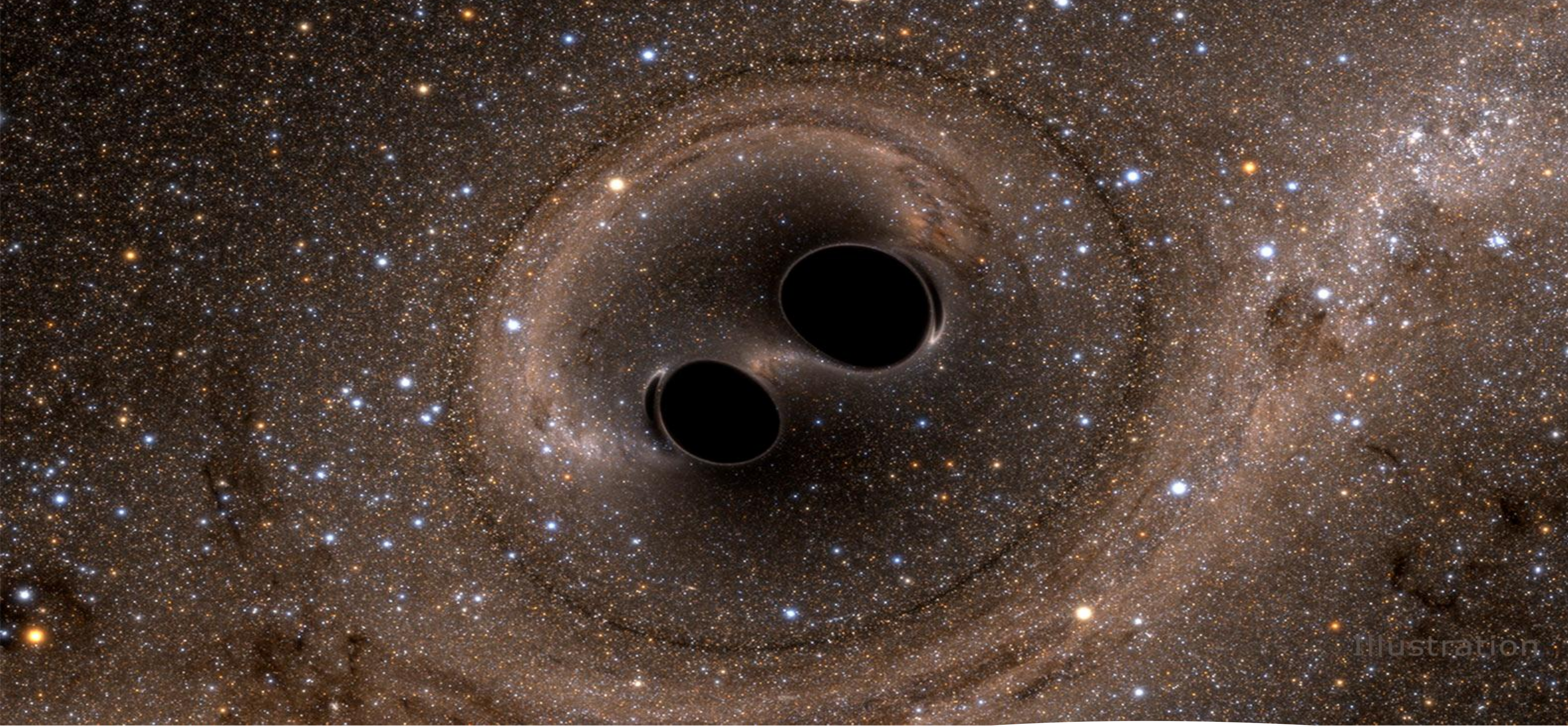


Estimating the Hubble constant from compact binary coalescences without electromagnetic counterparts

