The challenge with using dark sirens

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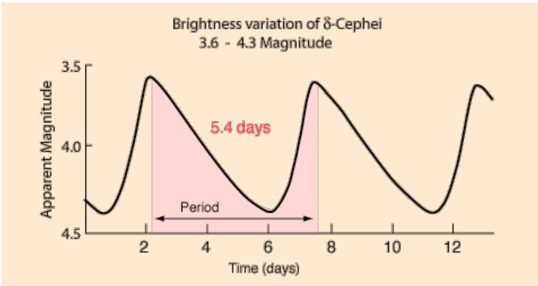
Hubble tension

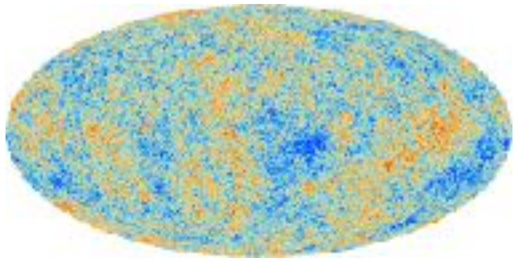
SH$_0$ES (Riess et al, arXiv: 2112.04510)

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



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

$$d(z) = \frac{1}{H_0} \int_0^z \frac{dz'}{E(z')} \xrightarrow{z \ll 1} \frac{z}{H_0}$$

- at z ~ 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

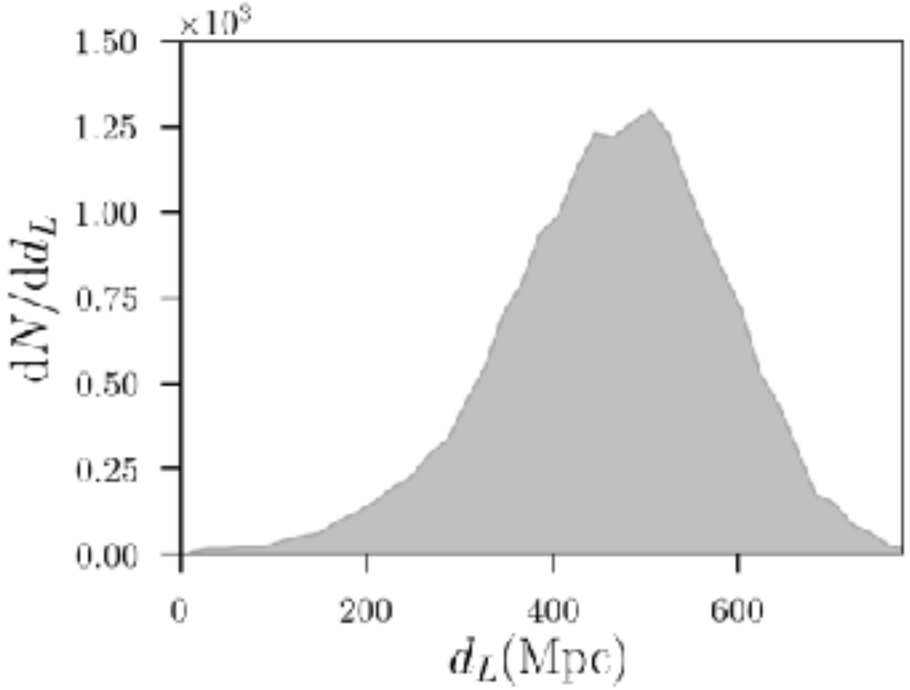
- **Bright sirens**: you get an EM counterpart (e.g. GW170817) - rare
- **Dark Sirens**: you do NOT have an EM counterpart. You get the distance, but you don't know the redshift since you don't know the source galaxy.

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

Dark sirens are **common**.

