Estimation of cosmological parameters from gravitational-wave observations and its cross correlation with a galaxy catalog

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with

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As part of

CBC-Cosmology Group

7th Belgium-Dutch Gravitational waves Meeting

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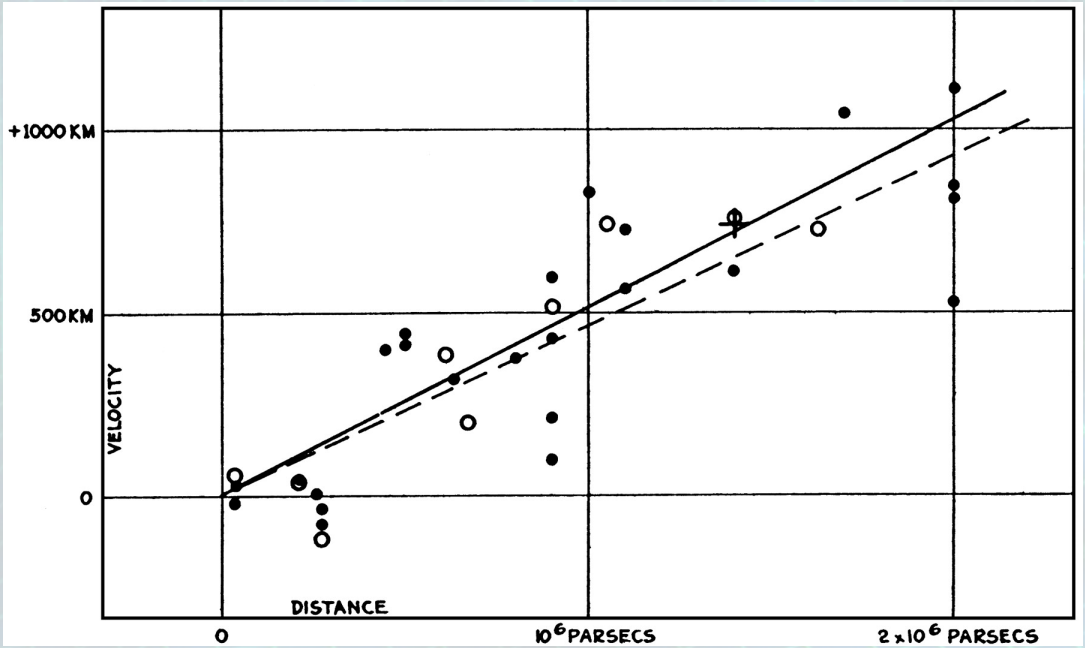
Measuring Hubble's Constant

- Plot velocity along y-axis and distance along x-axis
- Get the best fit



PNAS March 15, 1929. 15 (3) 168-173

$$v_{rec} = zc = \mathrm{H_0 D_L}$$

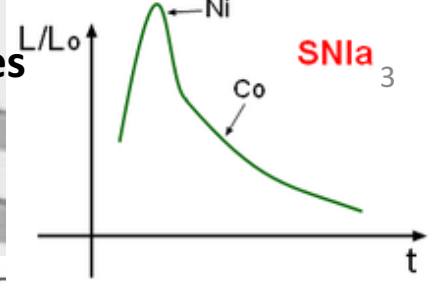
(in local universe)

Slope = $\mathrm{H_0}$

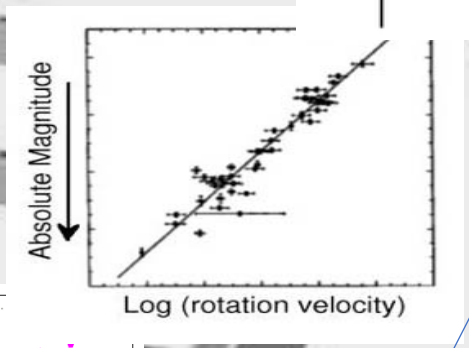
Important parameter in cosmology!

