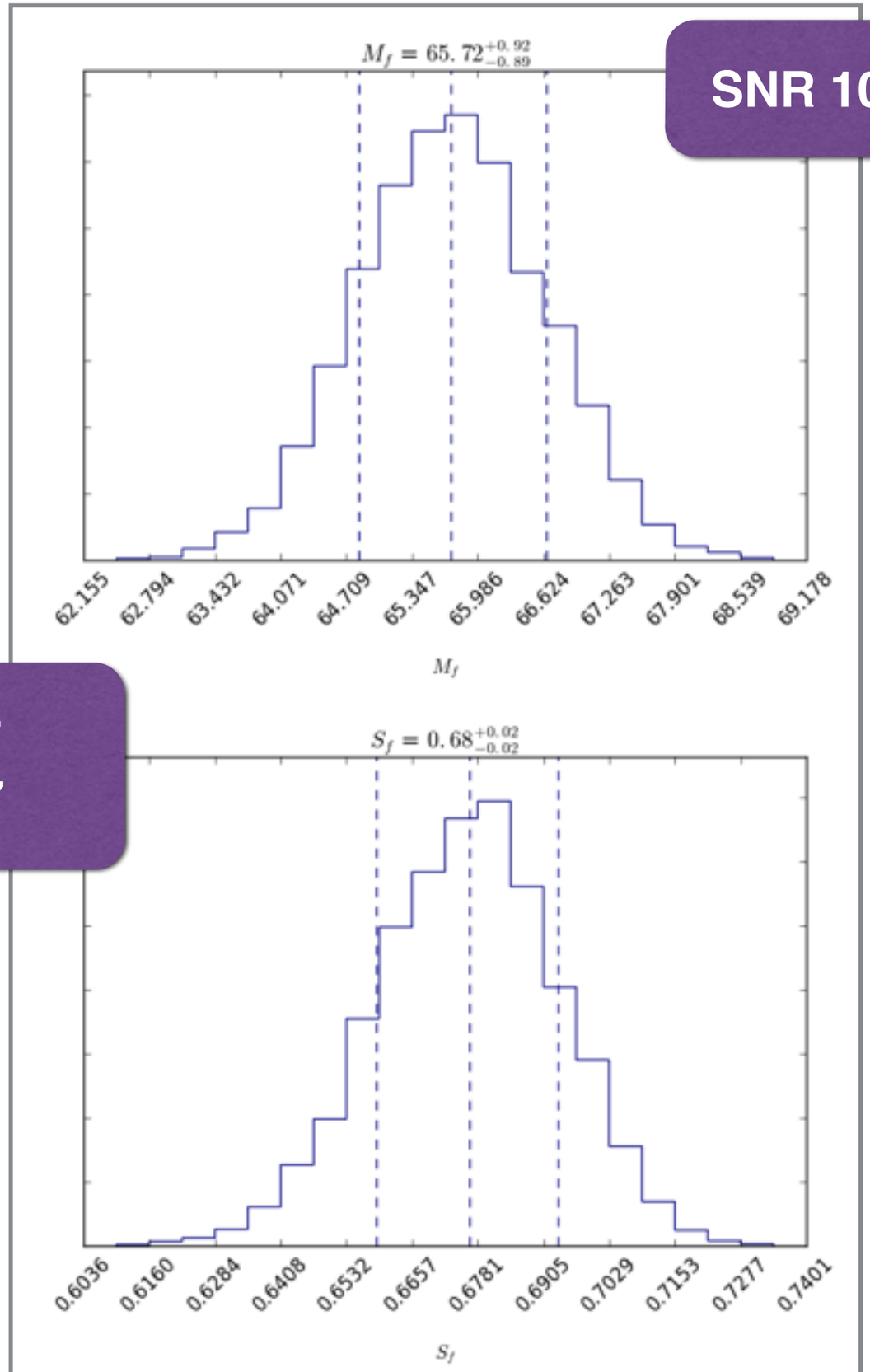
f = 258.4 Hz
tau = 4 ms

First tests

SNR 10

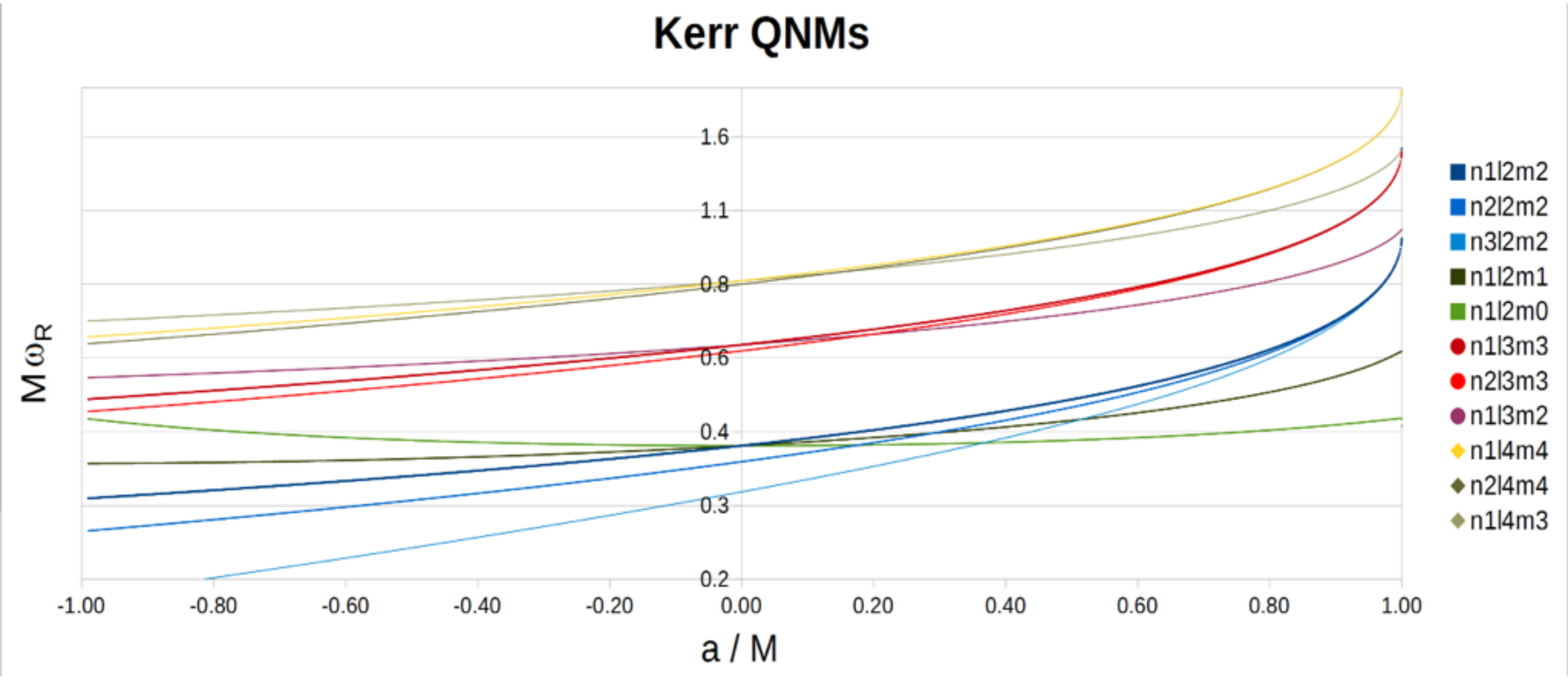


SNR 100



M = 67
S = 0.7

Higher quasi-normal modes



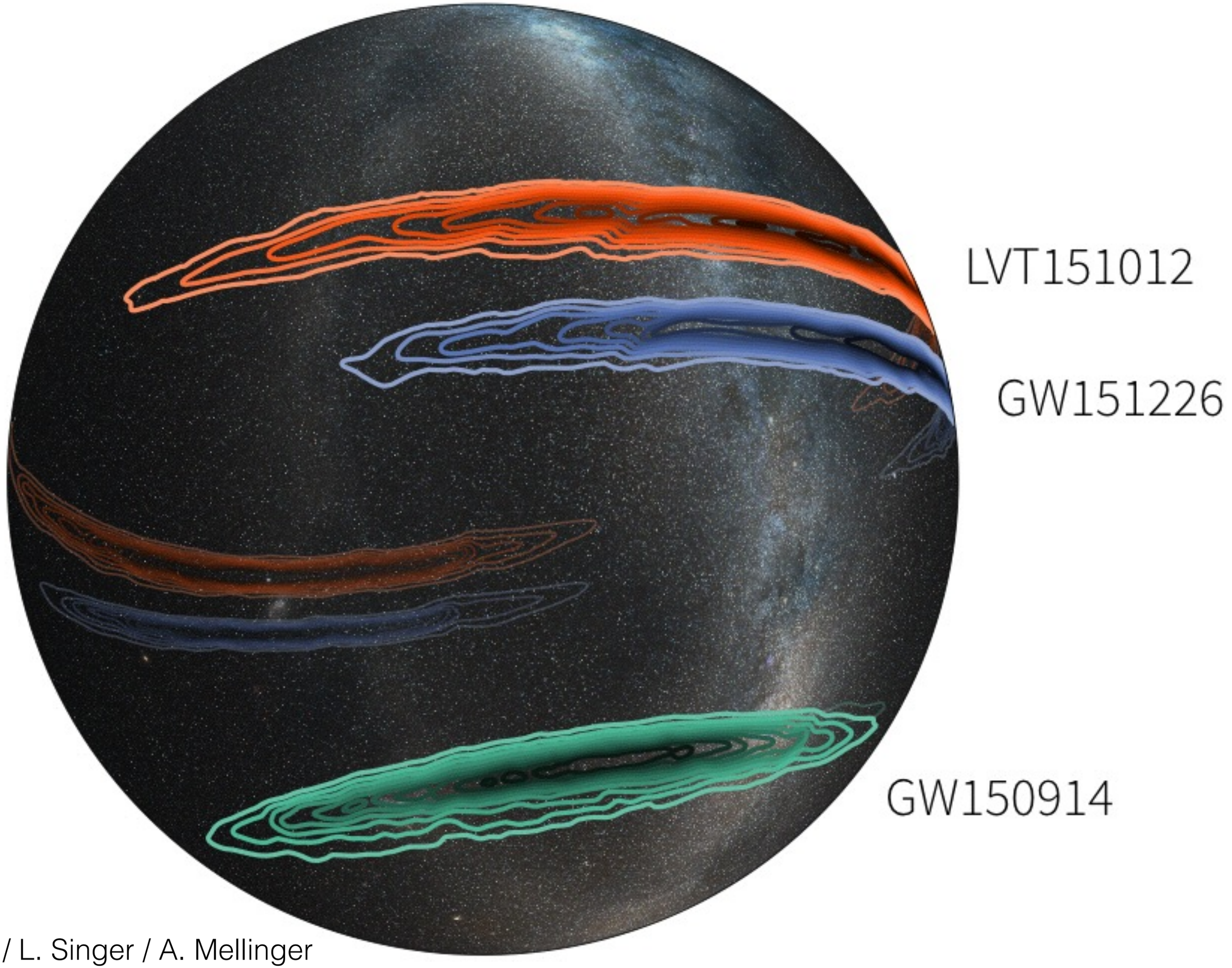
SUMMARY

- The observation of at least two quasi-normal modes can verify the Kerr nature of the final black hole and test if it satisfies the no-hair theorem.

- Single-mode ringdown analysis results look promising for the near future.

- Multi-mode ringdown analysis appears very challenging, ongoing work.

- Ongoing tests and development will tell us the feasibility of multi-mode observations in future detections of gravitational waves.



LIGO / L. Singer / A. Mellinger