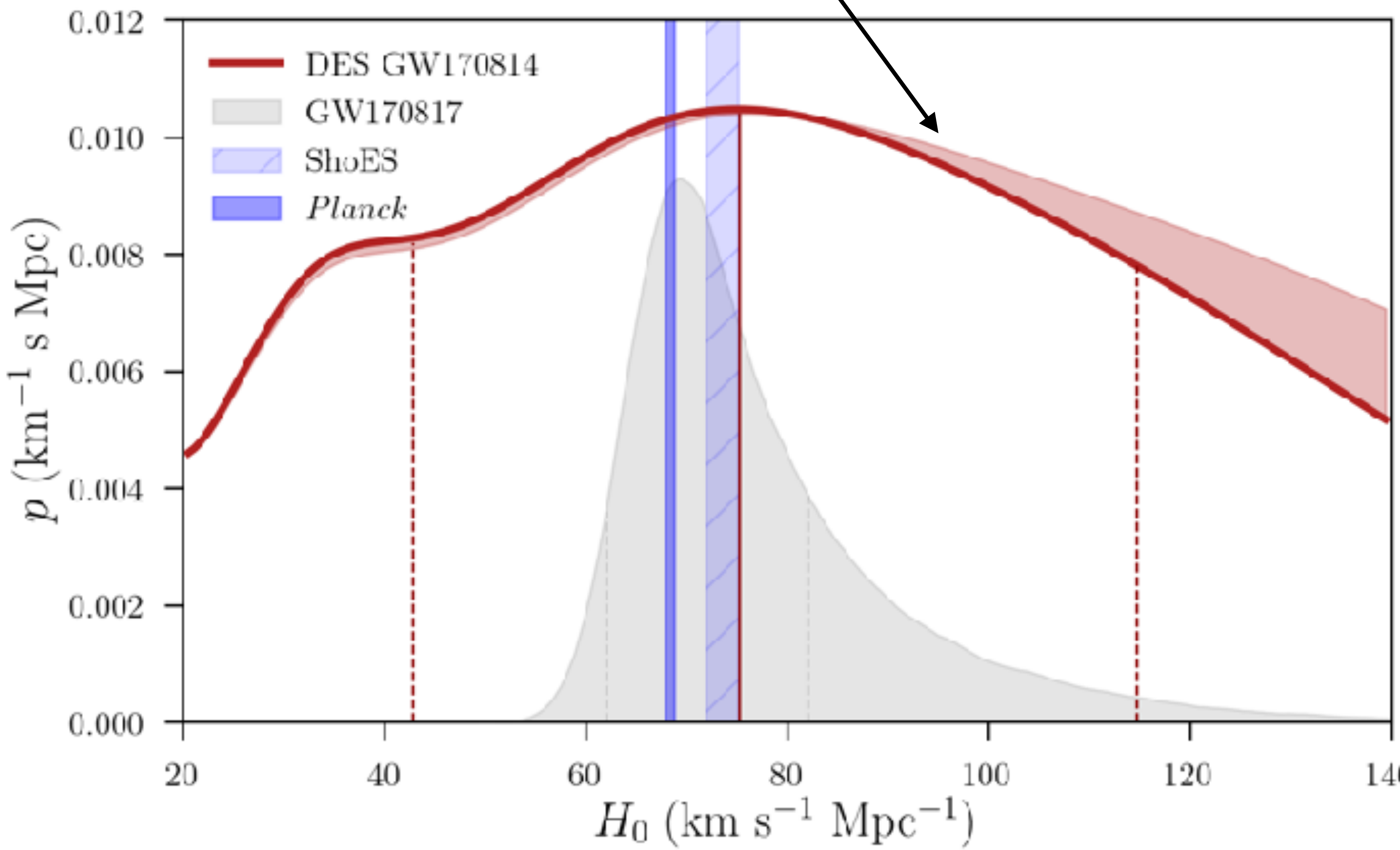
To utilize dark sirens, one can attempt to average over all <u>possible</u> GW sources in a galaxy survey.

Schutz 1986



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

$$d \simeq \frac{z}{H_0}$$



Soares-Santos, Palmese et al 2019

But: can this possibly work?

$$d \simeq \frac{z}{H_0}$$

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

$$p(H_0 \mid d_{\mathrm{gw}}, d_{\mathrm{em}}) \propto \frac{\int p(d_{\mathrm{gw}} \mid d_L(z, H_0)) p(z) \mathrm{d}z}{\int p(z) \mathrm{d}z}$$

