Snakes but no ladders

a standard-siren measurement of the Hubble parameter

Archisman Ghosh

Nikhef, Amsterdam

Cosmic fireworks: Celebrating the dawn of multimessenger astronomy

ICTS Bangalore, 2017 October 19

Abbott *et al.* Nature (2017), DOI: 10.1038/nature24471

Hubble's law

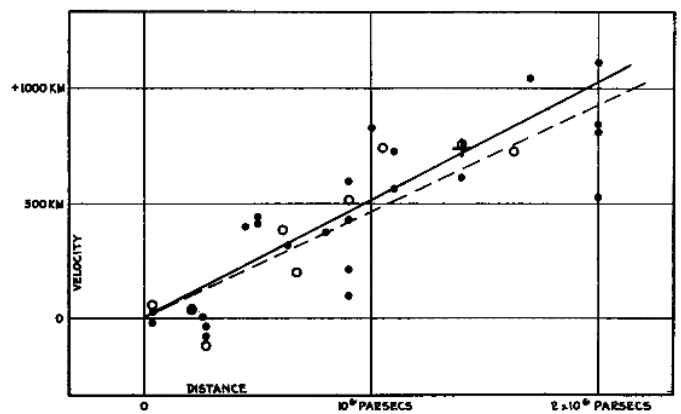
recession velocity of a galaxy in the local universe $\longrightarrow$ $v_H = H_0\, d$ $\longleftarrow$ distance to the galaxy

$\uparrow$

Hubble parameter

recession $\longrightarrow$ stretching of spacetime itself $\longrightarrow$ expansion of the universe

usually measured as a cosmological redshift $v_H = c\, z$

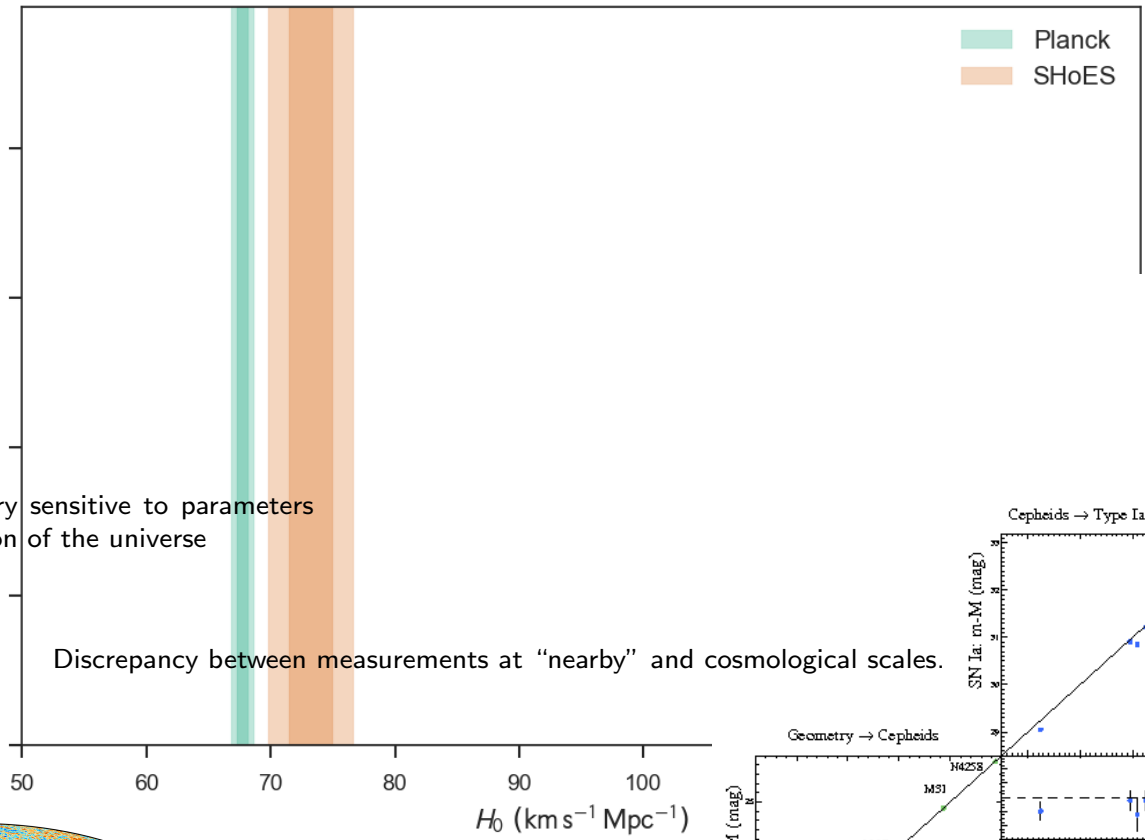


Edwin Hubble, *Proc. Nat. Acad. Sciences.* (1929)

