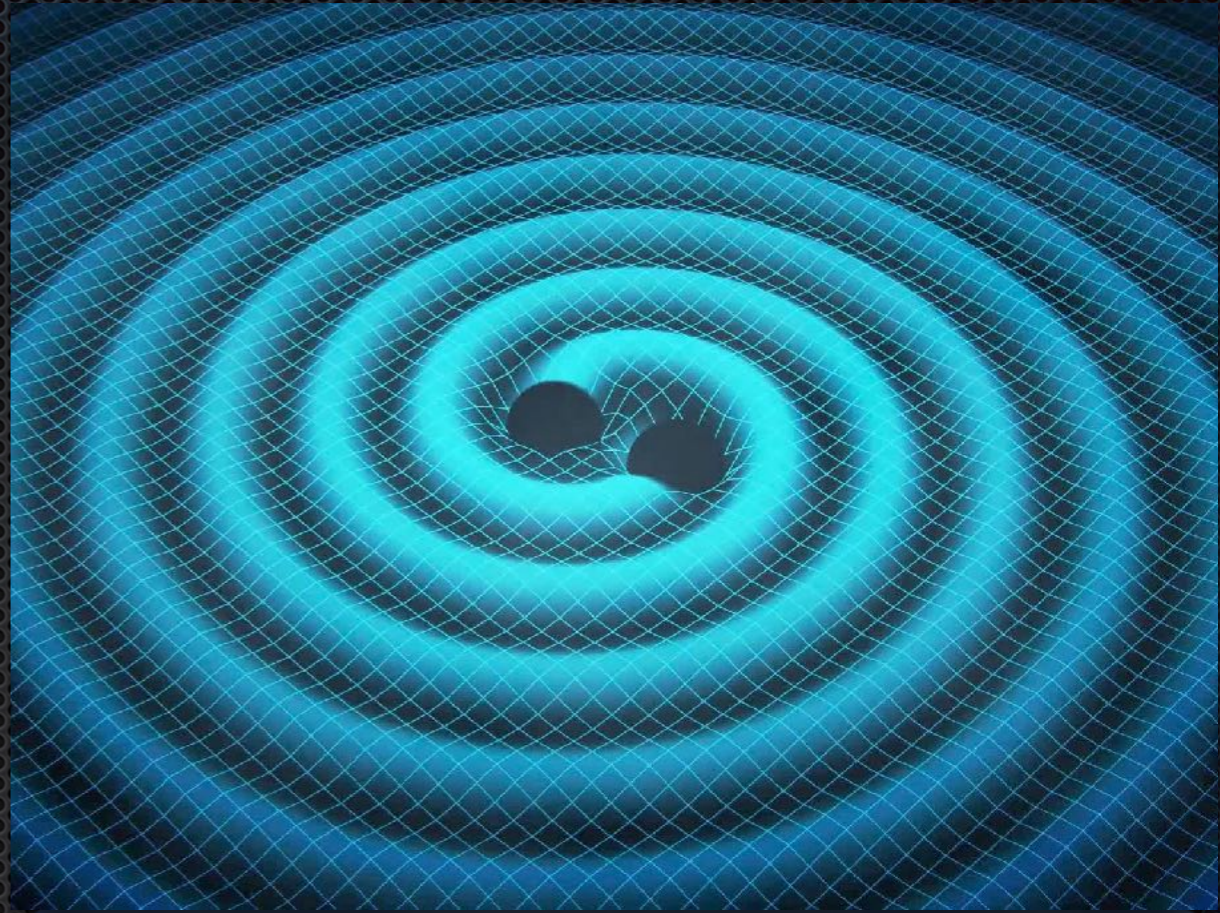


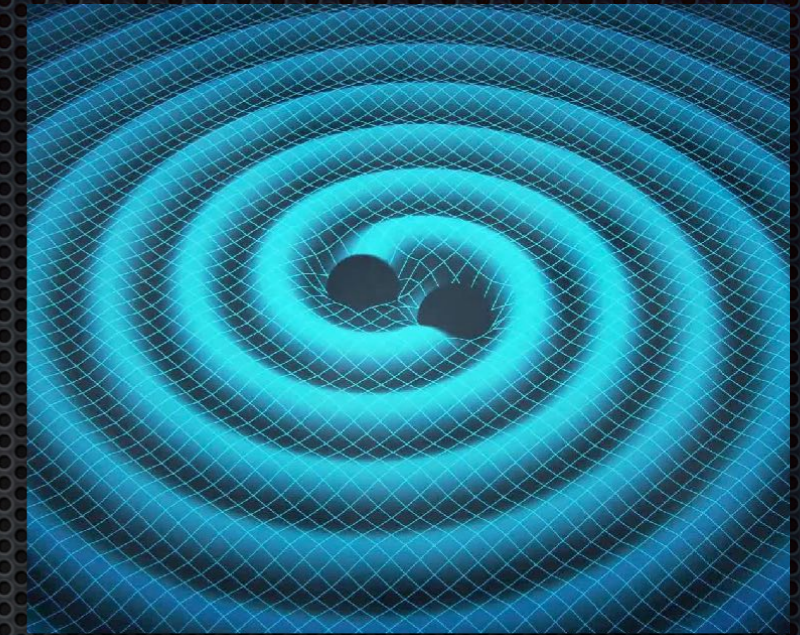
Gravitational Wave Standard Sirens



Maya Fishbach & Daniel Holz
The University of Chicago



GW standard sirens



- Binary coalescence is understood from first principles, and provides direct absolute measurement of luminosity distance
- Calibration is provided by General Relativity
- Need independent measurement of redshift to do cosmology*