(H_0 posterior)

where

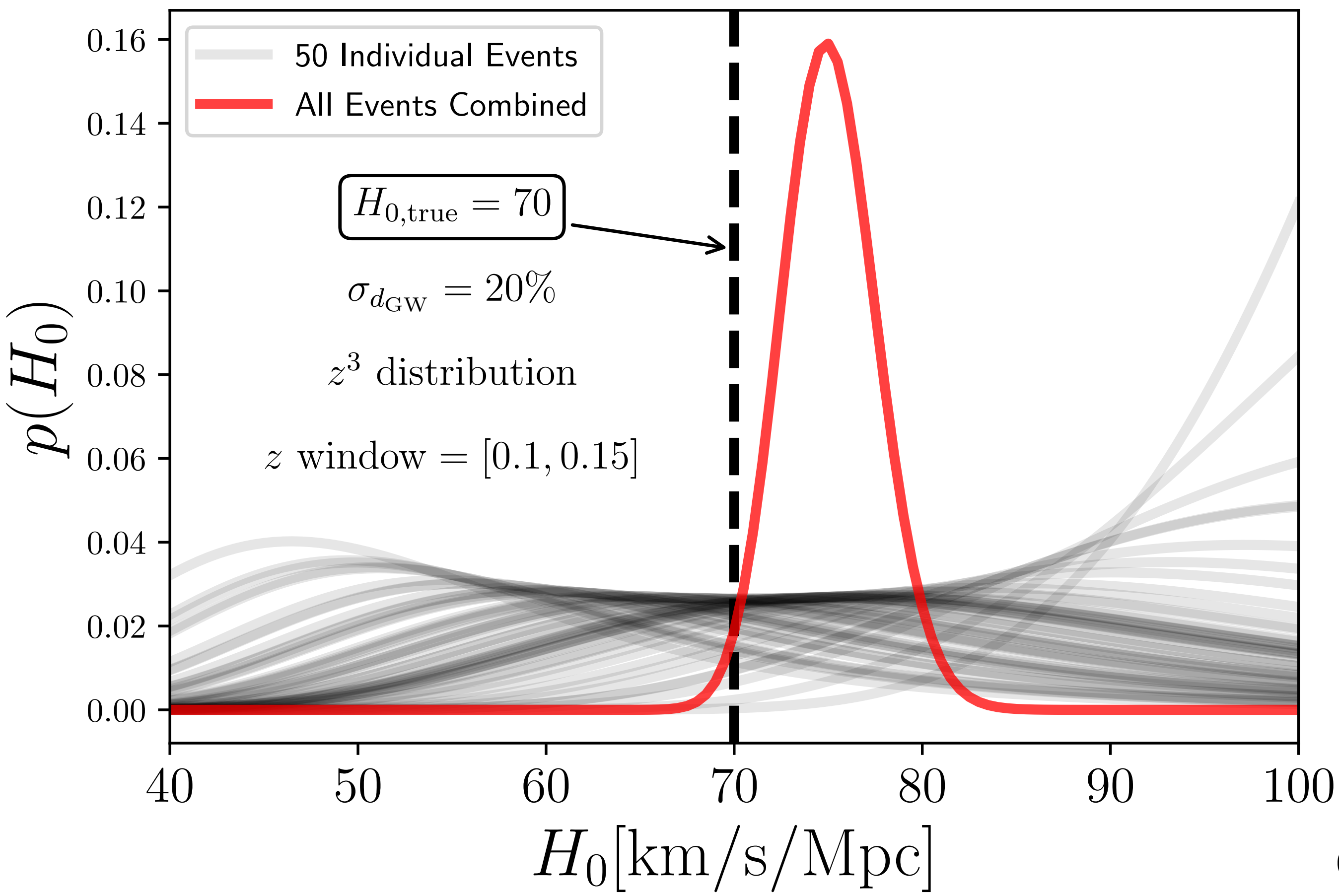
$$p(d_{\mathrm{gw}} \mid d_L(z, H_0)) \propto \exp\left[-\frac{1}{2} \left(\frac{d_L(z, H_0) - d_{\mathrm{gw}}}{\sigma_{d_{\mathrm{gw}}}} \right)^2 \right]$$

(likelihood)

