Measuring the Hubble constant with GWs

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Take-home message

- Precision measurement of the Hubble constant is important for cosmology
- Ground-based GW detections of stellar-mass binary coalescence may be able to measure the Hubble constant to ~1%
Hubble constant is not important

- Just one number: \( H_0 = \frac{v}{D} = \frac{\dot{a}}{a} \)
- Gives us the age/size of the Universe. So what?
- Local, \( z=0 \) measurement, so has nothing to do with dark energy/cosmological evolution
Cosmology is now the search for one number!

- What is the equation-of-state of the dark energy?
- $w = -1$?
Measuring $H_0$ is important!

Key point: we have exquisite precision cosmological constraints from the CMB
CMB is great

- $z=1100$
- standard ruler: sound horizon at recombination
- standard fluctuation: initial amplitude of fluctuations at $k=0.05\, Mpc^{-1}$
- full spectrum matches: we understand the universe at high redshift
CMB+$H_0$ is even better

Combining CMB at $z = 1100$ with $H_0$ at $z = 0$ constrains the dark energy equation of state

$w = -2/3$

CMB+Hubble = precision constraints on dark energy!
We don’t know $H_0$ to 5%

Planck and WMAP are $5\sigma$ inconsistent
We don’t understand type Ia SNe
The distance ladder is plagued by systematics
GW standard sirens

- Black holes are “simple”: they have no hair
- Binary black hole inspirals are well-modeled, and understood from first principles
- The absolute distance to a GW inspiral can be measured directly and precisely
- Must have electromagnetic counterpart to determine redshift
Statistical standard sirens

- Statistically match host galaxies
- Converges for sufficient numbers of sirens

Schutz, 1986
Del Pozzo, 2012
Gamma-ray Burst Standard Sirens

- Short GRBs are known to occur at low redshift ($z < 0.2$)
- Short GRBs are thought to be the result of binary mergers (NS or BH)
- Will be seen by aLIGO. Perfect standard siren!

Systematic “free” absolute distance

Dalal, DH, Hughes, & Jain 2006, PRD
How well do GRB standard sirens measure distance?

- Markov-Chain Monte Carlo code
- Non-spinning restricted 3.5 post-Newtonian waveform
- Detection priors in population selection
- Independent interferometric noise realizations
- Advanced GW detector configurations

Measuring the Hubble constant

- advanced LIGO/Virgo
- 15 isotropic NS-NS binaries
- assuming GW+EM: standard sirens
- distributions are non-Gaussian
- 3% measurement of $H_0$
Measuring the Hubble constant

add Japan+India: factor $\sim 2$
if GRBs are beamed: factor $> 2$
NS-NS$\rightarrow$NS-BH: factor $\sim 4$
Precision cosmology from GWs

- Measure the Hubble constant to the few percent level
Measurement of dark energy

- Short GRB rate: $10 \text{ yr}^{-1} \text{Gpc}^{-3}$
- PLANCK CMB priors
- advanced LIGO

<10% measure of dark energy EOS
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