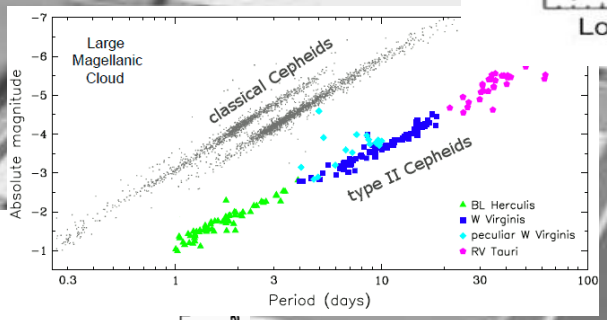
Cosmic Distance Ladder

Standard Candles

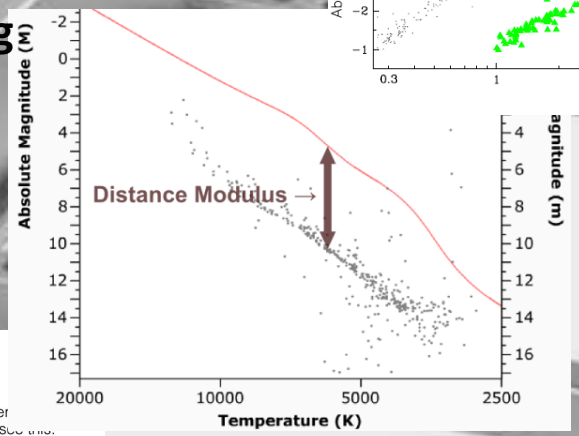


Tully Fisher Relation





Main sequence fitting



Cepheids

200 Mpc

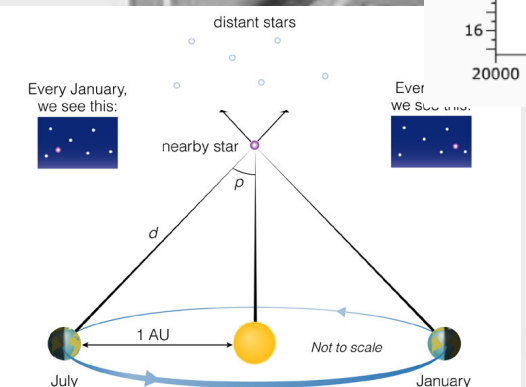
25 Mpc

10 Mpc

10 kpc

100 pc

parallax



Gravitational Waves

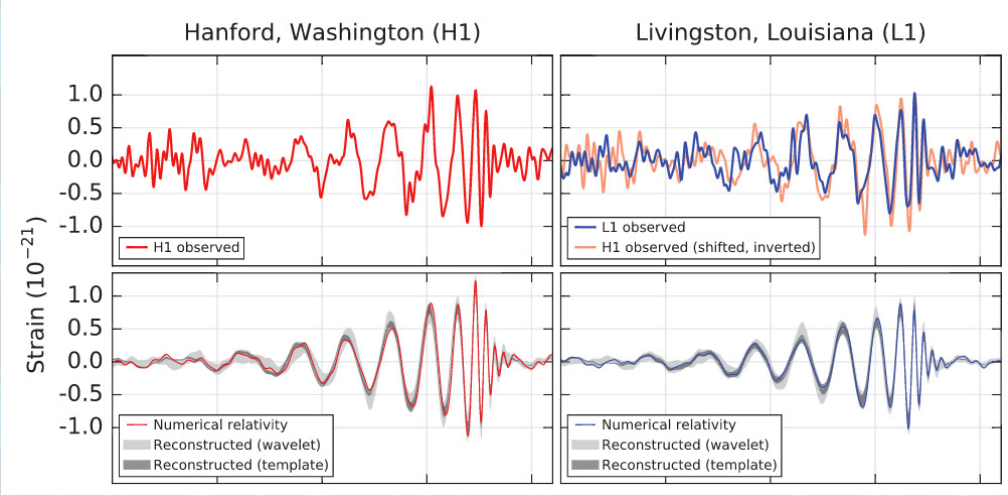
- Detected by LIGO and VIRGO

$$h(t) \sim \frac{M^{5/3}}{D_L}$$

- Phase = Chirp Mass
- Strain = D_L

Standard Sirens!