PHAROS CONFERENCE
April 2019

LIGO Scientific Collaboration
VIRGO

Ankan Sur
Nicolaus Copernicus Astronomical Center

The Hubble's Law

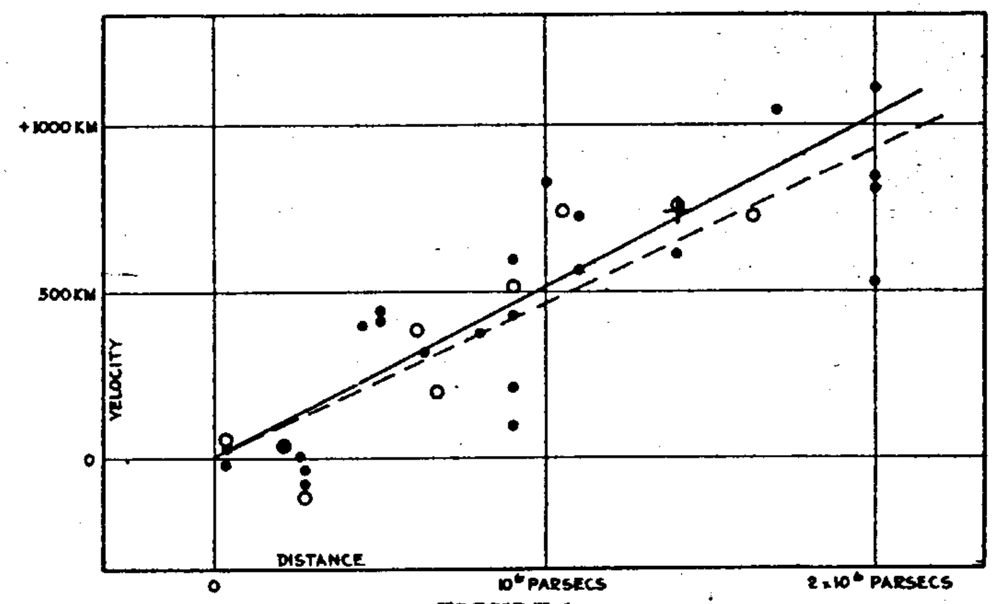


FIGURE 1

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

Recessional velocity

Hubble constant

$$cz = H_0 d_L$$

In local Universe

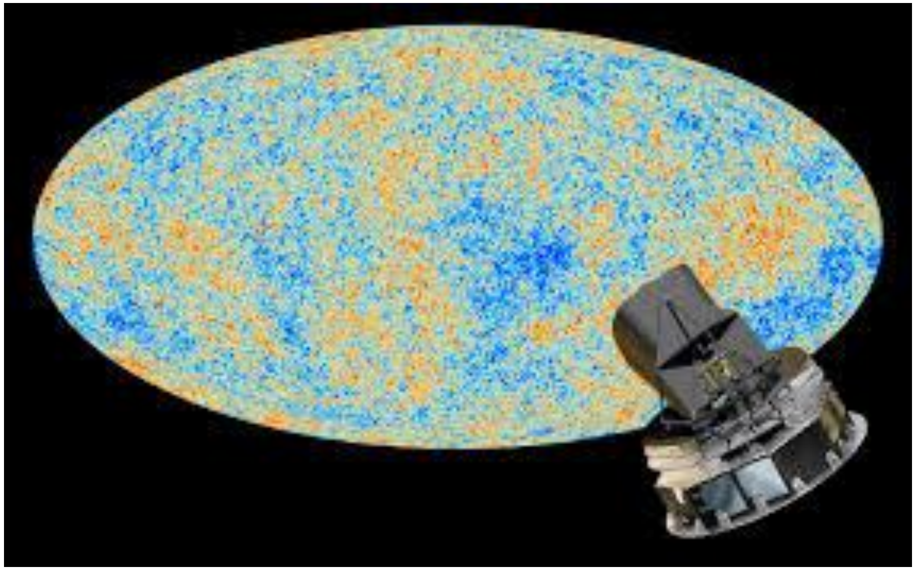
$$d_L = c(1+z)\int_0^z \frac{z'}{H(z')}$$

Distance-redshift relationship

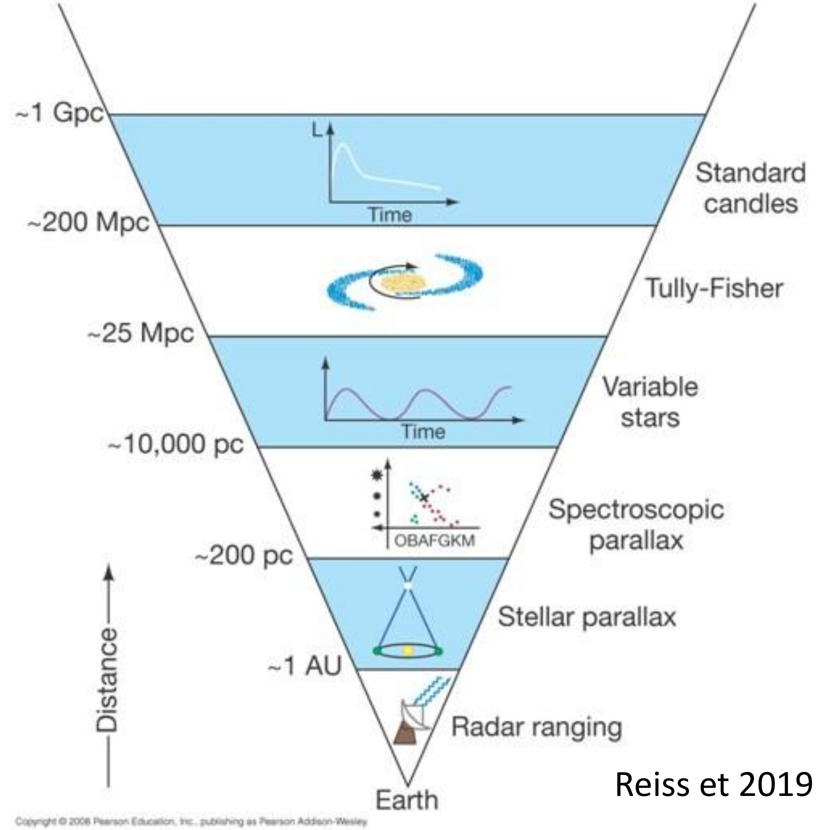
$$H(z') = H_0\sqrt{\Omega_m(1+z')^3 + \Omega_k(1+z')^2 + \Omega_\Lambda \exp\left\{3\int_0^z \frac{z''}{H(z'')}[1+w(z'')]\right\}}$$

Measures the expansion rate of the universe

The current tension



Planck collaboration 2018



Reiss et 2019

$$H_0 = 67.66^{+0.42}_{-0.42}\ \mathrm{Km}\ s^{-1}\mathrm{Mpc}^{-1}$$

$$H_0 = 74.03^{+1.42}_{-1.42}\ \mathrm{Km}\ s^{-1}\mathrm{Mpc}^{-1}$$

PLANCK Satellite

CMB measurements

SHoES experiment

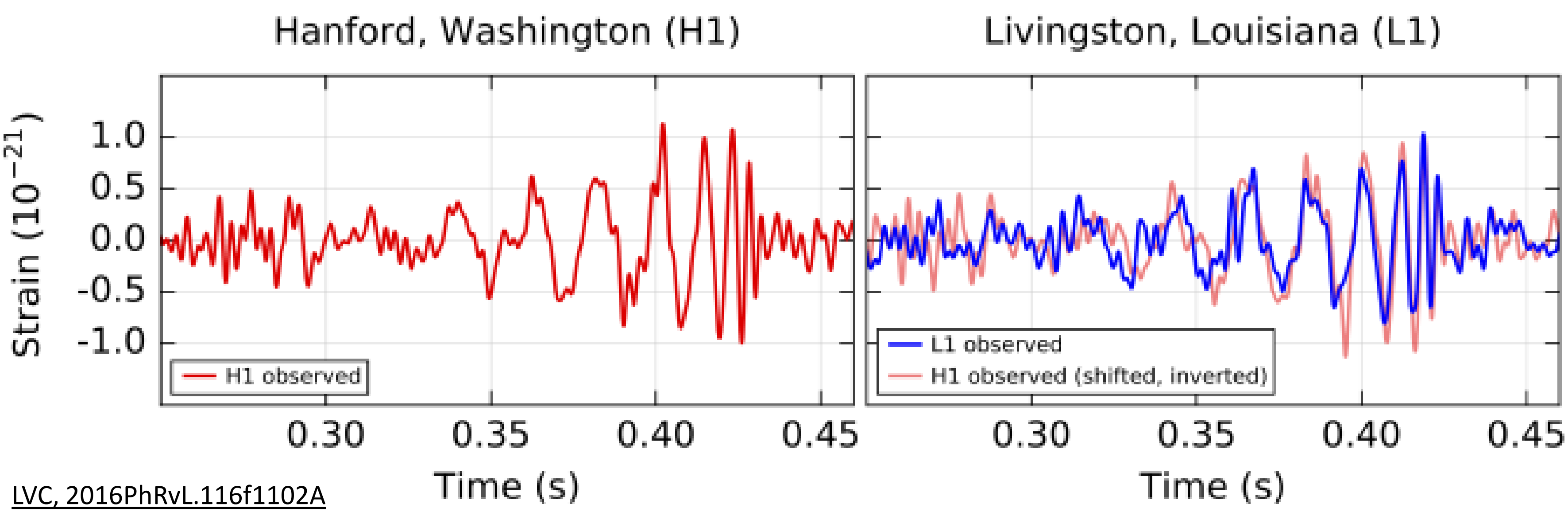
Distance ladder approach

Measurement tension of 4.4 sigma

Cosmology with Standard Sirens

Schutz 1986, Holz & Hughes 2005, Del Pozzo 2012

Gravitational Waves from compact binaries gives direct access to luminosity distance