Note: significant overestimate

State-of-the-art measurements of H_0

Two contrasting methods applied on nearby and very distant cosmological scales

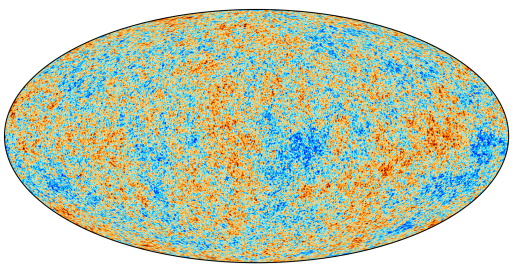


Standard candles

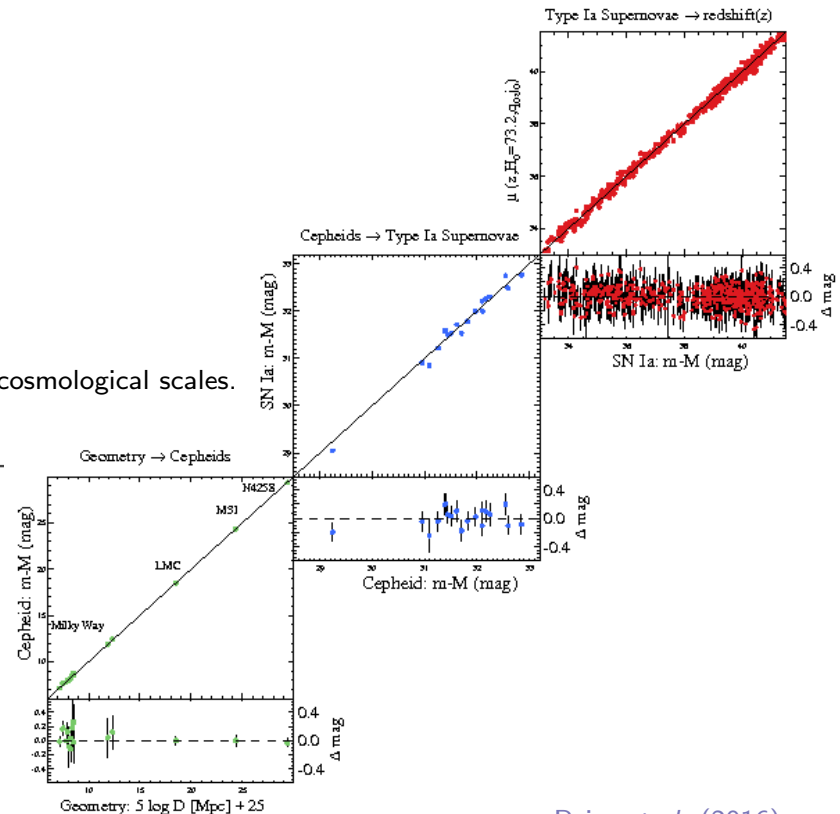
Cosmic distance ladder

CMB anisotropies: very sensitive to parameters that drive the expansion of the universe

Discrepancy between measurements at "nearby" and cosmological scales.