GWs from binary systems

- Strongest harmonic (widely separated):

$$h(t) = \frac{M_z^{5/3} f(t)^{2/3}}{D_L} F(\text{angles}) \cos(\Phi(t))$$

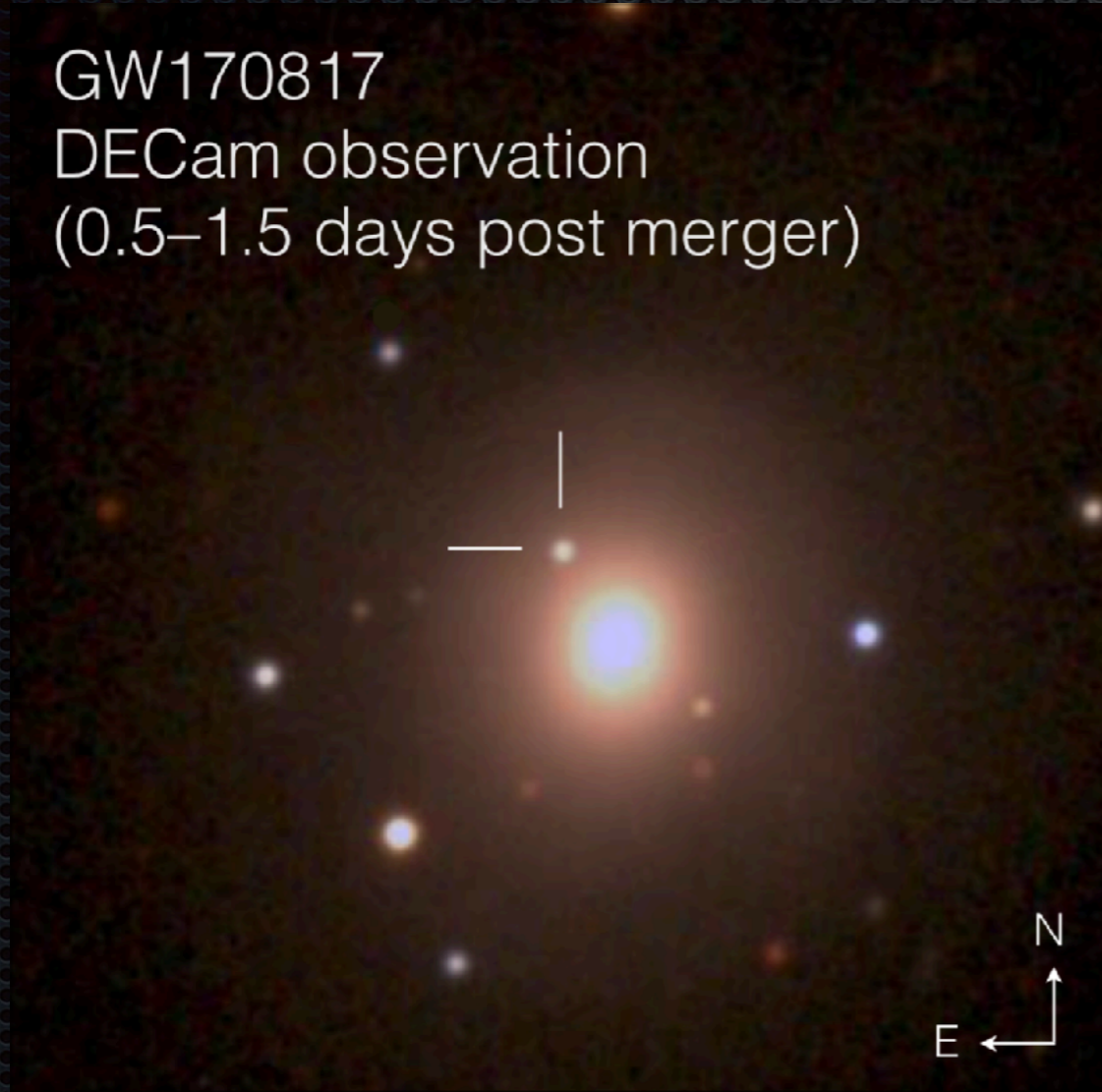
- dimensionless strain $h(t)$
- luminosity distance D_L
- accumulated GW phase $\Phi(t)$
- GW frequency $f(t) = (1/2\pi)d\Phi/dt$
- position & orientation dependence $F(\text{angles})$
- (redshifted) chirp mass:
$$M_z = (1+z)(m_1 m_2)^{3/5} / (m_1 + m_2)^{1/5}$$

Two standard siren approaches

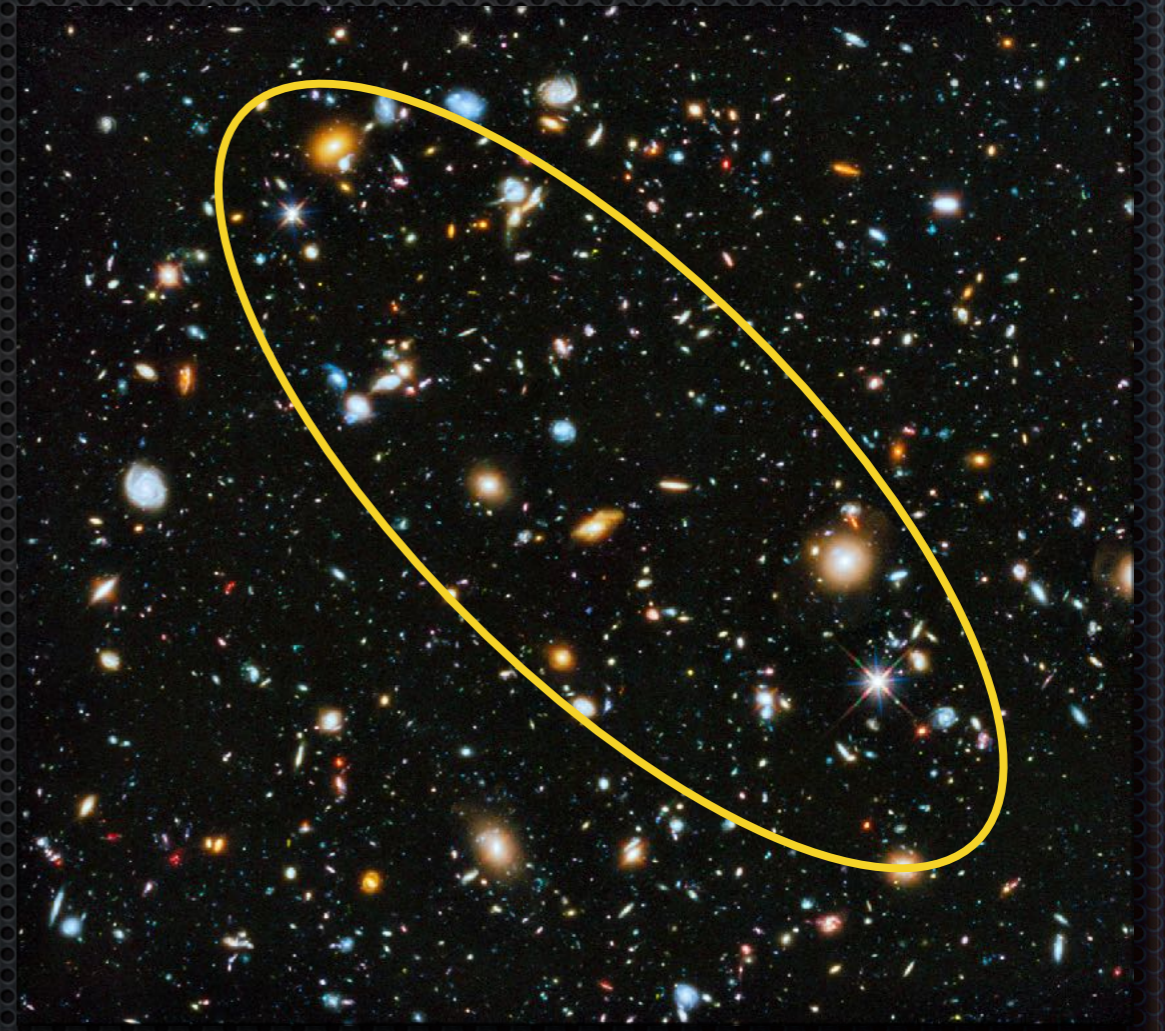
Counterpart

Statistical

GW170817
DECAM observation
(0.5–1.5 days post merger)