LVC, 2016PhRvL.116f1102A

Measure strain → $h \sim \frac{\mathcal{M}^z}{d_L}$ ← Redshifted Chirp Mass

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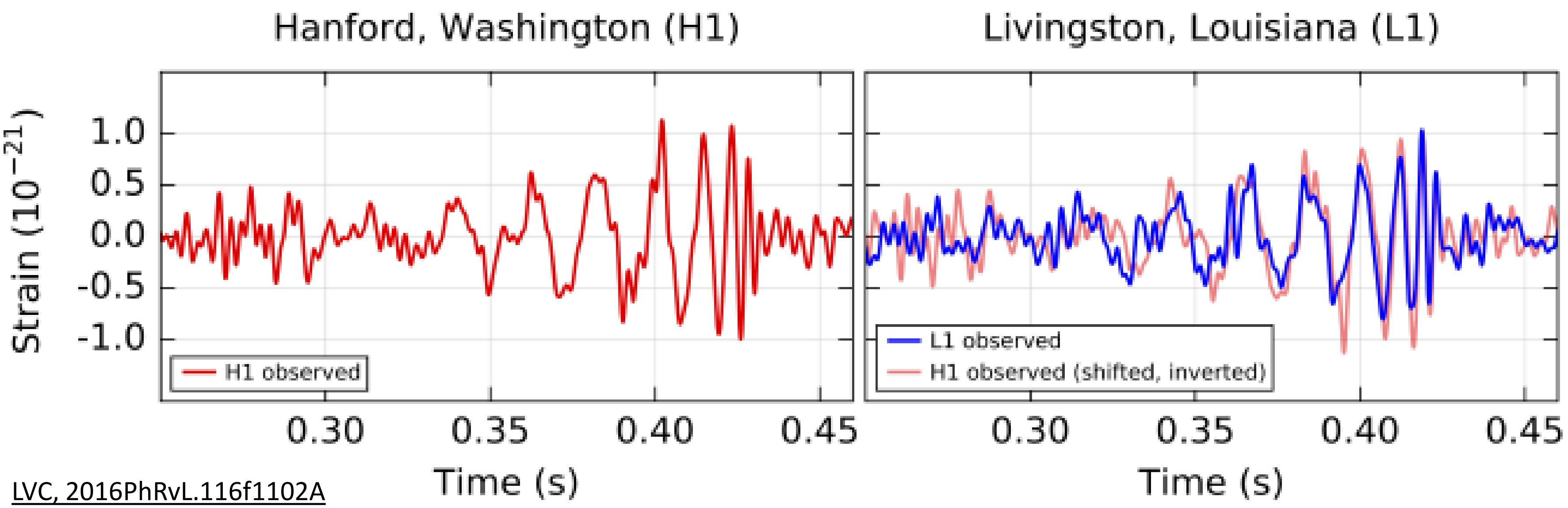


LVC, 2016PhRvL.116f1102A

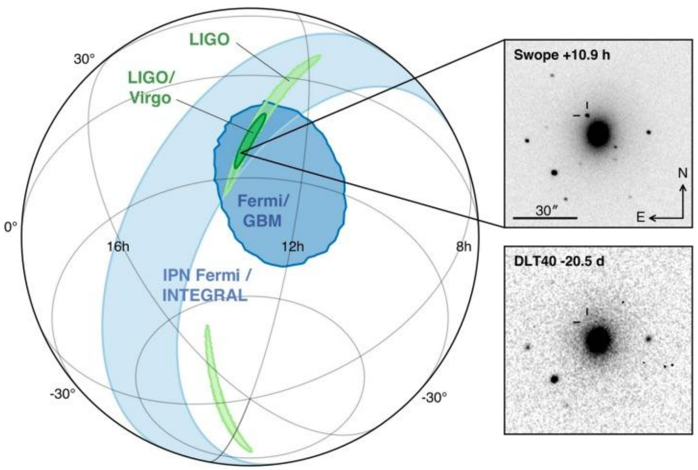
Measure strain → $$h \sim \frac{\mathcal{M}^z}{d_L}$$ ← Redshifted Chirp Mass

