The challenge with using dark sirens

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Hubble tension

SHoES (Riess et al, arXiv: 2112.04510)

\[
H_0 = 73.04 \pm 1.04 \text{ (km/s/Mpc)}
\]

CMB: (Planck 2018)

\[
H_0 = 67.36 \pm 0.54 \text{ (km/s/Mpc)}
\]

Currently the premier challenge for the standard cosmological model, and the most exciting development in cosmology imo.

The tension just crossed the 5-sigma threshold; this is an important step!
Standard sirens

• Get distance from GW waveform
• Get redshift from electromagnetic counterpart - find which galaxy hosted the GW event, and use its redshift
• Then you get a measurement of distance and redshift

Then, because

\[ d(z) = \frac{1}{H_0} \int_0^z \frac{dz'}{E(z')} \rightarrow \frac{z}{H_0} \]

• at \( z \sim 1 \) you contain dark-energy parameters (in \( E(z) \))
• at \( z<<1 \), you constrain \( H_0 \)

Schutz 1986, Holz & Hughes 2005
Standard sirens: two kinds

- **Bright sirens**: you get an EM counterpart (e.g. GW170817) - rare
- **Dark Sirens**: you do NOT have an EM counterpart. You get the distance, but you don’t know the redshift since you don’t know the source galaxy.

Bright sirens are **rare** (thus far).
Dark sirens are **common**.

To utilize dark sirens, one can attempt to average over all possible GW sources in a galaxy survey.

Schutz 1986
Constraint from one GW event (gives $d$), and 77,000 DES galaxies (possible $z$)

$$d \simeq \frac{z}{H_0}$$
But: can this possibly work?

\[ d \approx \frac{z}{H_0} \]

With dark sirens, you have \( r \) but not either \( z \) or \( H_0 \).

One equation with two unknowns!

Can Bayesian-ism (somehow averaging over many possibilities for \( z \)) save it?

Answer: No (Trott & Huterer, arXiv:2112.00241)

[Note that the constraint from Soares-Santos is probably ok, since only one GW event and huge uncertainty]
Some equations

\[ p(H_0 \mid d_{gw}, d_{em}) \propto \frac{\int p(d_{gw} \mid d_L(z, H_0)) p(z) dz}{\int p(z) dz} \]

(H_0 posterior)

where

\[ p(d_{gw} \mid d_L(z, H_0)) \propto \exp \left[ -\frac{1}{2} \left( \frac{d_L(z, H_0) - d_{gw}}{\sigma_{d_{gw}}} \right)^2 \right] \]

(likelihood)

\[ p(z) \propto \frac{1}{N_{gal}} \frac{r^2(z)}{H(z)} \sum_{i} \exp \left[ -\frac{1}{2} \left( \frac{\bar{z}^i - z}{\sigma_{z}^i} \right)^2 \right] \]

(prior from each candidate galaxy)
Basic process:

\[ H_{0,\text{true}} = 70 \]
\[ \sigma_{\text{GW}} = 20\% \]
\[ z^3 \text{ distribution} \]
\[ z \text{ window } = [0, 0.15] \]

Dependence on \( z \) range of galaxies:

\[ H_{0,\text{true}} = 70 \]
\[ \sigma_{\text{GW}} = 20\% \]
\[ z^3 \text{ distribution} \]

\[ z \text{ window matches events} \]
Dependence on $N(z)$ of population:

$H_{0,\text{true}} = 70$

$\sigma_{dG} = 20\%$

$z$ window $= [0.1, 0.15]$

Dependence on error in GW $d$:

$H_{0,\text{true}} = 70$

$z^3$ distribution

$z$ window $= [0.1, 0.15]$

$\sigma_{dG} = 10\%$

$\sigma_{dG} = 20\%$

$\sigma_{dG} = 30\%$
Takeaways

- Don’t get me wrong, standard sirens are great and a very promising probe of DE and H0
- However, that’s true for bright sirens. Dark sirens - different matter
- Apparently irreducible degeneracy between z and H₀
- There are lots of details in the Bayesian formalism that can be tweaked one way or the other (under investigation at present)
- However, we do not see how any new tweak in this statistical GW method can possibly reduce or remove the degeneracy inherent in the problem