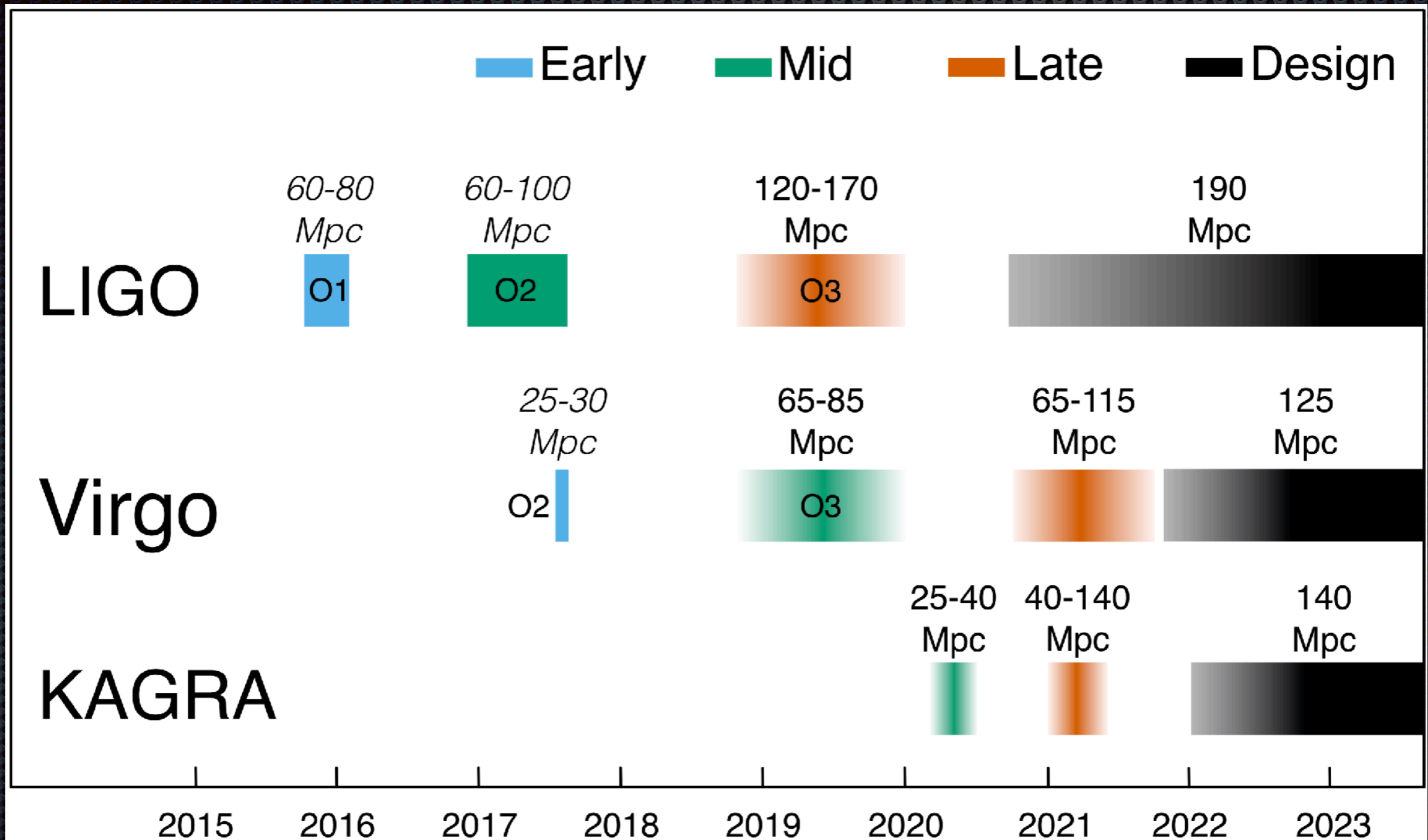


Unique host galaxy



Consider all potential host galaxies within localization region

What does the future hold?