Independent of any Cosmic Distance Ladder

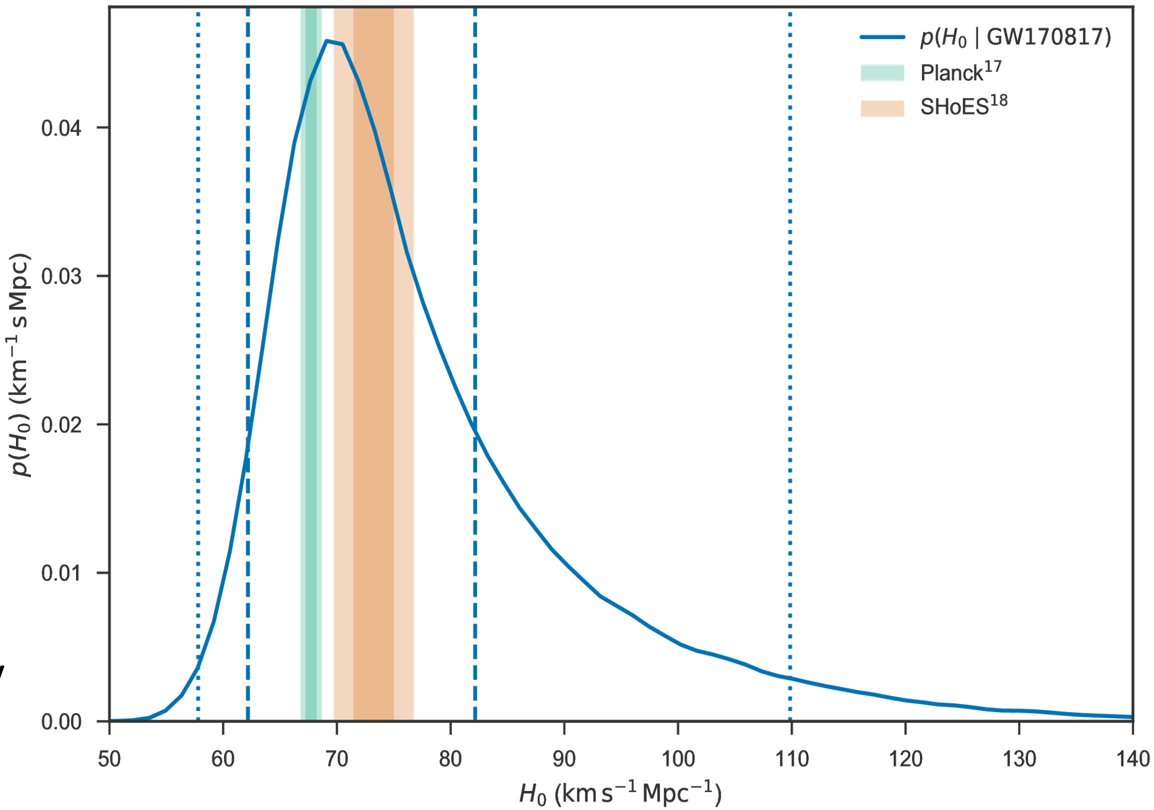
H_0 with GW170817

Gravitational Waves from Binary Neutron Star Merger

Phys. Rev. Lett. **119**, 161101



Recessional velocity from host galaxy NGC4993

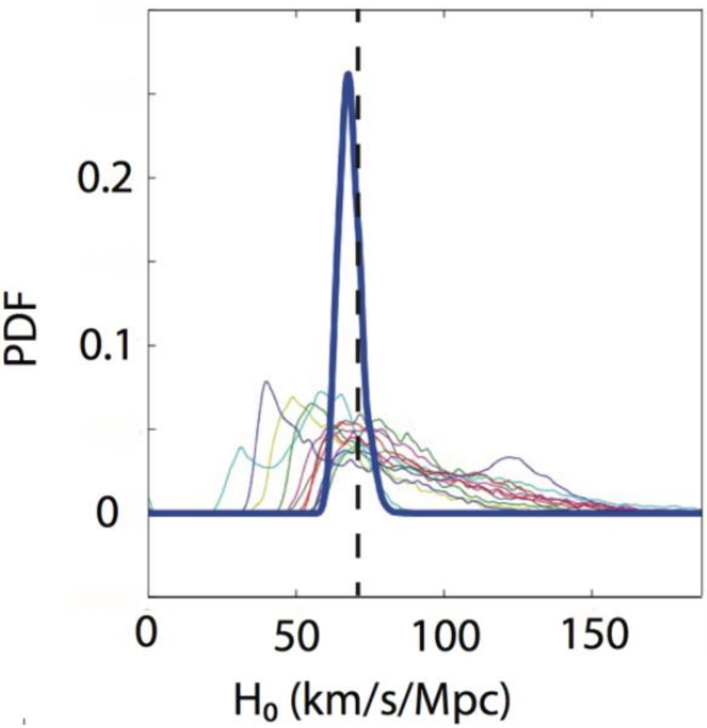


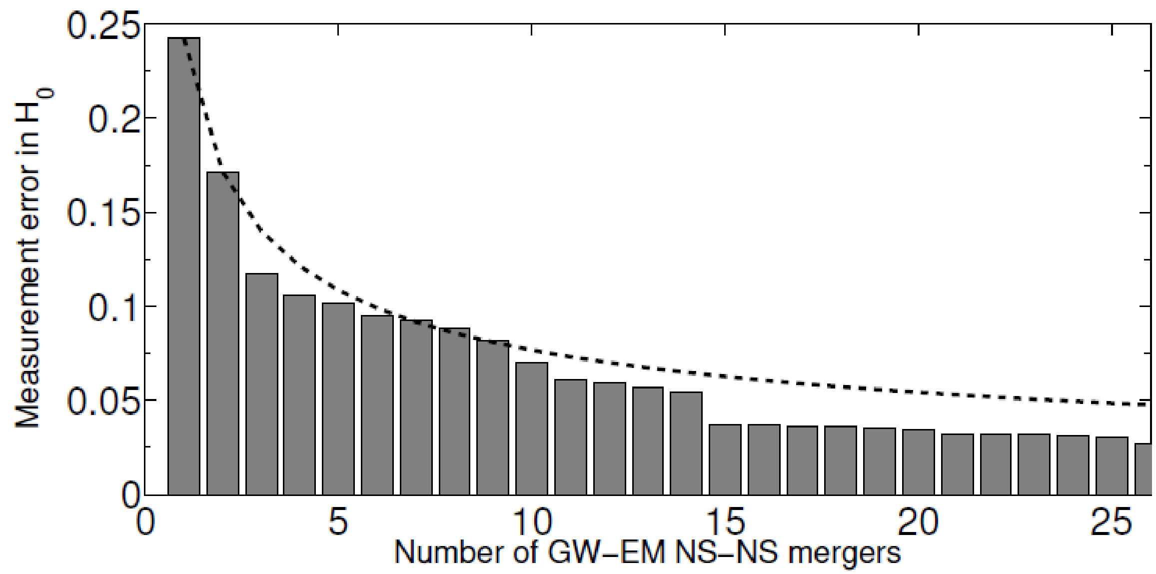
Nature 551,8588 (02 November 2017)

$$H_0 = 70^{+12}_{-8}\ \mathrm{Km}\ s^{-1}\mathrm{Mpc}^{-1}$$

Better with more detections!

Nissanke et al (ArXiv:1307.2638)





Combined measurements with identification of host galaxies and hence redshifts!