Credit:LIGO Caltech

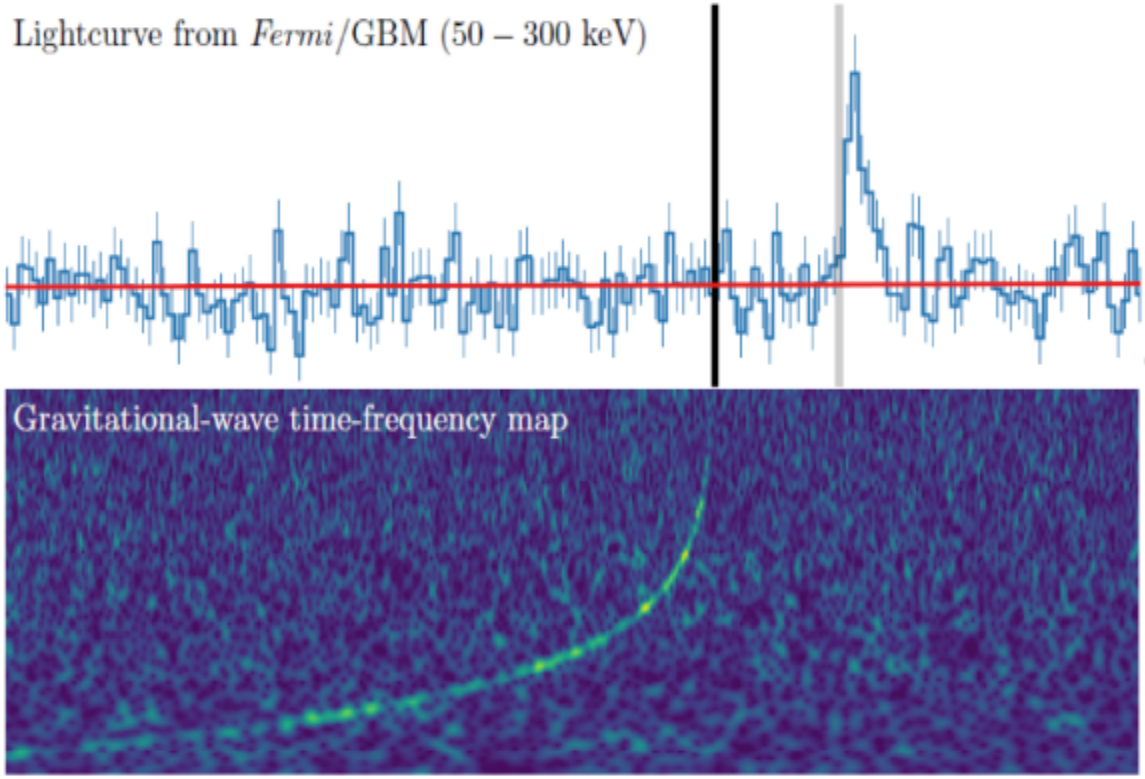


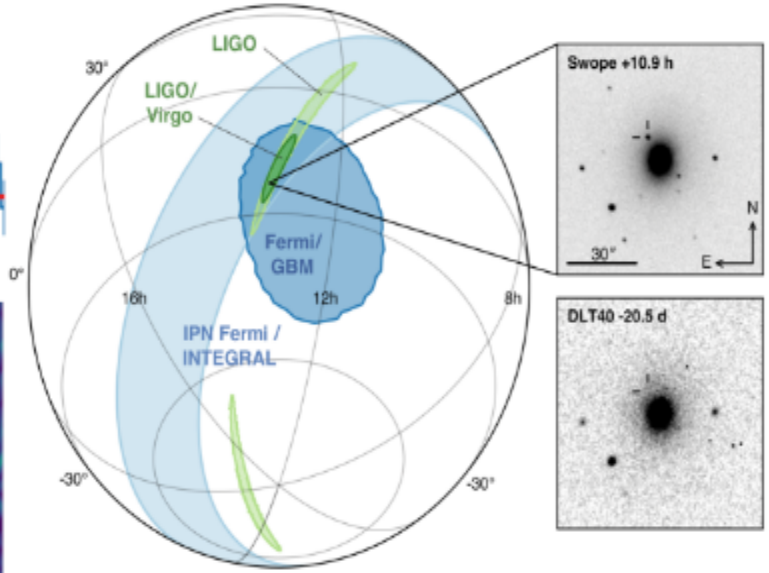
PRL 116, 061102 (2016)

Motivation:

GW170817 + Electromagnetic counterpart = redshift

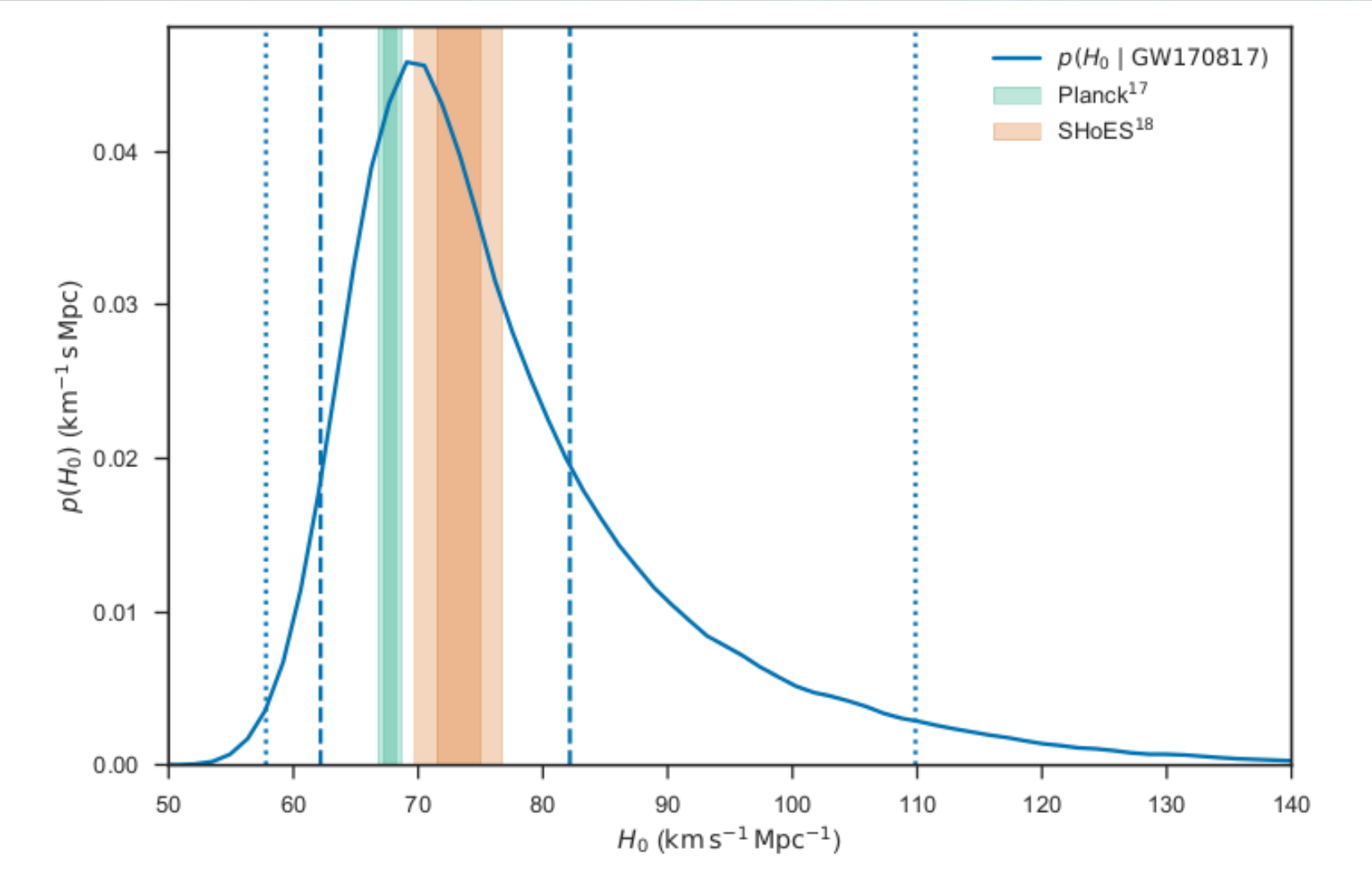
LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars