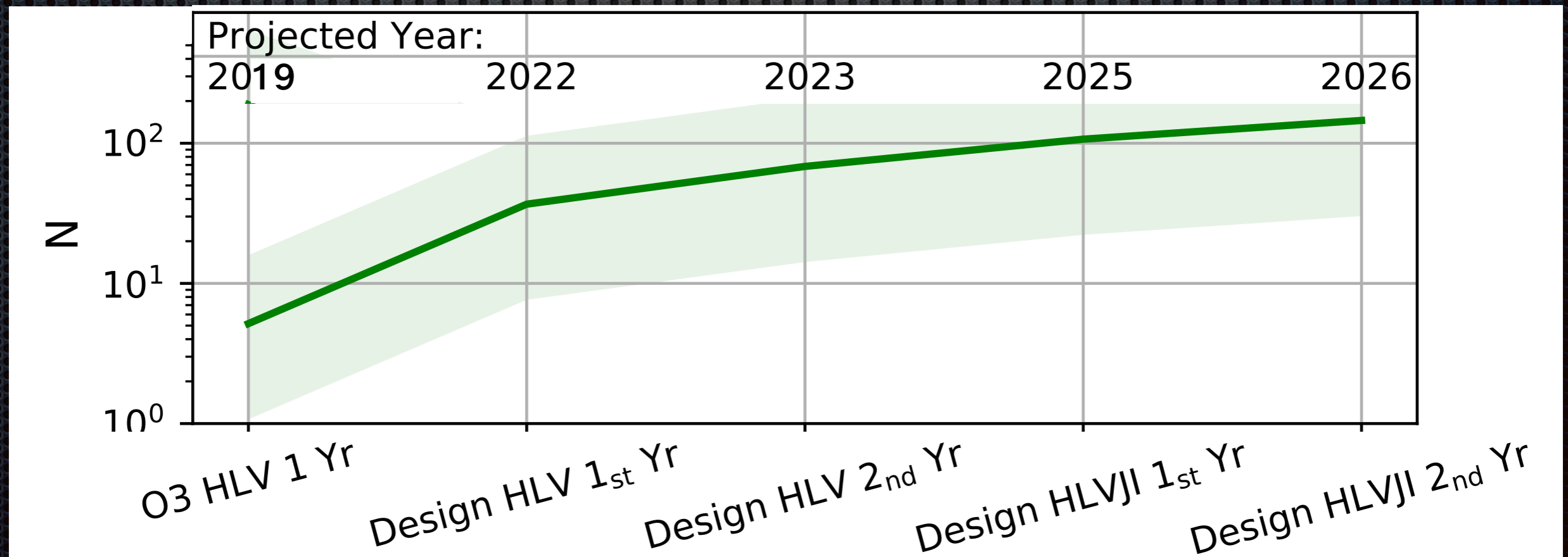


How many systems will we get?

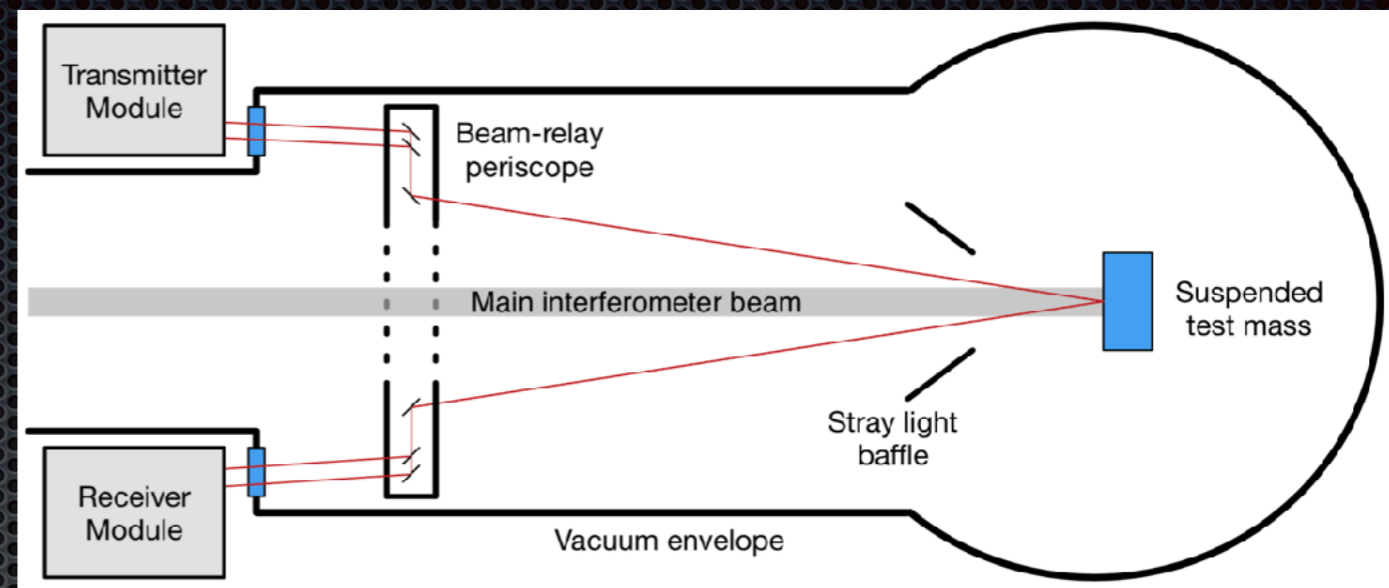
Rate is somewhat uncertain (based on 1 event):

$$R = 1540^{+3200}_{-1220} \text{ Gpc}^{-3} \text{ yr}^{-1}$$

Estimated number of detections:



Systematics



- ✦ Absolute calibration of GW detectors: amplitude response as a function of frequency
- ✦ Inclination degeneracy (if not all GW sources have associated EM counterparts; can be fit)
- ✦ Peculiar velocities (should become negligible soon)
- ✦ Model selection (priors over GW population impact final results [e.g. rate evolution, mass distribution])
- ✦ Galaxy mis-identification? Redshift systematics?

Systematics (statistical approach)

- ✦ Galaxy catalog completeness
- ✦ Photo-z systematics
- ✦ GW selection (mass distribution, rate evolution, etc.)
- ✦ Systematics with types of host galaxies, correlations with metallicity, etc.?
- ✦ ...