The Statistical Method

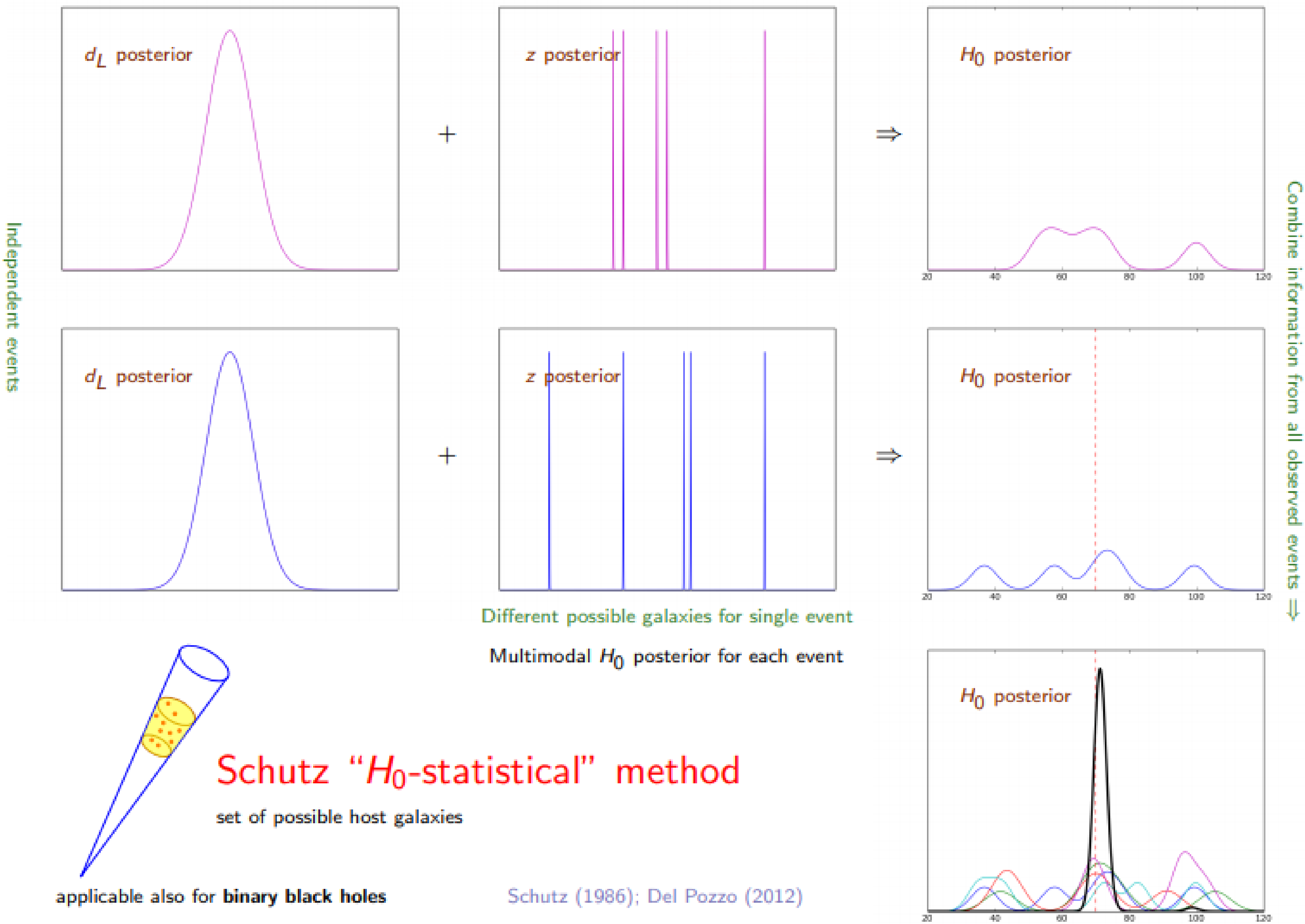


Illustration: Archisman Ghosh

gwcosmo :code and the method

Magana Hernandez, Gray, …..

BAYESIAN approach

Brady, Chen, Del Pozzo, Gair, Ghosh, Holz, Messenger, Veitch, …..

- Probability :

$$p(H_0|x_{GW}, D_{GW}) \propto p(H_0)p(N_{det}|H_0)\prod_i^{N_{det}} p(x_{GW_i}|D_{GW_i}, H_0)$$

