Search for gravitational waves from binary black hole inspiral, merger and ringdown

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LIGO Scientific Collaboration

VIRGO

Outline

This talk is about a recently conducted search for gravitational waves from binary black holes using LIGO data taken between 2005 – 2007. Here is how it is organized

1. An introduction to the sources
2. An explanation of what makes these sources and this search unique
3. A discussion of previous searches
4. Results
5. Conclusion

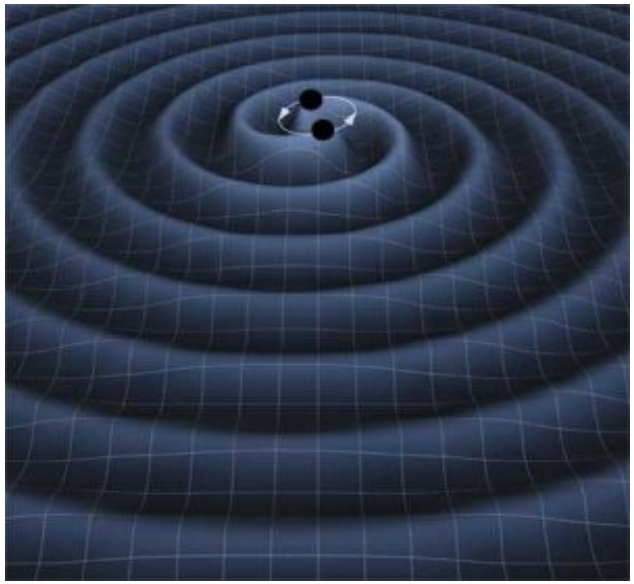


Image: K. Thorne (Caltech) and T. Carnahan (NASA GSFC)]

Binary black holes

Only a small fraction of binary star systems are massive enough to form neutron stars or black holes, which are needed to generate gravitational waves that are observable by current ground-based detectors.

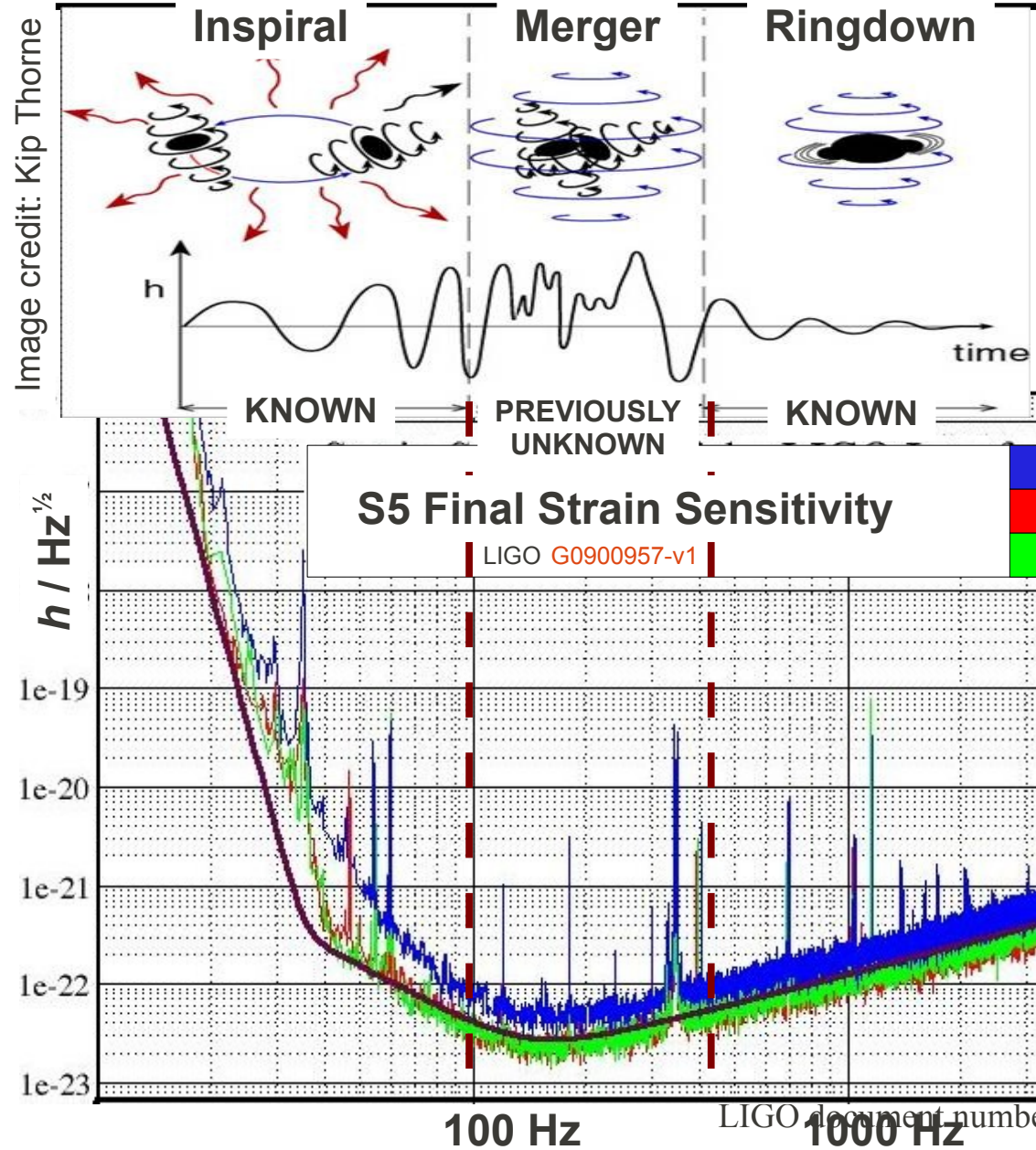
Aurore Simonnet
Sonoma State University/NASA