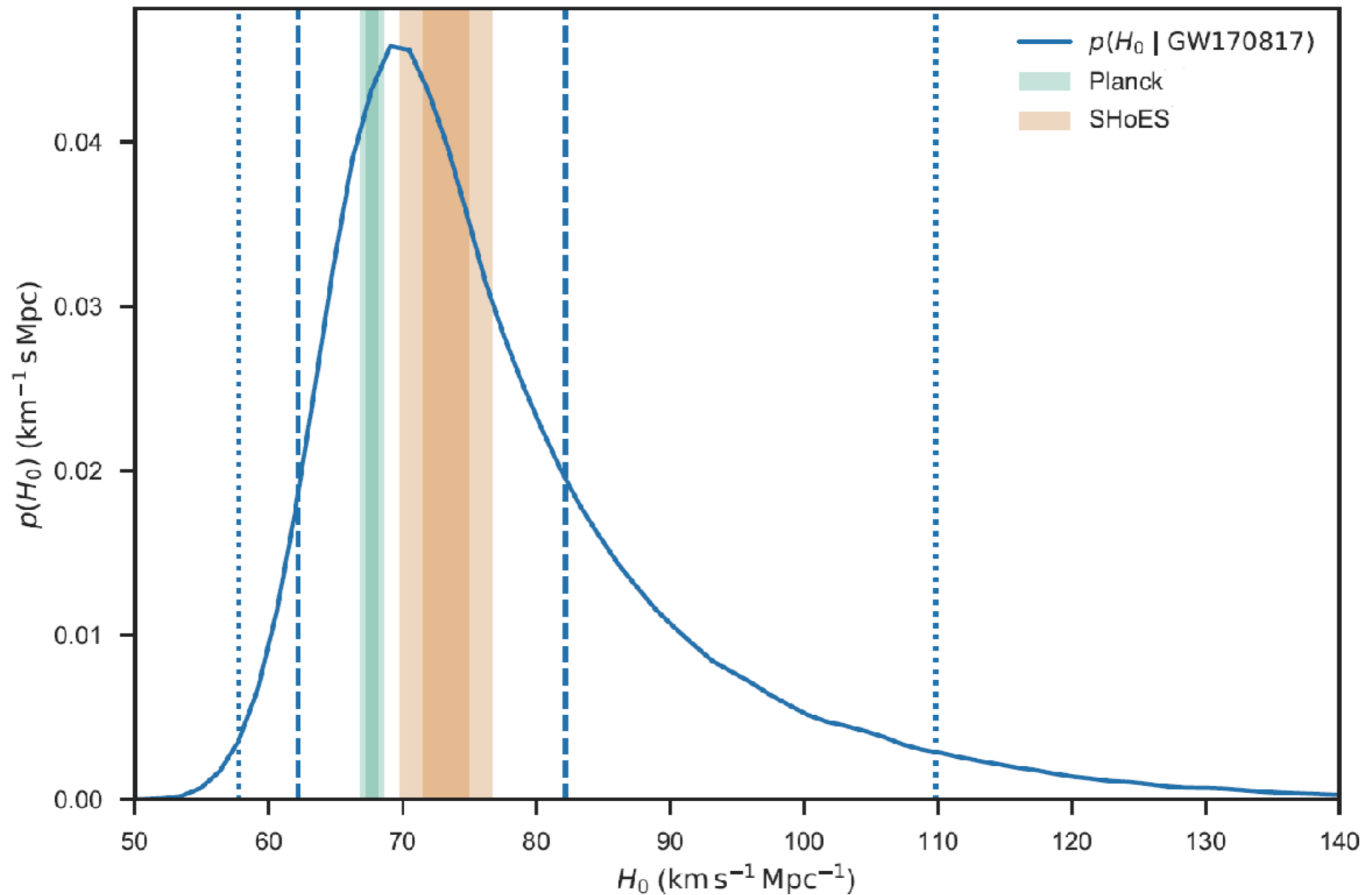
First Standard Siren Measurement: GW170817

- GW distance measurement: $43.8^{+2.9}_{-6.9}$ Mpc
- NGC 4993 is a member of a group, with center-of-mass velocity (CMB-frame): 3327 ± 72 km/s
- Coherent bulk flow velocity: 310 ± 150 km/s

H0 from GW170817

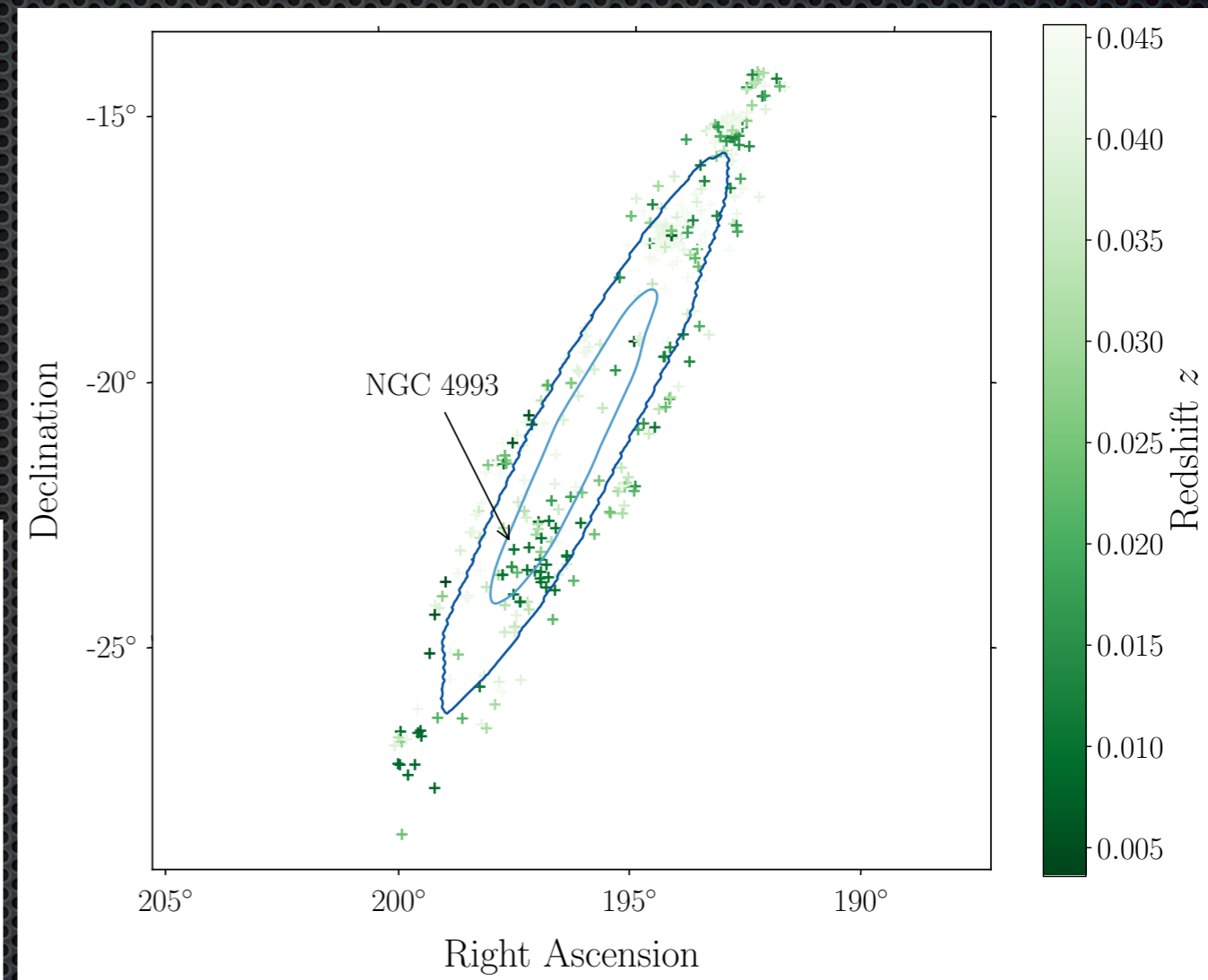
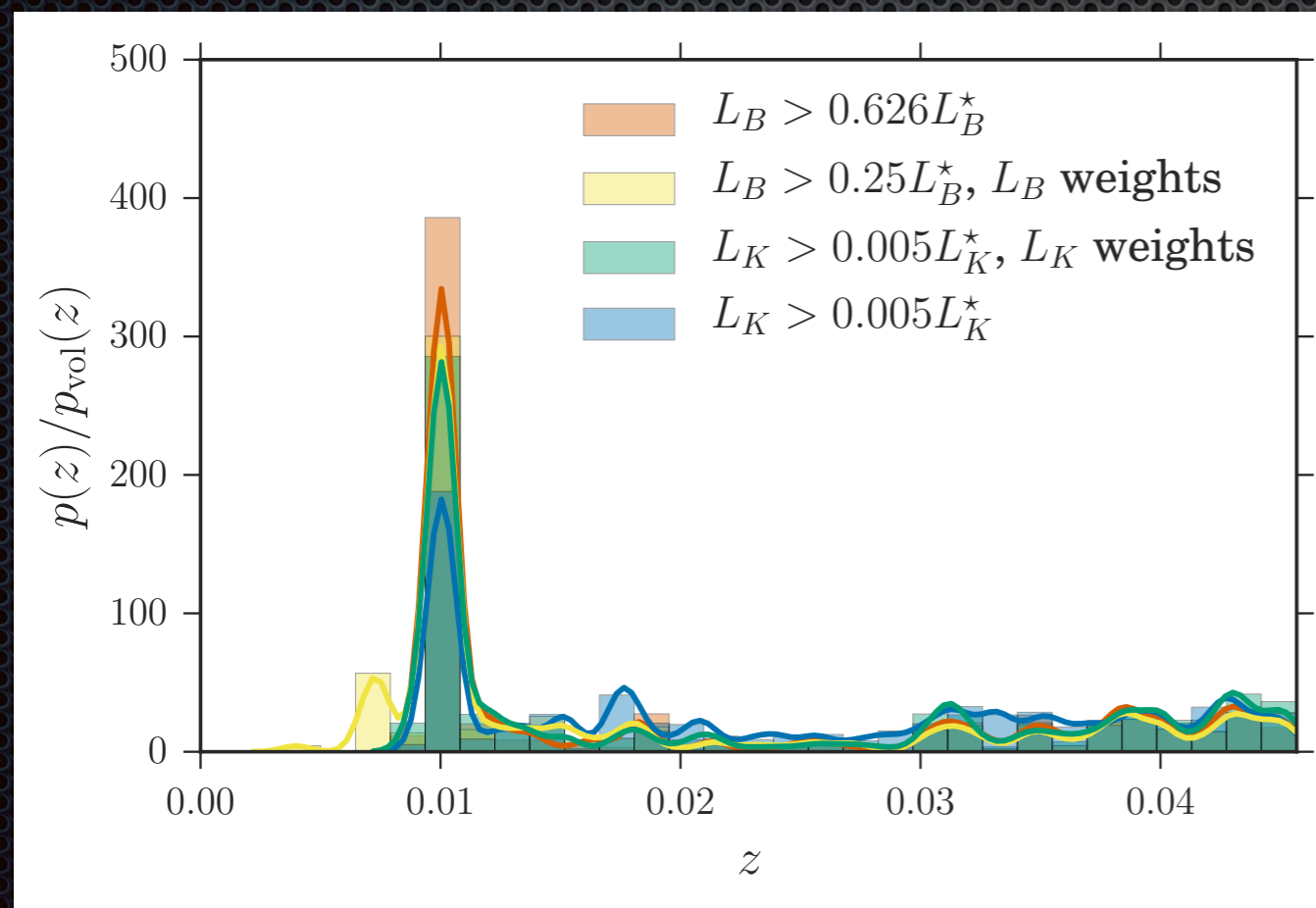
$$H_0 = 70^{+12}_{-8} \text{ km/s/Mpc}$$