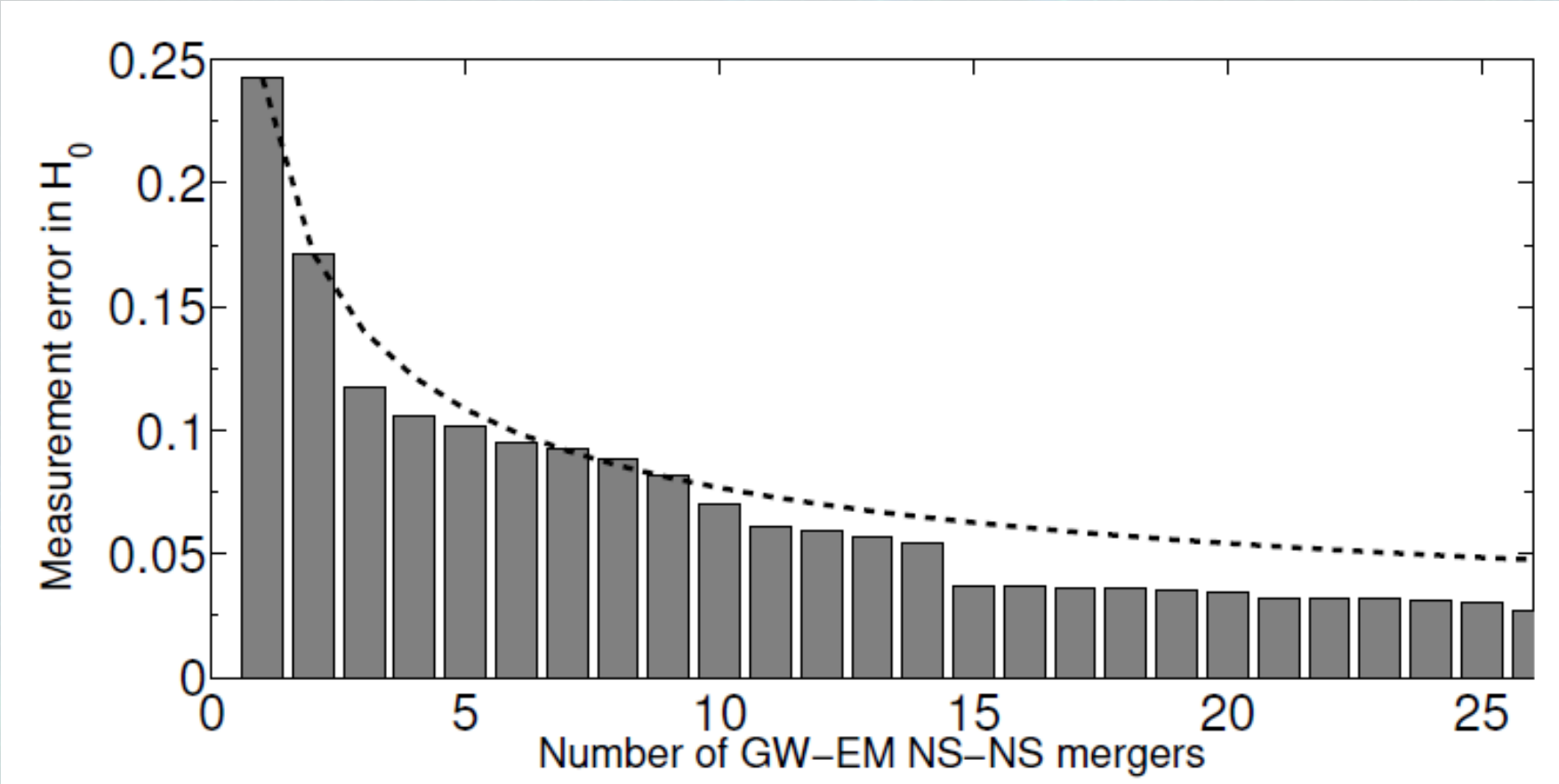
From https://www.ligo.org/

First standard siren measurement of H_0



Nature 551,8588 (02 November 2017)

Convergence Plot



Nissanke et al (ArXiv:1307.2638)

Statistical Approach

- In the absence of transient EM counterpart, we use information present in a galaxy catalog.
- Take into account:
  - GW selection effects: detectors can only detect above a certain signal to noise ratio ($\rho_{th} = 8.0$)
  - EM selection effects: Use Schechter magnitude function to account for missing galaxies.