Recently binaries have been observed with larger than expected black holes.

IC 10 X-1 has a [24-31] solar mass black hole. Its companion star may also form a black hole some day, potentially making this source a binary black hole (BBH). If such BBH systems exist now they will be great sources of gravitational waves.

Bulik et al. arXiv:0803.3516

Something that makes BBHs interesting



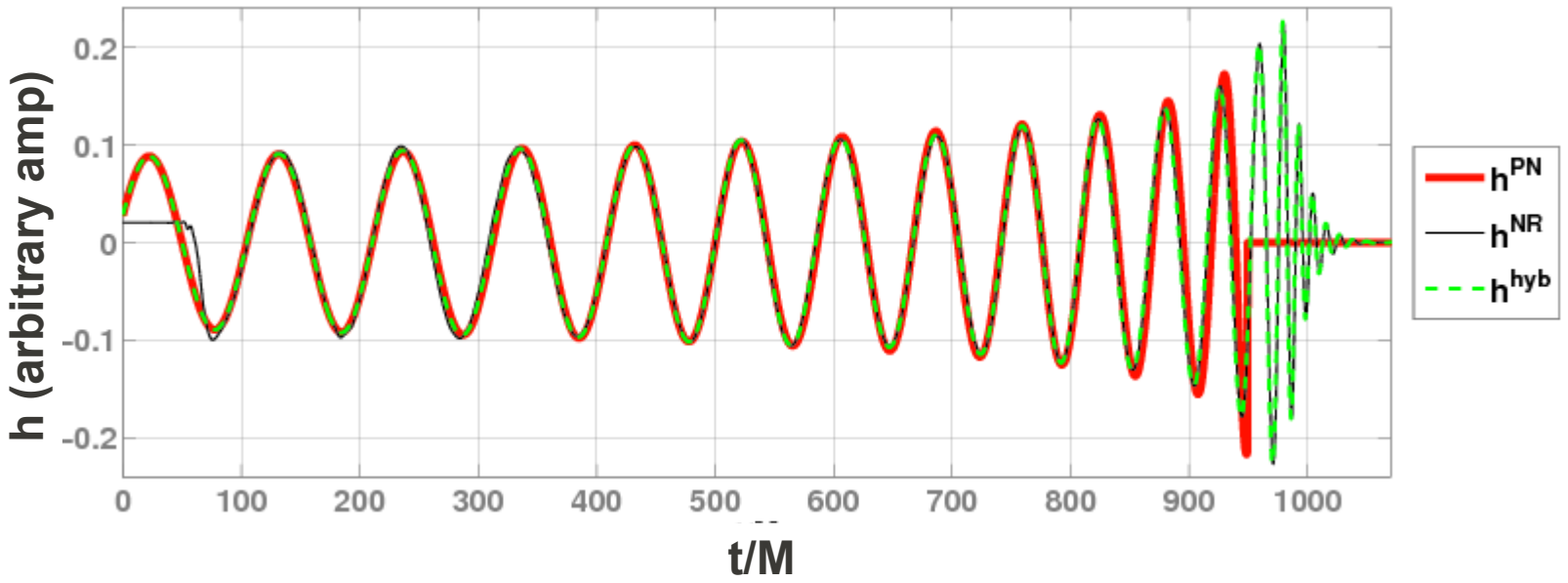
For BBHs with total mass between ~25-100 solar masses all three phases of coalescence, inspiral, merger and ringdown (IMR) are in the most sensitive region of the LIGO detectors.