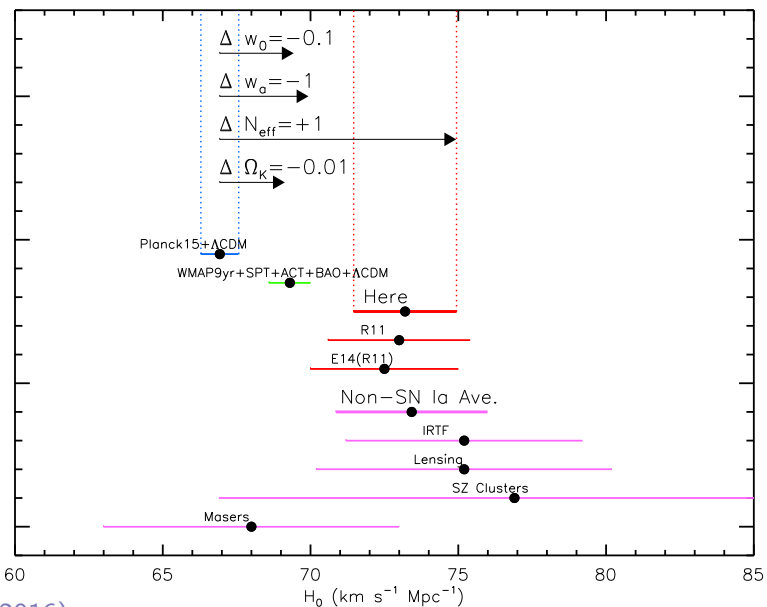
Planck collaboration (2015)



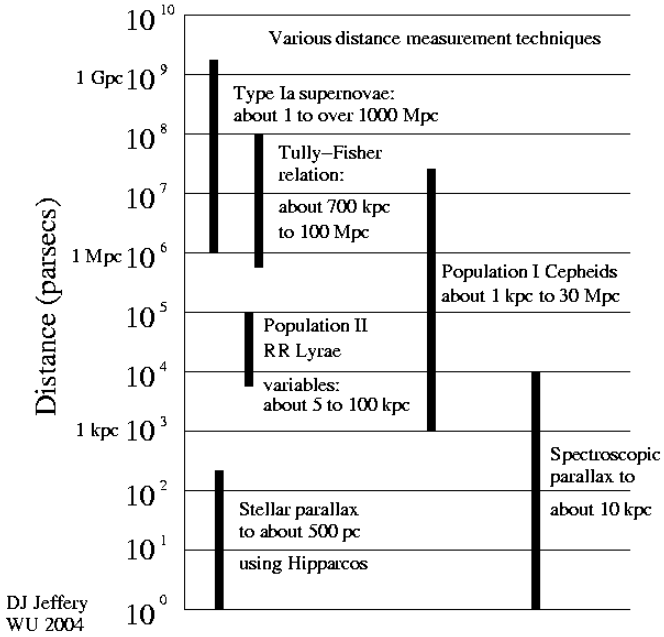
Reiss *et al.* (2016)

H_0 measurement: take-home messages

- Crucial parameter in cosmology
- Measurement not yet free of discrepancies



Reiss *et al.* (2016)