- Use Bayesian analysis
  - $P(\Omega|\varepsilon) = \frac{p(\varepsilon|\Omega)p(\Omega)}{p(\varepsilon)}$

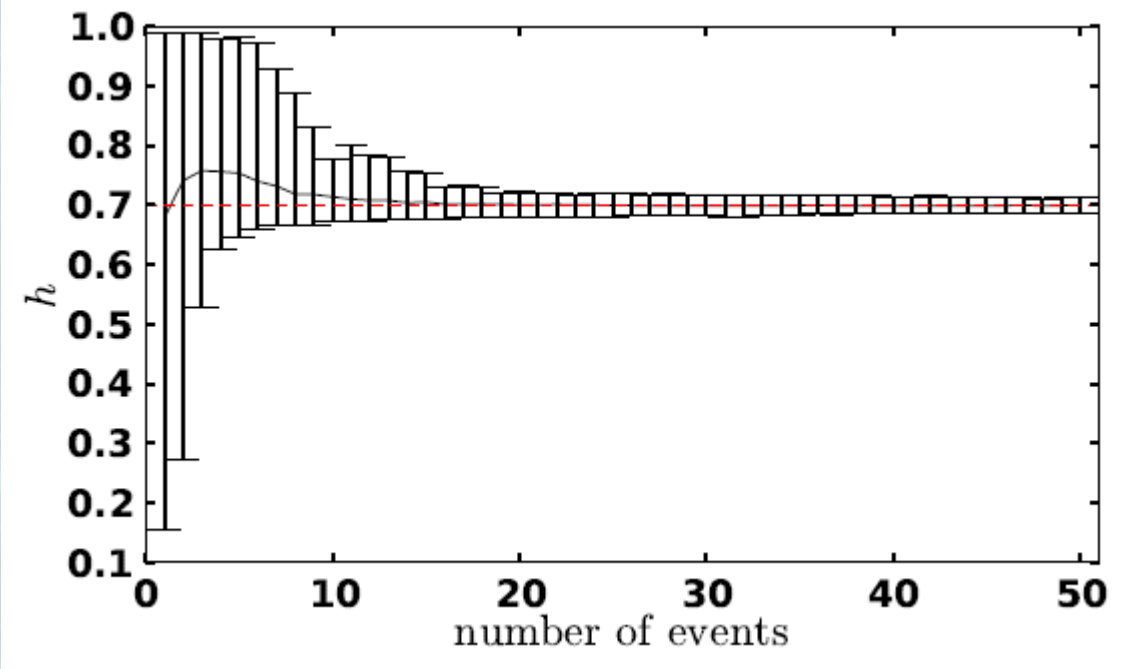
flat prior on H_0

- $p(\varepsilon|\Omega) = \underbrace{\frac{N_o}{N_g}\sum w_o\, p\big(D_L(z_o,\Omega)\big)}_{\text{Information from catalog}} + \underbrace{\frac{N_u}{N_g}\int dz dM\, p(\varepsilon|M,z,\Omega)\phi(M)\Theta(m(M,z,\Omega)-mth)p(z|\,\Omega)}_{\text{Term accounting for missing information in the catalog}}$

