Measuring neutron-star properties with LIGO and Virgo

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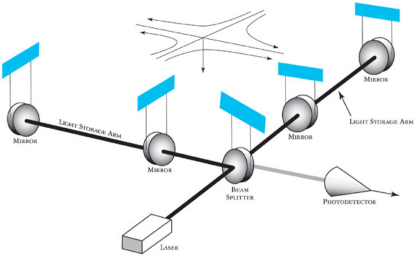
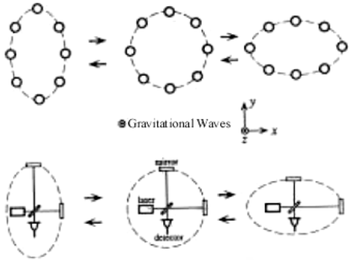
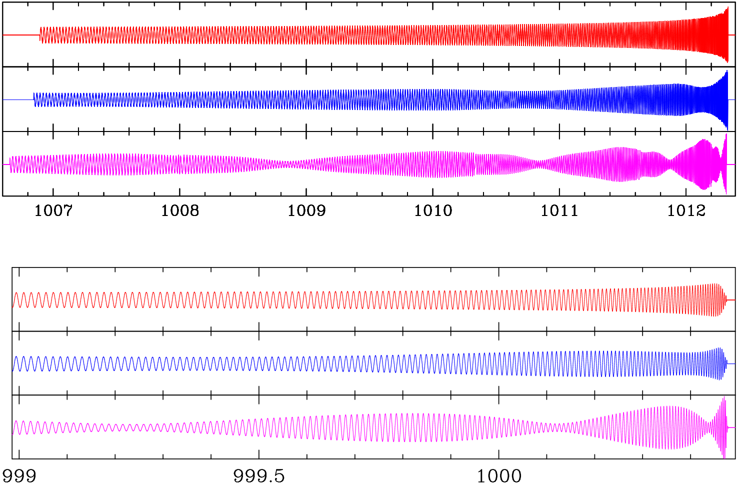
LIGO and Virgo





Inspiral waveforms with increasing spin

Initial LIGO and Virgo can detect the last $\sim 10\,\mathrm{s}$ of a binary inspiral:



$10\,M_\odot$ BH + $1.4\,M_\odot$ NS; $a_{\mathrm{spin,BH}} \equiv S/M^2 = 0.0$, 0.1 and 0.5

Predicted detection rates of binary inspirals

Horizon distances (Mpc):

	NS-NS	BH-NS	BH-BH
Initial LIGO/Virgo	32	67	160
Advanced LIGO/Virgo	364	767	1850

Detection-rate estimates (yr^{-1}):

	NS-NS	BH-NS	BH-BH
Initial LIGO/Virgo	2×10^{-4} – 0.2	7×10^{-5} – 0.1	2×10^{-4} – 0.5
Advanced LIGO/Virgo	0.4 – 400	0.2 – 300	0.4 – 1000

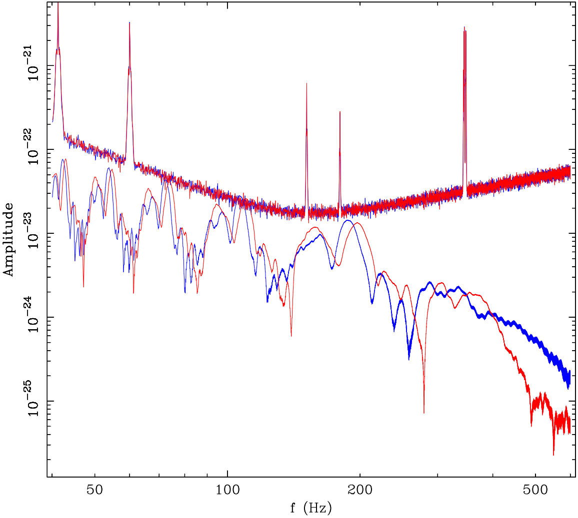
Estimates assume $M_{\mathrm{NS}} = 1.4\, M_\odot$ and $M_{\mathrm{BH}} = 10\, M_\odot$

Abadie et al. (2010)

Signal injection into detector noise

Example:

- Using two 4-km detectors H1, L1
- Inject signal coherently
- Σ SNR = 17
- Retrieve physical parameters using MCMC