Post Newtonian theory describes the inspiral...

BH perturbation theory describes the ringdown...

Recently numerical relativity described the merger and evolved BBHs through all 3 phases

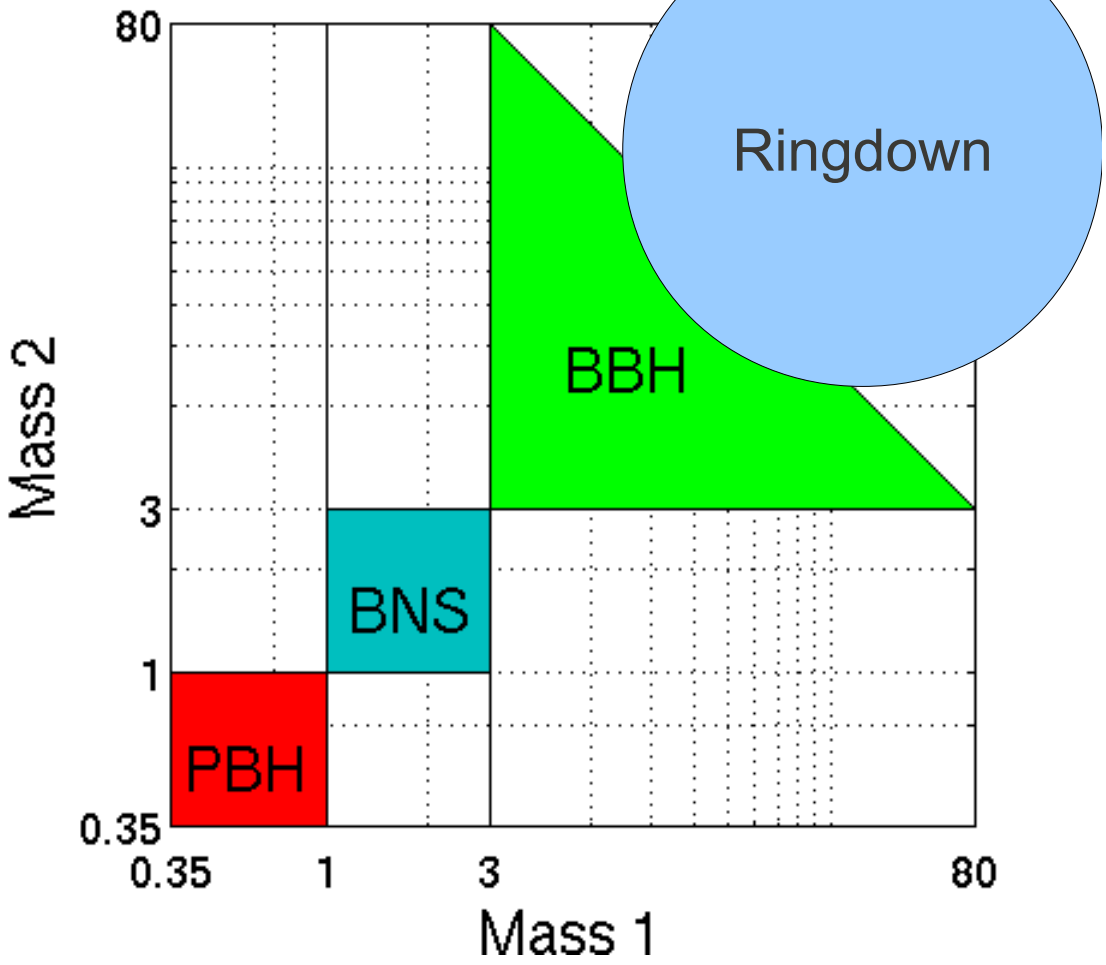
IMR waveforms



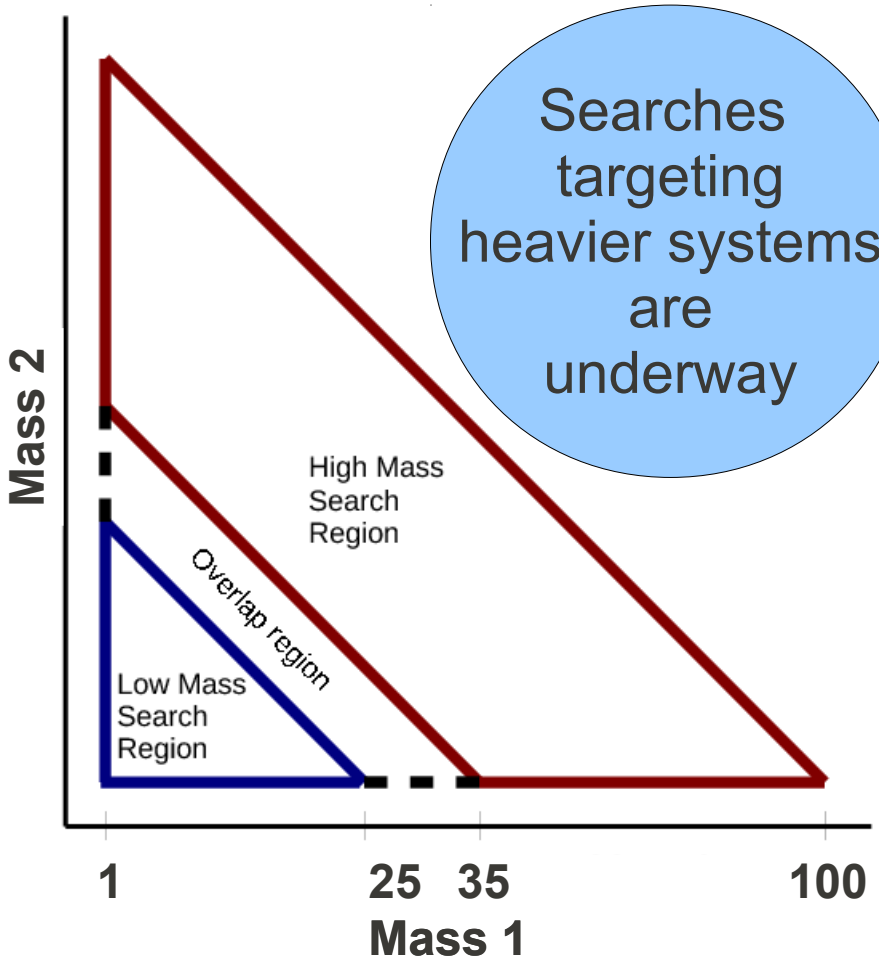
Since the numerical relativity community began simulating BBH mergers various analytic and phenomenological waveform models have been developed. We can make direct use of them in this search rather than searching for the three phases of coalescence separately.