Combine multiple observations

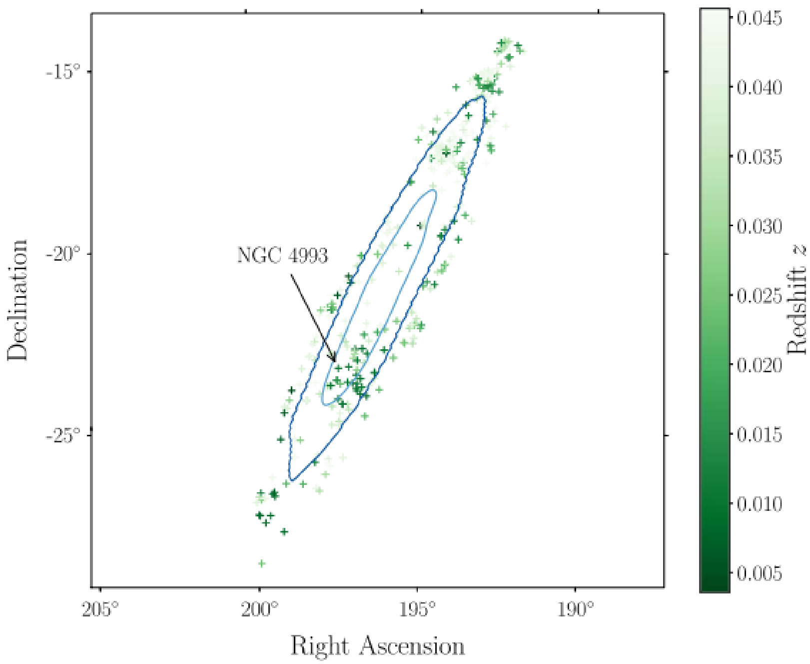
- The statistical method: likelihood

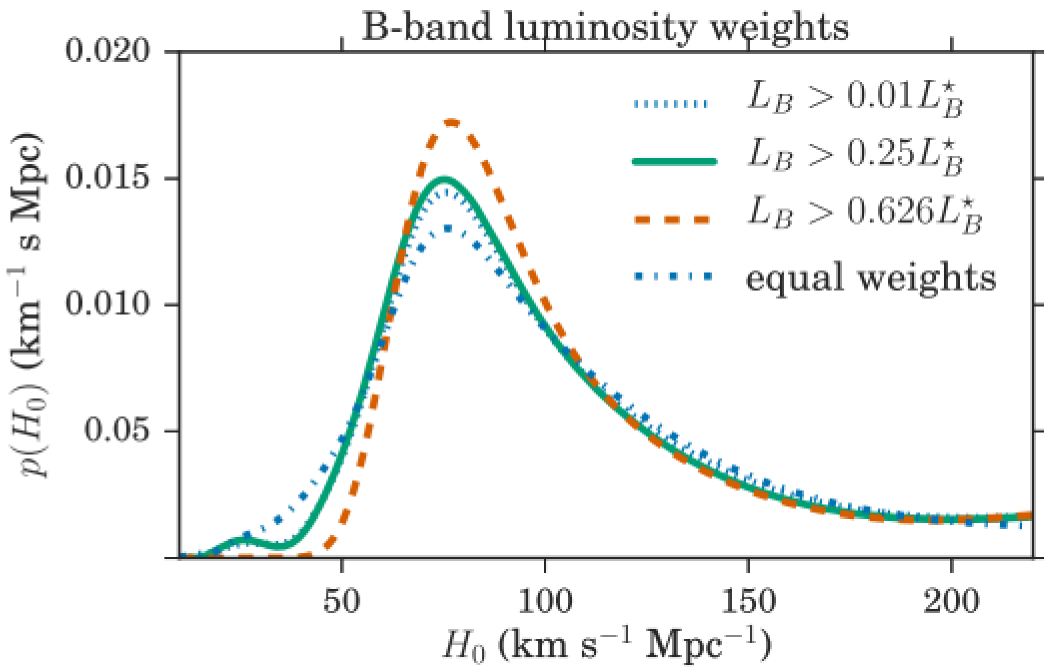
$$p(x_{GW}|D_{GW}, H_0) = \frac{p(x_{GW}|G, H_0)}{p(D_{GW}|G, H_0)}p(G|D_{GW}, H_0) + \frac{p(x_{GW}|\bar{G}, H_0)}{p(D_{GW}|\bar{G}, H_0)}p(\bar{G}|D_{GW}, H_0)$$

Information from the catalog and host galaxies outside the catalog

H_0 Statistical with GW170817

Fishbach et al, ApJL 2019 Jan 20





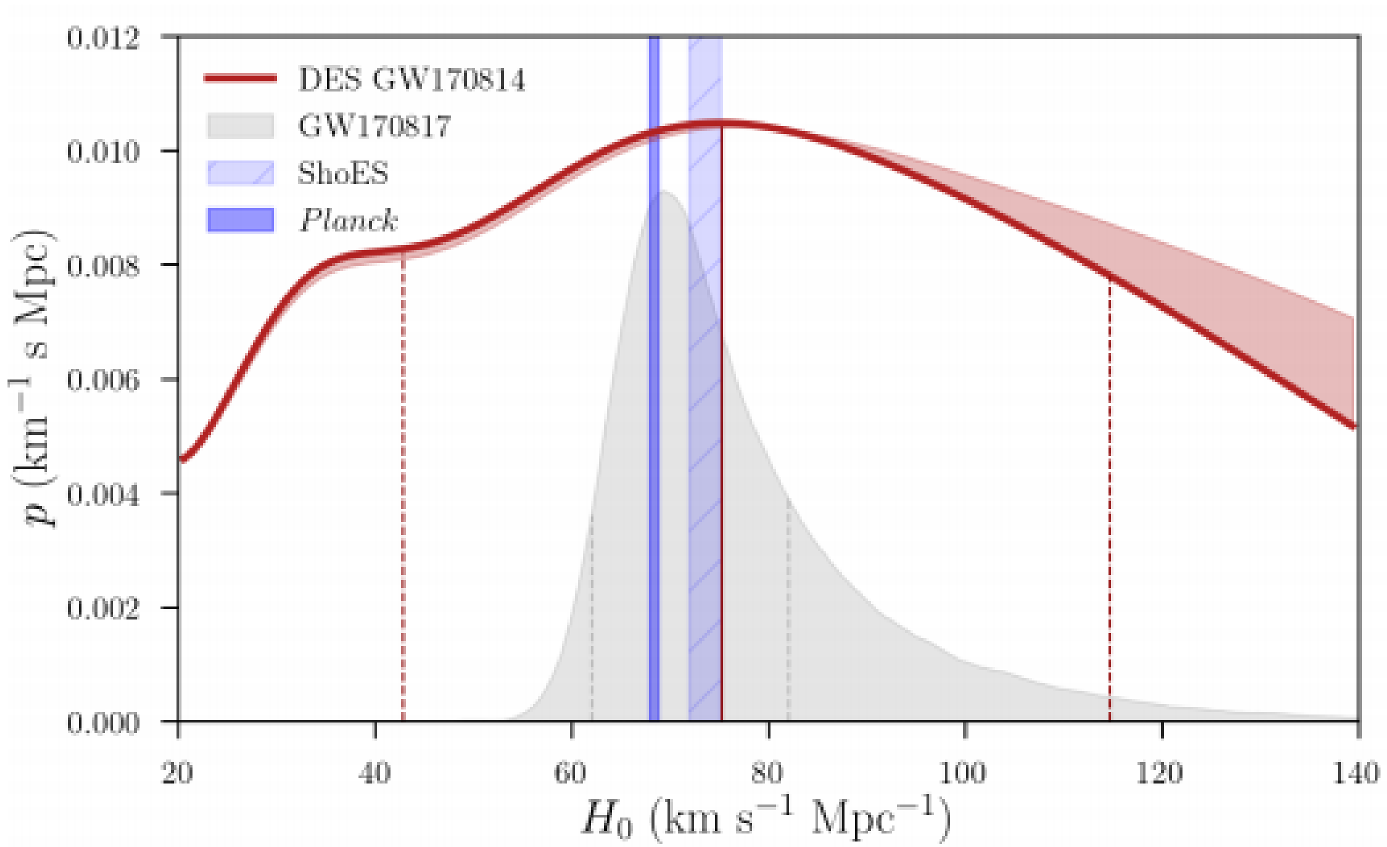
- Assume no counterpart
- Correct for incompleteness of galaxy catalogs
- Luminosity weighting