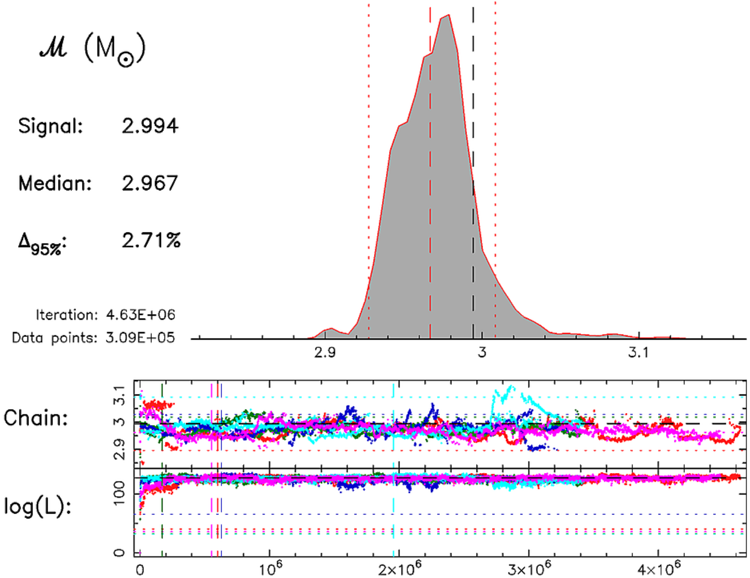
Purpose:

- Use Markov-Chain Monte Carlo for parameter estimation
- Follow-up after detection
- Gaussian, stationary noise or LIGO/Virgo/other detector data
- Analyse software injections, hardware injections, detection candidates/interesting events
- Include spin in injections and analysis
- Use any network composed of LIGO/Virgo detectors:
  - $\mathrm{PDF}(\vec{\lambda}) \propto \mathrm{prior}(\vec{\lambda}) \times \prod_i L_i(d|\vec{\lambda})$

Output:

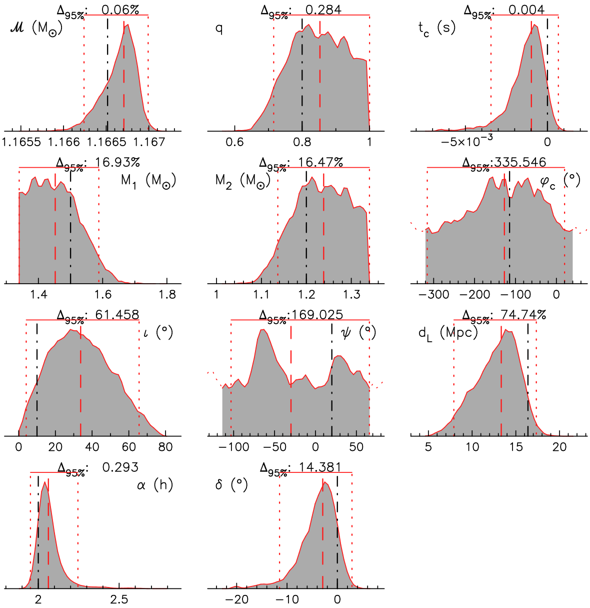
- Posterior probability-density function (PDF) of the parameter set that describes the model (9–12–15 D)

MCMC example



spinspiral.sf.net

Short GRB (NS-NS inspiral): GW data only



NS-NS, no spins

- $M_{1,2} = 1.5 + 1.2\,M_\odot$
- 3 detectors (initial H1,L1,V)
- $d_L \approx 16.4$ Mpc (Σ SNR ≈ 15.0)
- $\iota = 10^\circ$

- black dash-dotted line: true value
- red dashed line: posterior median
- red dotted lines: 95%-probability range