Buonanno et al, Phys. Rev. D 76, 104049 (2007). Ajith et al, Class. Quant. Grav. 24, S689-S700 (2007) and subsequent references

Previous, current searches



Ringdown



Searches targeting heavier systems are underway

S4 Feb.-Mar. 2005

S5, Nov 2005 – Sep 2007

Previous results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.

$$R_{90\%} \propto (VT)^{-1}$$

Where V is the volume of space that the search was sensitive to (Mpc^3) and T is the observation time (note that previous rates were also computed using blue light of the galaxies surveyed in units of 10^{10} blue solar luminosity.)

S4 BBH (inspiral only ~40 solar masses) $R_{90\%} = 6000$ $Mpc^{-3}\,Myr^{-1}$
Phys. Rev. D 77 062002 (2008)

S4 Ringdown (85 – 390 solar masses) $R_{90\%} = 32$ $Mpc^{-3}Myr^{-1}$
Phys. Rev. D 80 062001 (2009)

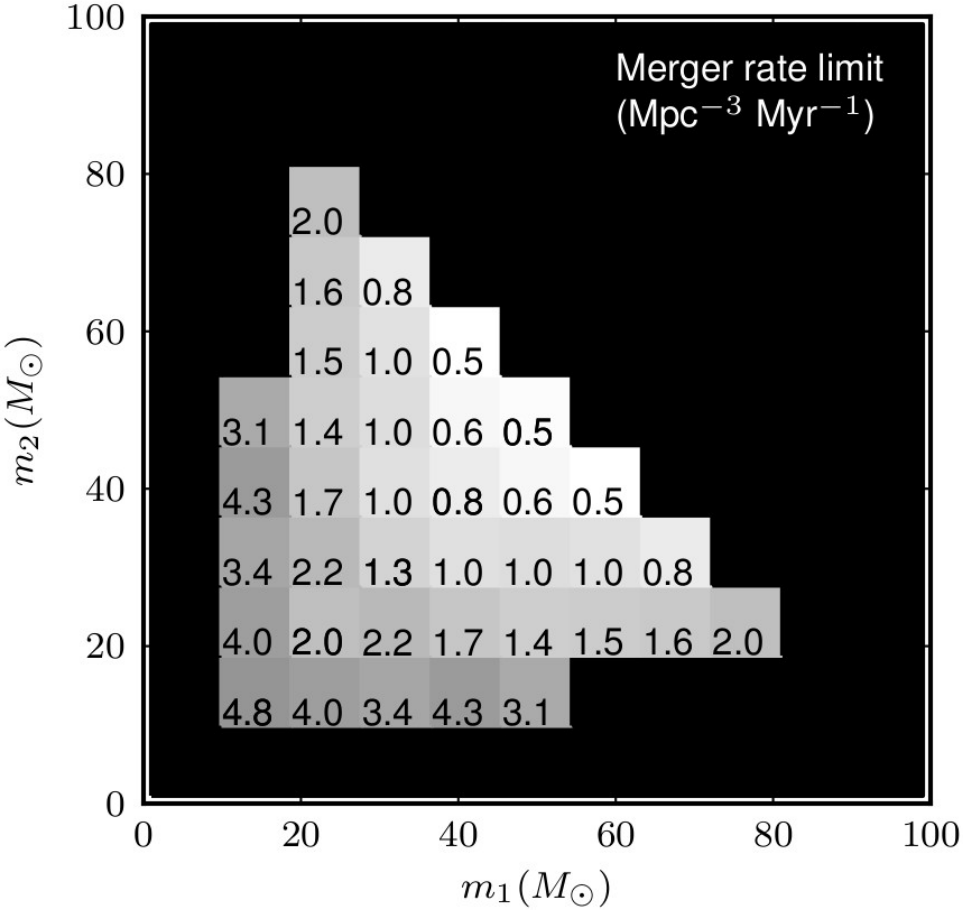
S5 BBH (inspiral only ~30 solar masses) $R_{90\%} = 6$ $Mpc^{-3}\,Myr^{-1}$
Phys. Rev. D 82 102001 (2010)