Statistical Approach

- applicable to sources without counterparts and even binary black hole coalescences.

- Combining information across events is crucial for measurement of H_0 be it the counterpart or the statistical approach. Understanding systematic effects is important, since even small systematic effects can get amplified over statistical errors while combining information from multiple events.

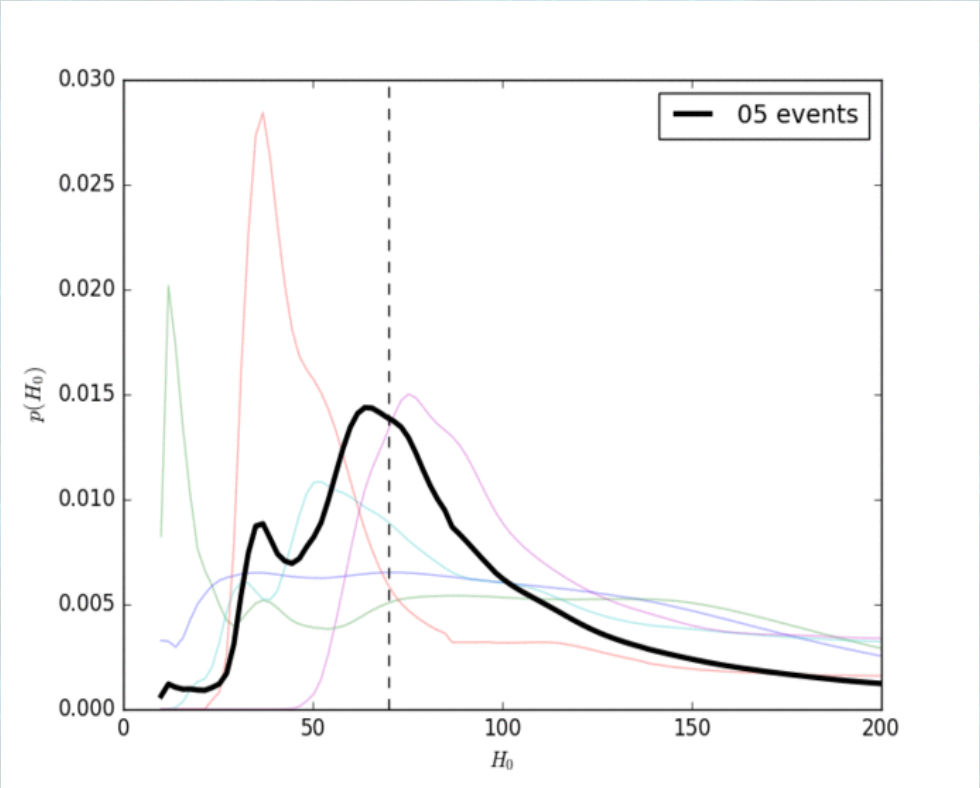


From: Del Pozzo, Phys. Rev. D **86**, 043011

Results

Mock galaxy catalog (Gray et al. in preparation)

- Simulations carried for binary neutron stars
- 250 sources
- Maximum redshift = 0.4
- Catalog complete up to $z = 0.1$ (distance = 435.5 Mpc)



Combined posterior on H_0

Conclusions and future directions

- H_0 can be statistically measured.
- Extend our analysis to determine other cosmological parameters.
- More luminous galaxies have higher probability of hosting GW sources.
- Account for redshift uncertainties in our analysis.