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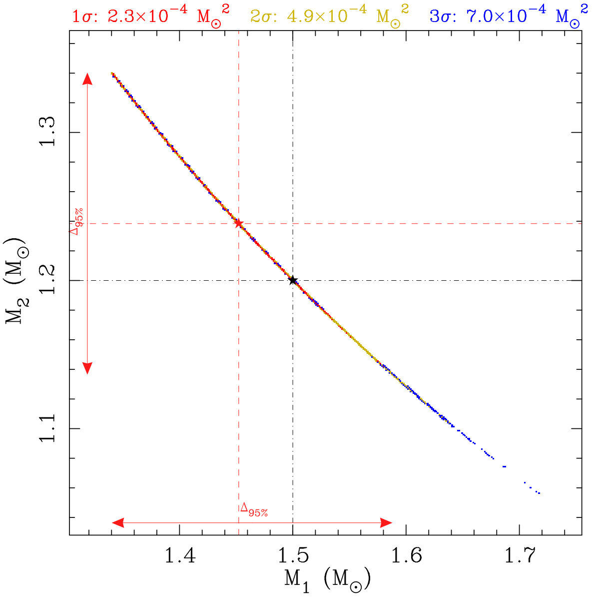

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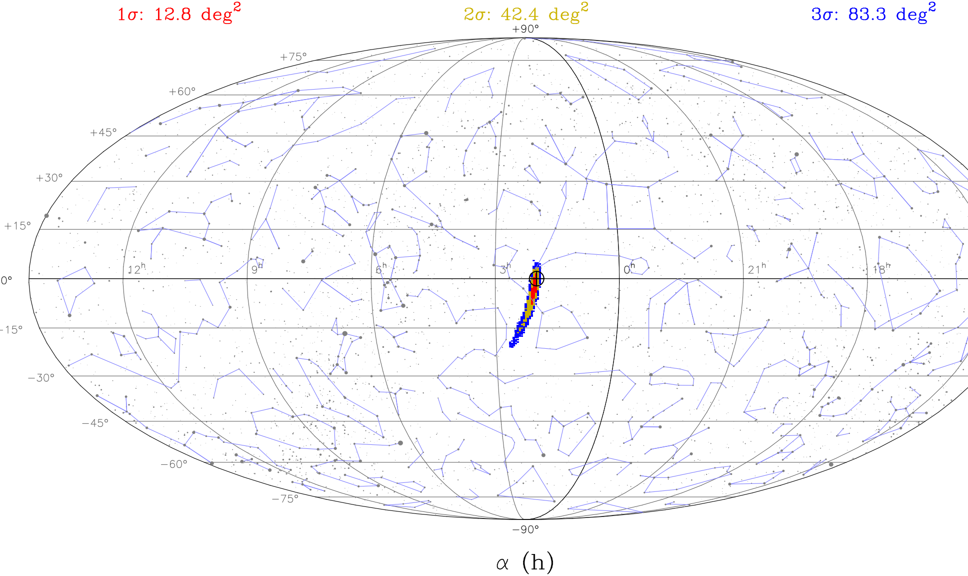
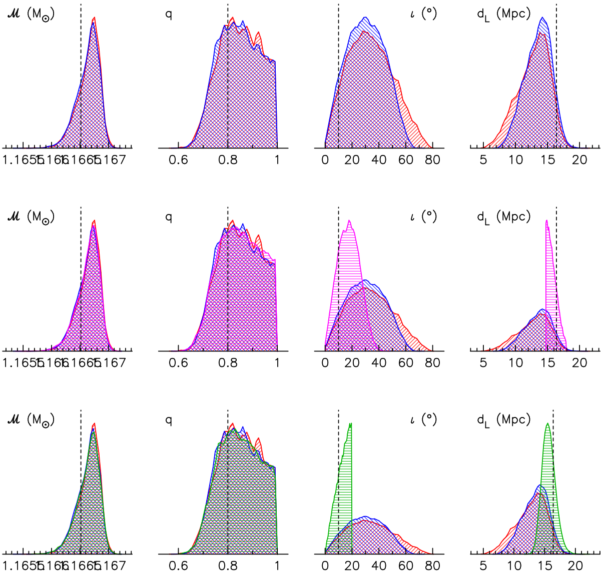


Short GRB: NS-NS inspiral without spin



NS-NS, non-spinning:
$1.2 + 1.5\,M_\odot$
$d_L \approx 10.2 - 17.8\,\mathrm{Mpc}$
(Σ SNR=15.0)