$$H_0 = 77^{+37}_{-18}\ \mathrm{Km}\ s^{-1}\mathrm{Mpc}^{-1}$$

H_0 Statistical with GW170814

Soares-Santos et al, arXiv:1901.01540

DES Y3 data



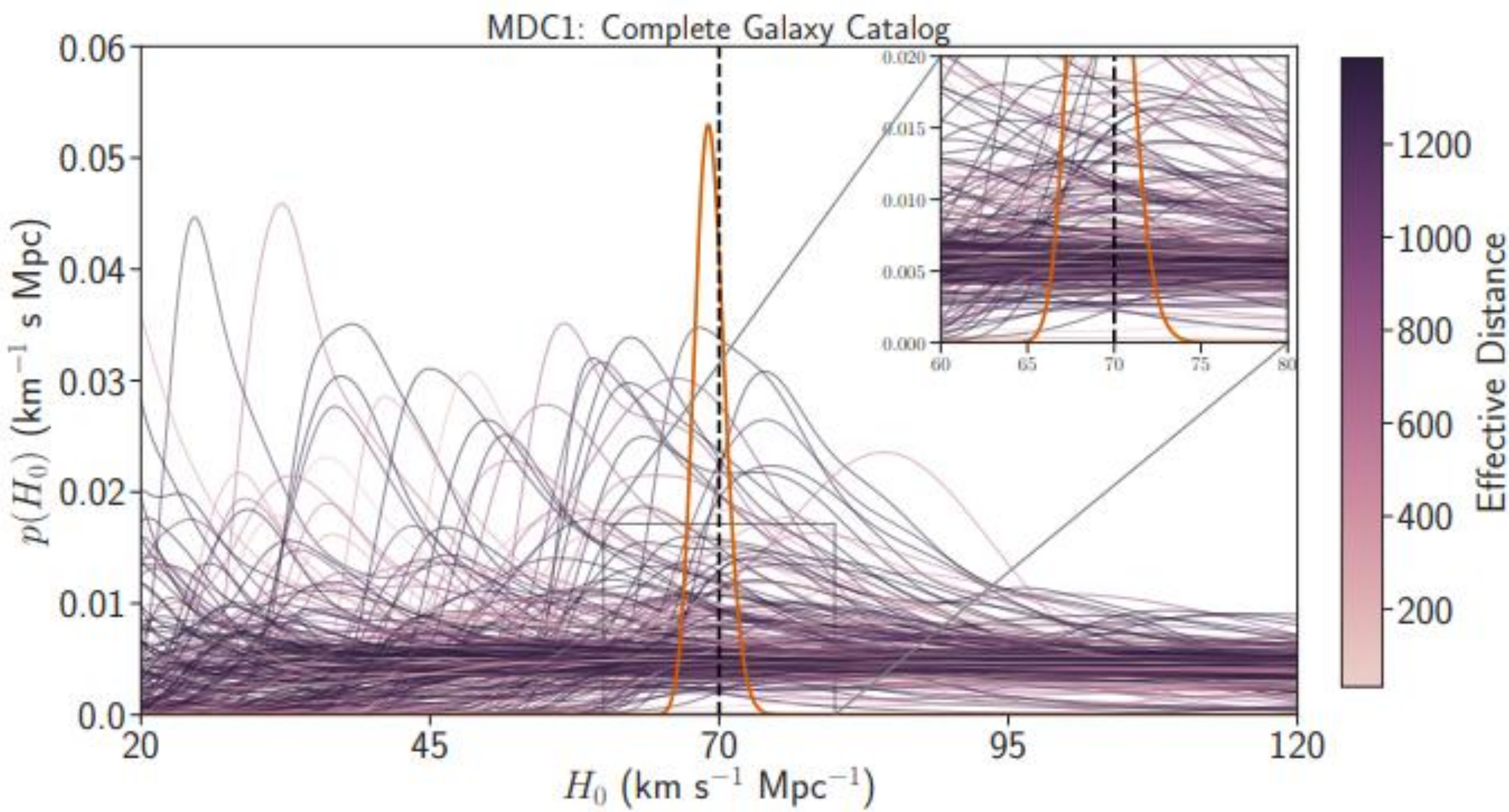
First measurement of H_0 from binary black hole

$$H_0 = 75^{+40}_{-32} \text{ Km } s^{-1}\text{Mpc}^{-1}$$

Results on Simulations

250 simulated events of Binary Neutron Stars with varying catalog completenesses

Gray, Magana Hernandez, Qi, Sur, Fishbach…



Gray et al. (in prep)

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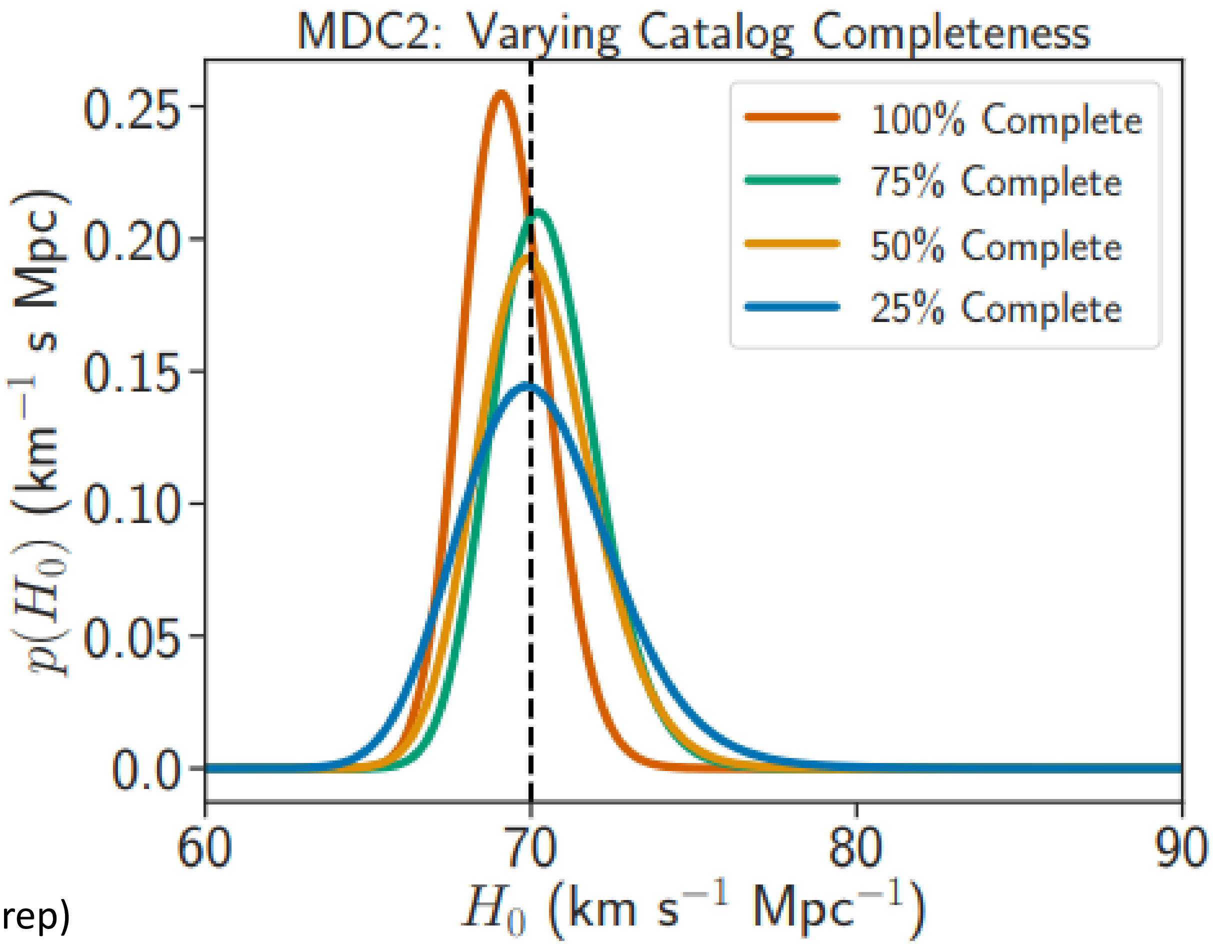