Abbott et al. *Nature* 551, 85-88 (2017)



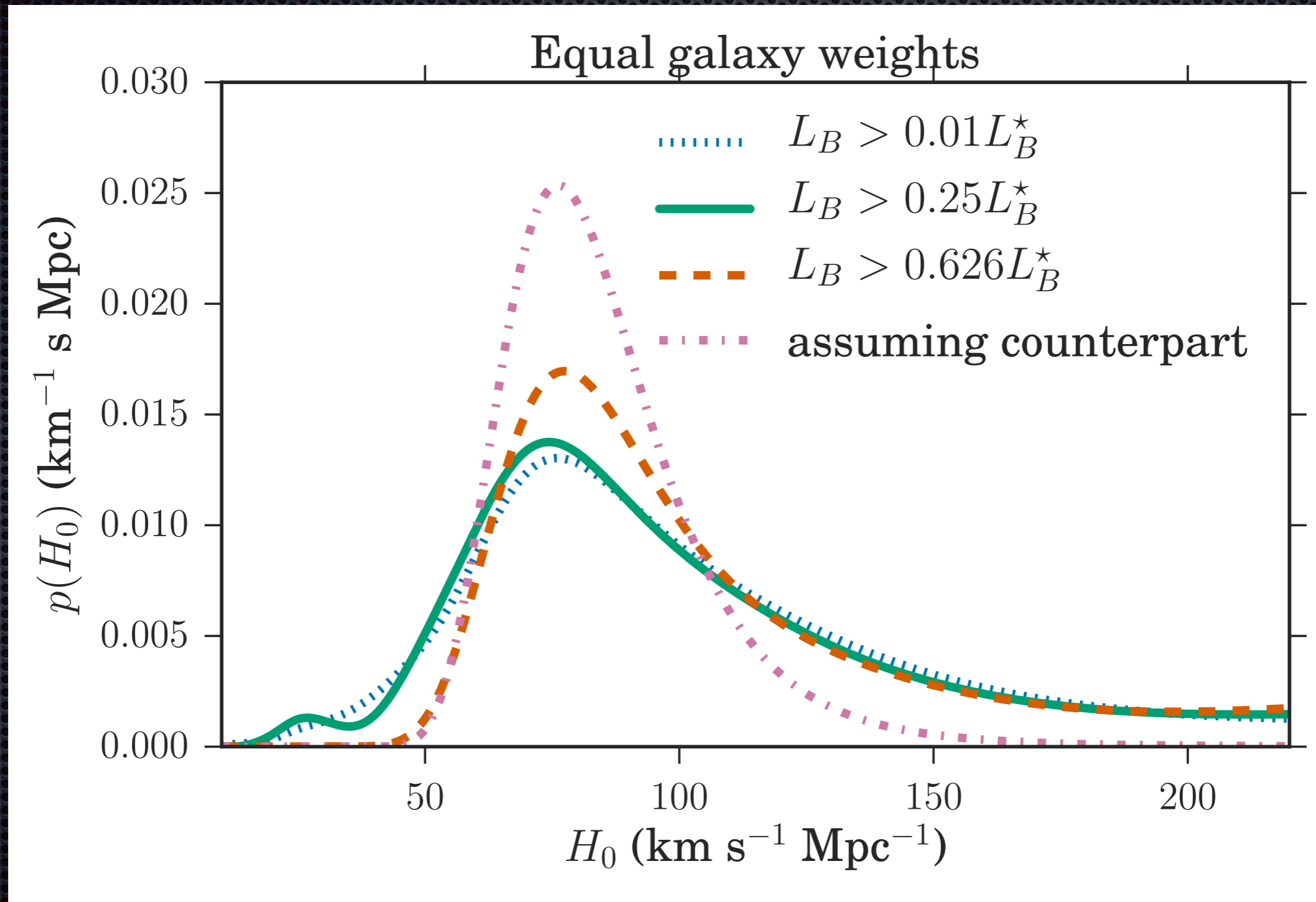
What if we didn't know the host galaxy?