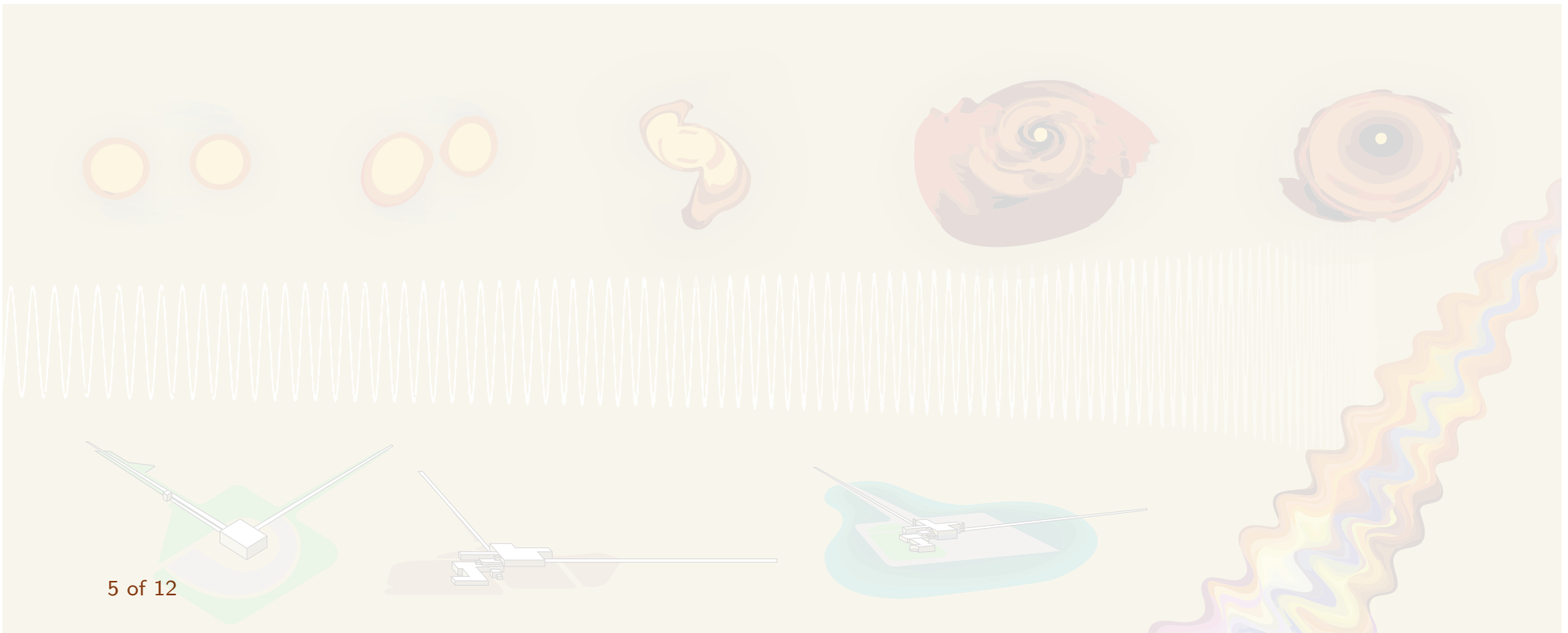
Standard sirens

GW detectors are sensitive to both amplitude and phase evolution of the chirp signal.

For a compact binary coalescence: phase evolution $\Rightarrow$ masses

amplitude $\Rightarrow$ distance and inclination

Schutz (1986); Holz & Hughes (2005)



Recession velocity (redshift) measurement

- Incredibly difficult with gravitational wave data alone.

  Total mass is largely degenerate with cosmological redshift

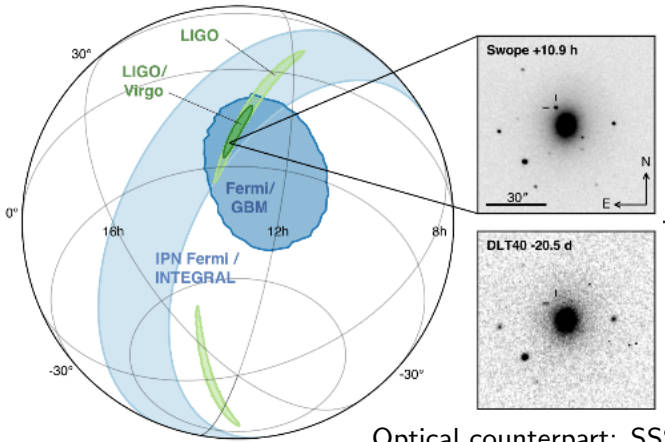
- Input can be solicited from electromagnetic observations.

Over to GW170817 . . .

Summary of GW170817 analysis and illustration of result

observed $v_{\text{recession}} = v_H + v_{\text{peculiar}}$

universe is not homogeneous at small scales:
galaxies attracted towards local matter overdensities