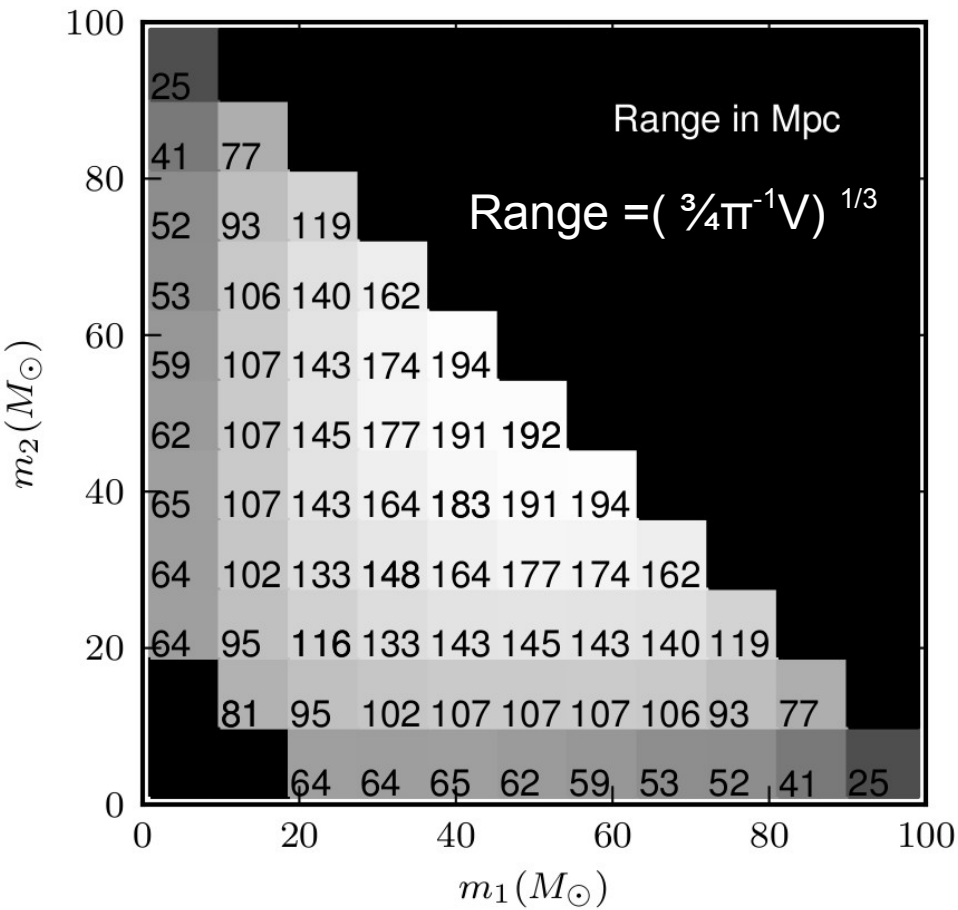
Compared to the optimistic rate prediction for

A 10,10 solar mass binary Class. Quant. Grav. 27 173001 (2010) 0.3 $Mpc^{-3}\,Myr^{-1}$

S5 results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.





Conclusion and discussion

The merger rate limit result is about an order of magnitude higher than optimistic predictions. However, currently S6, VSR2/VSR3 data are being analyzed with an improved sensitivity, and advanced LIGO and Virgo detectors will soon be operating.

We hope to begin observing these systems within the next decade!