From GW data, 90% sky localization of 16 deg²,
90% volume of 216 Mpc³



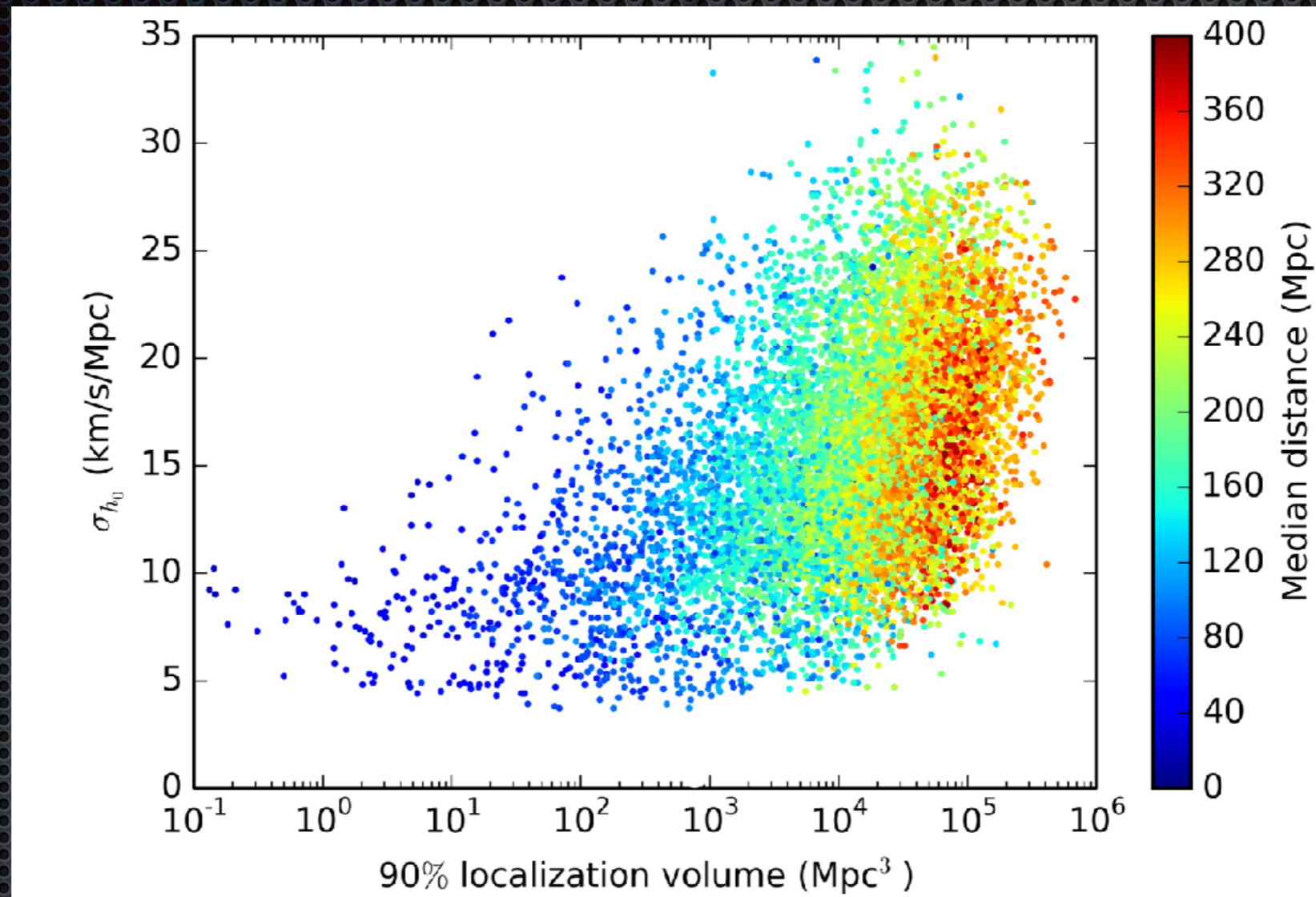
Single dominant group of galaxies

H0 from GW170817 without the EM counterpart



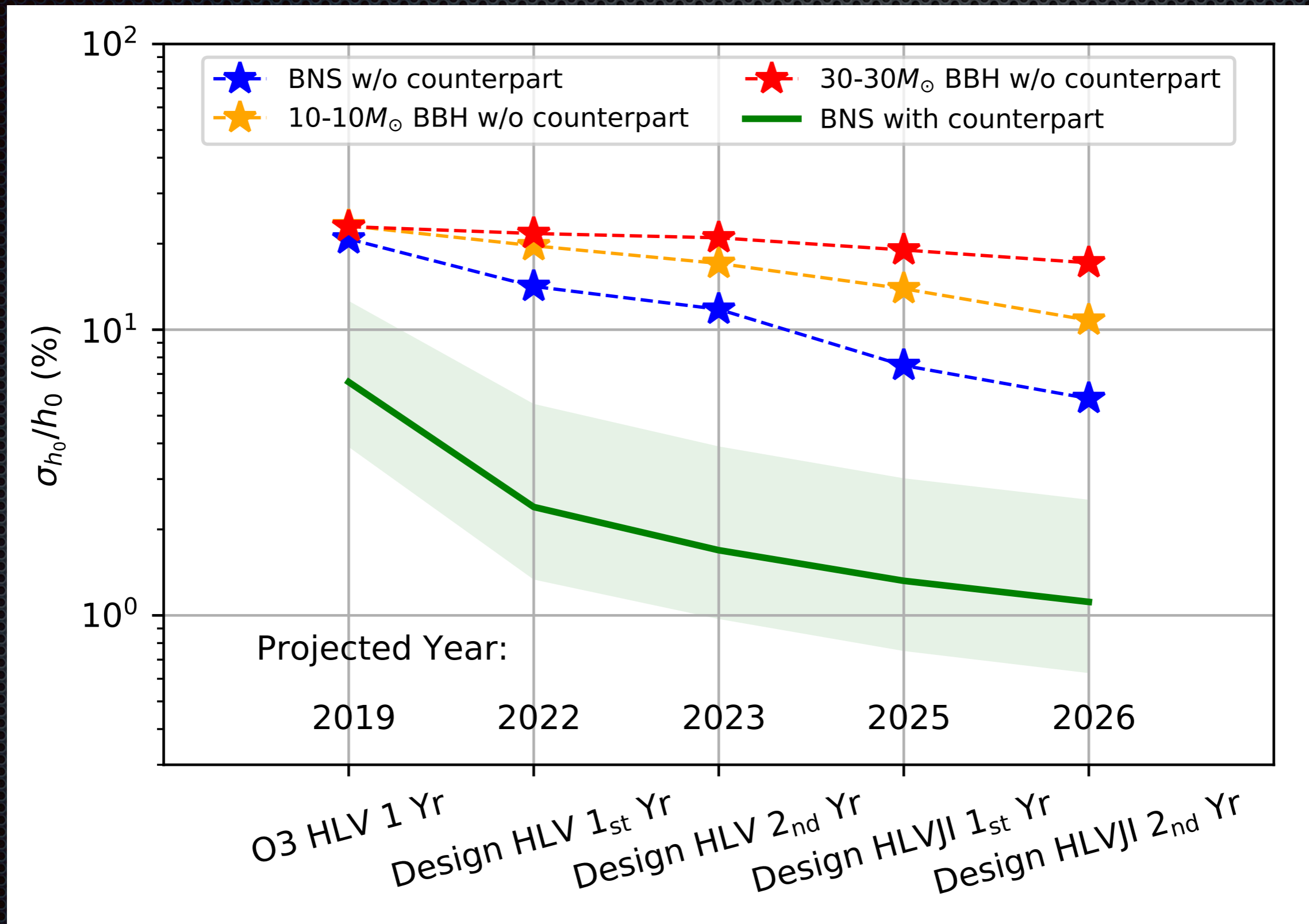
The Future

- GW170817 was a golden event; most events will yield worse constraints individually

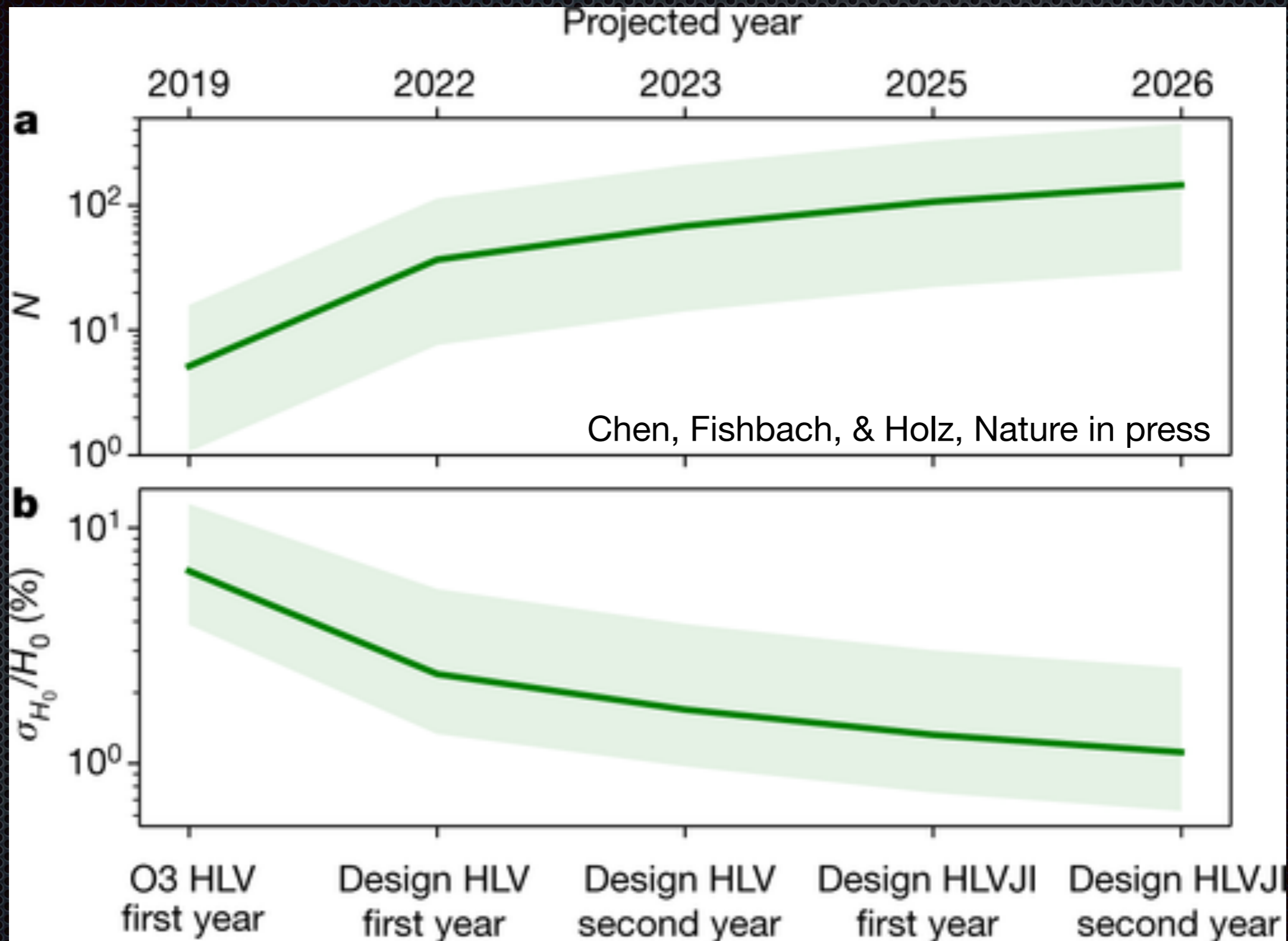


- Because of non-Gaussian posteriors, convergence is still quite fast: $15\%/\sqrt{N}$ for 3-detector network and $13\%/\sqrt{N}$ for 5-detector network, where N is number of events

GW sources with EM counterparts are the most promising



H0 to 2% by 2023, 1% by 2026*



*convergence may be a few times slower if the merger rate is low