Optical counterpart: SSS17a

Host galaxy: NGC 4993

NGC 4993: $v_{\text{recession}} = 3327 \pm 72\,\text{km}\,\text{s}^{-1}$

Correct for peculiar velocity of group of galaxies

$$v_H = 3017 \pm 166\,\text{km}\,\text{s}^{-1}$$

Distance, $d_L = 43.8^{+2.9}_{-6.9}\,\text{Mpc}$

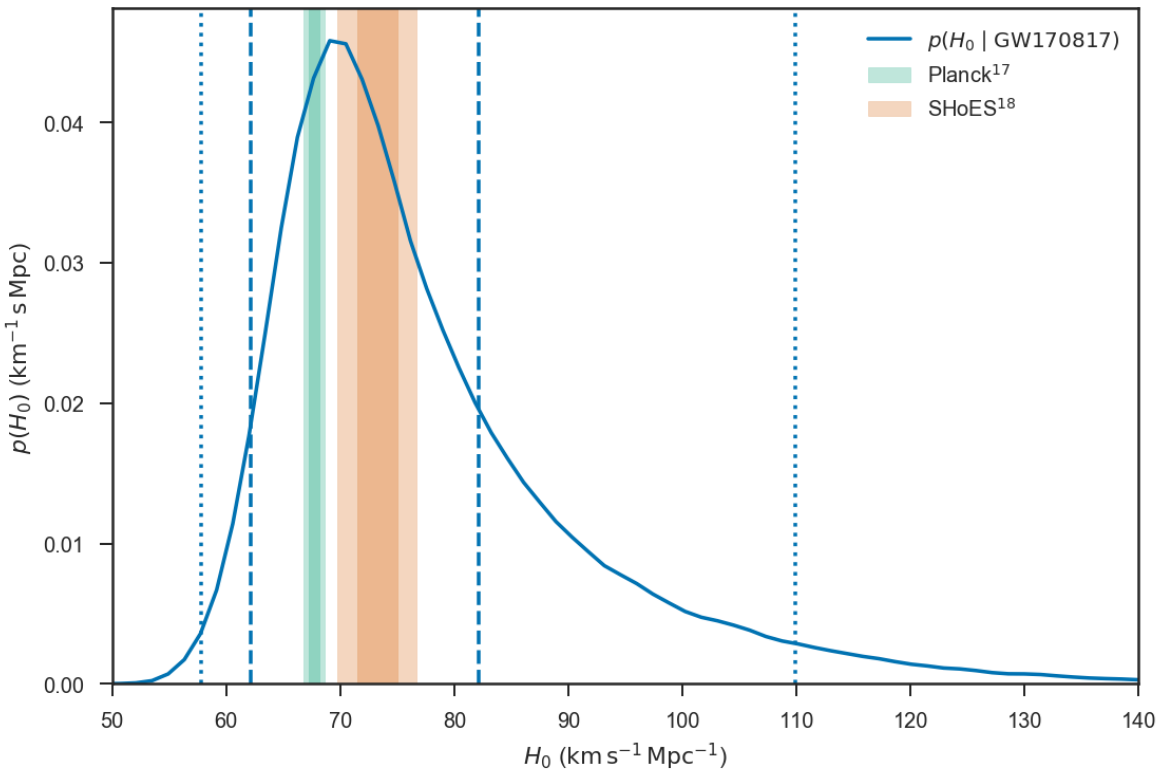
(assuming sky location of counterpart)

Abbott *et al.* Astrophys. J. Lett. (2017), DOI: 10.3847/2041-8213/aa91c9; LSC-EPO

Key result: $p(H_0|\text{GW170817})$

Bayesian parameter estimation

marginalized posterior probability density



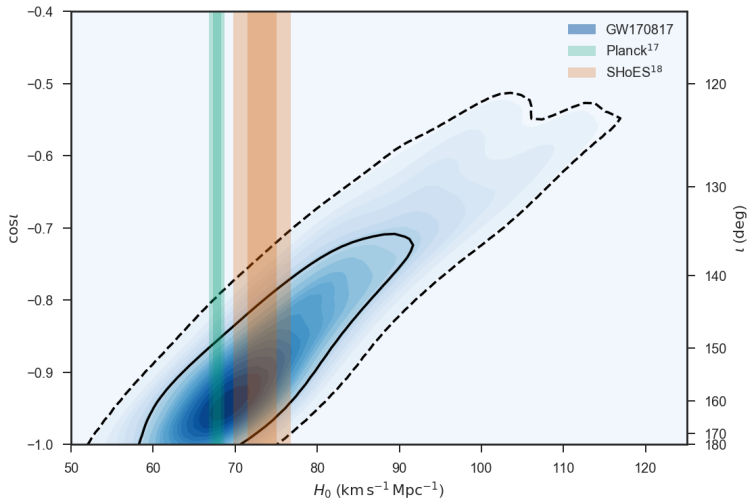
$H_0 = 70.0^{+12.0}_{-8.0}\,\text{km}\,\text{s}^{-1}\text{Mpc}^{-1}$

Broadly consistent with state-of-the-art determinations of H_0.