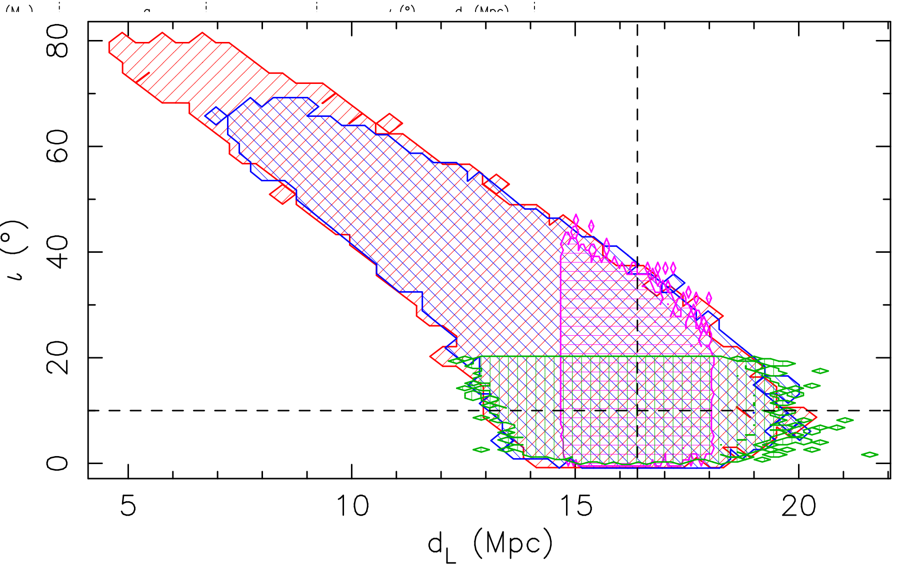
No astrophysical information

Sky position known exactly

Sky position known exactly
+ distance known $\pm 10\%$

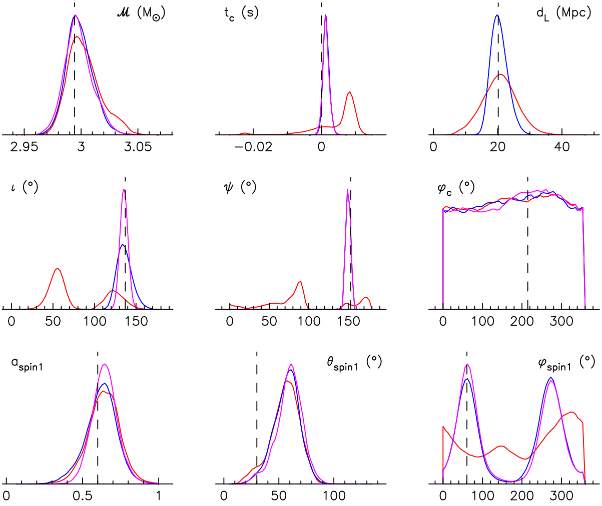
Sky position known exactly
+ inclination known: $\iota < 20^\circ$

Short GRB: NS-NS inspiral without spin



Short GRB: BH-NS inspiral with spin

2 detectors (H1,L1):



BH-NS, spinning BH:
$10 + 1.4\,M_\odot$, $a_{\rm spin} = 0.6$
$d_L \approx 20.2$ Mpc (Σ SNR=15.0)

No astrophysical information

Sky position known

Sky position and distance known

GW parameter-estimation code

- Can recover the 9–12–15 parameters of a binary inspiral, including one or two spins, using an MCMC technique

- Sky-position reconstruction (few $\times 10^{\circ^2}$) is poor for astrophysical standards
- Combination of position, distance and time can lead to association with an electromagnetic detection (*e.g.* GRB)

Measuring NS masses

- Individual masses can be measured with an accuracy of $\sim 15 - 20\%$
- Chirp mass well determined – most uncertainty is in mass ratio
- Uncertainty in $M_1 \times M_2$ is few $\times 10^{-4}\, M_\odot^2 \sim (0.02\, M_\odot)^2$

Conclusions (numbers are preliminary)

Using astrophysical knowledge for GW data analysis: no spins

- Knowing the sky position of a source improves determination of:
  - distance ($\sim 20 - 50\%$)
  - inclination (≥ 2 detectors)
- Knowing the position *and distance* improves inclination further, also in 1-detector analysis

Using astrophysical knowledge for GW data analysis: spins

- Knowing the sky position of a source improves determination of:
  - distance ($\sim 50\%$)
  - inclination, polarisation angle ($50 - 90\%$)
  - masses ($\sim 20\%$)
  - spin angles
- Knowing the position *and distance* improves:
  - spin magnitude ($\sim 20\%$)