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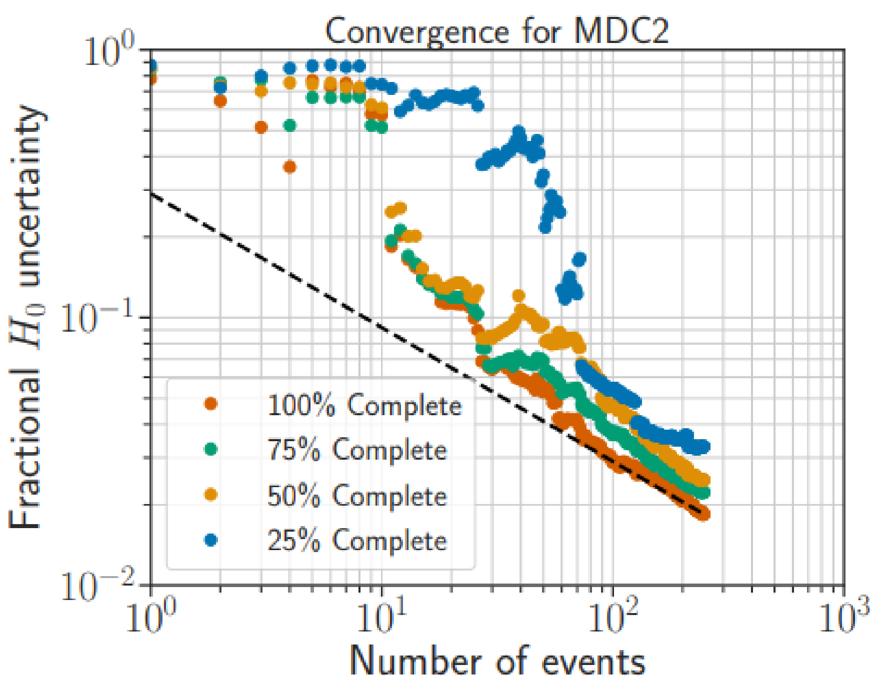

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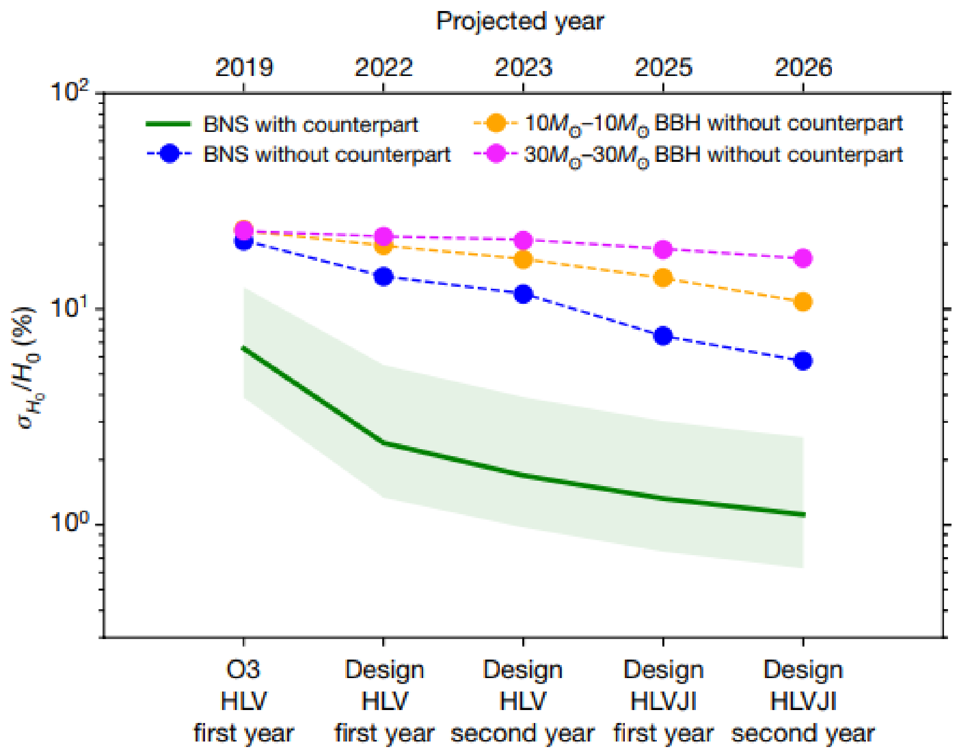

Chen et al, Nature, 2018

Expected a 2 per cent measurement of the Hubble constant within 5 years!

Conclusions

- Gravitational waves are an important tool in cosmology
- Expected a well constrained measurement of the Hubble constant
- Understanding systematic effects is important
  - Gravitational waves selection effects
  - Electromagnetic selection effects
- Can be applied for other measurements