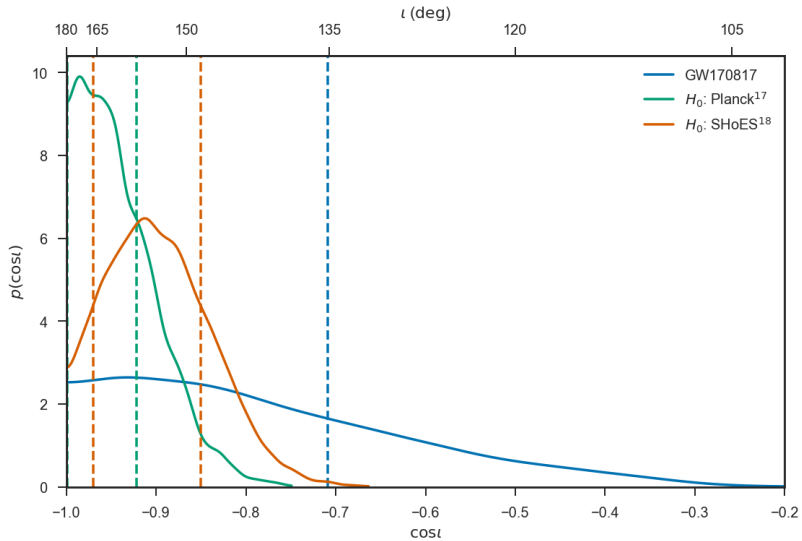
Abbott *et al.* Nature (2017), DOI: 10.1038/nature24471

Constraints on H_0 and inclination

Distance-inclination degeneracy: Gravitational-wave amplitude from by a distant binary viewed face-on or face-off is similar to that of a closer binary viewed edge-on.



Joint constraint on H_0 and inclination



Constraint on the inclination angle

Marginalization over $\cos\iota$ (vertical projection) gives H_0 result

Alternatively, marginalize over H_0 (horizontal projection)

Abbott *et al.* Nature (2017), DOI: 10.1038/nature24471

Conclusion

- First standard-siren measurement of the Hubble constant:

  GW $\Rightarrow$ distance estimate

  EM $\Rightarrow$ recession velocity

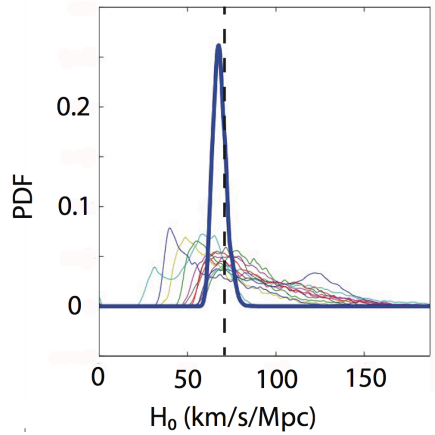
- Completely independent of the cosmic distance ladder.

- Consistent with SHoES (nearby) and Planck (very distant) estimates.

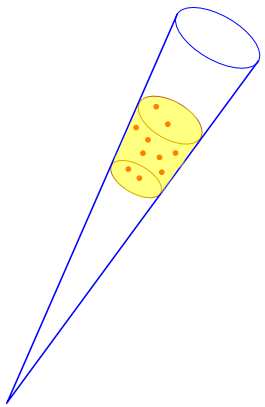
- Heralds the age of multimessenger cosmology.

GW cosmology: the way ahead

Nissanke *et al.* (2013)



- Multiple observations with transient counterparts.

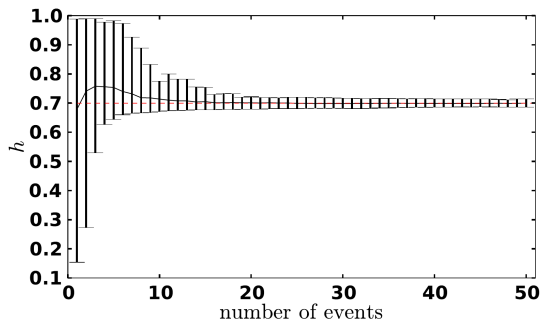


- Narrow beam with potential host galaxies around optical counterpart if host galaxy not uniquely identified.

- A fully statistical analysis using cross-correlation with a galaxy catalog in absence of a transient optical counterpart.

applicable also for binary black holes

extension to other cosmological parameters?



Del Pozzo (2012)

THANK YOU!

Background: Urania's mirror (1825)