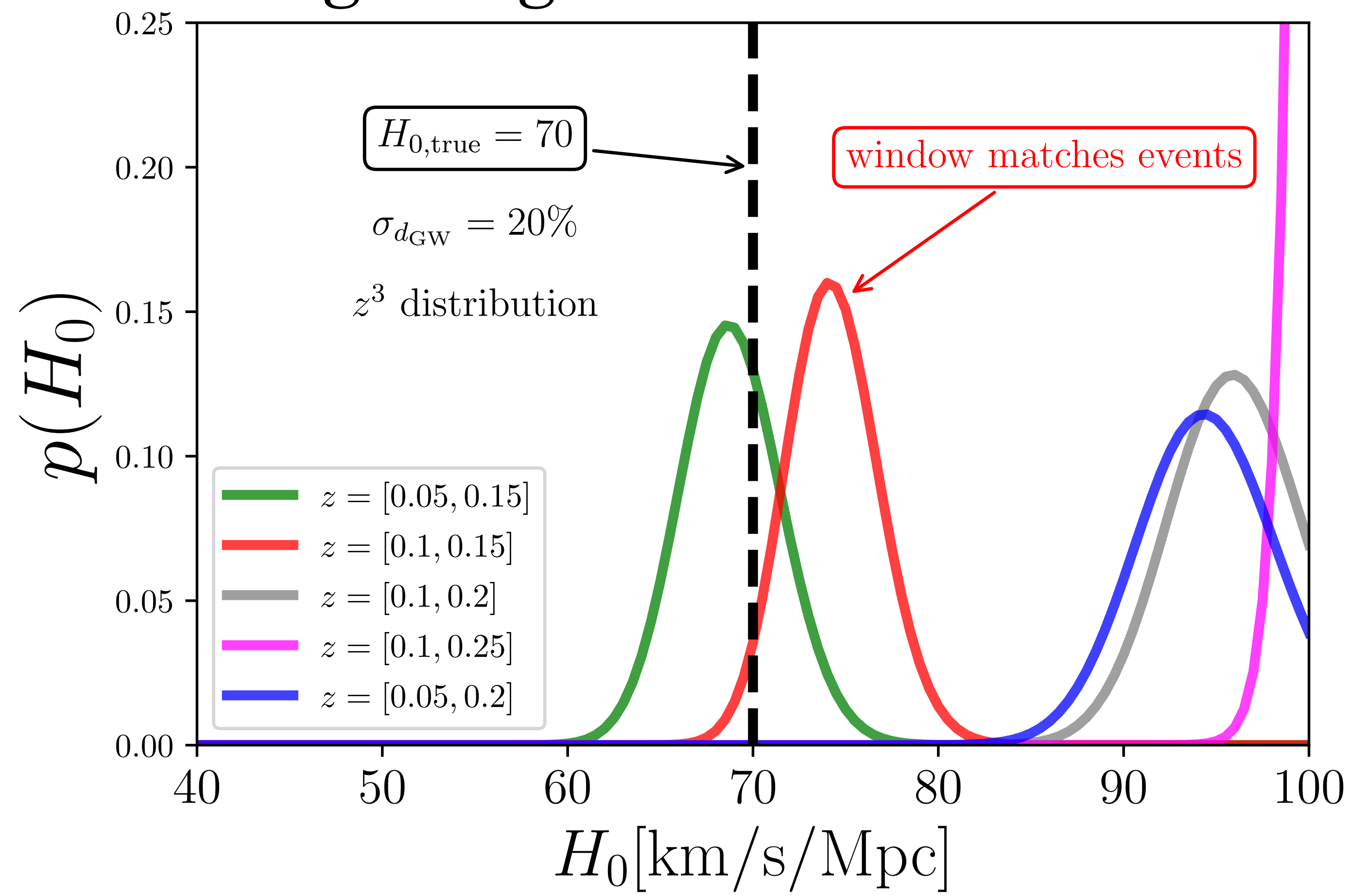
$$p(z) \propto \frac{1}{N_{\mathrm{gal}}} \frac{r^2(z)}{H(z)} \sum_i^{N_{\mathrm{gal}}} \exp\left[-\frac{1}{2} \left(\frac{\bar{z}^i - z}{\sigma_z^i} \right)^2 \right]$$

(prior from each candidate galaxy)

Basic process:

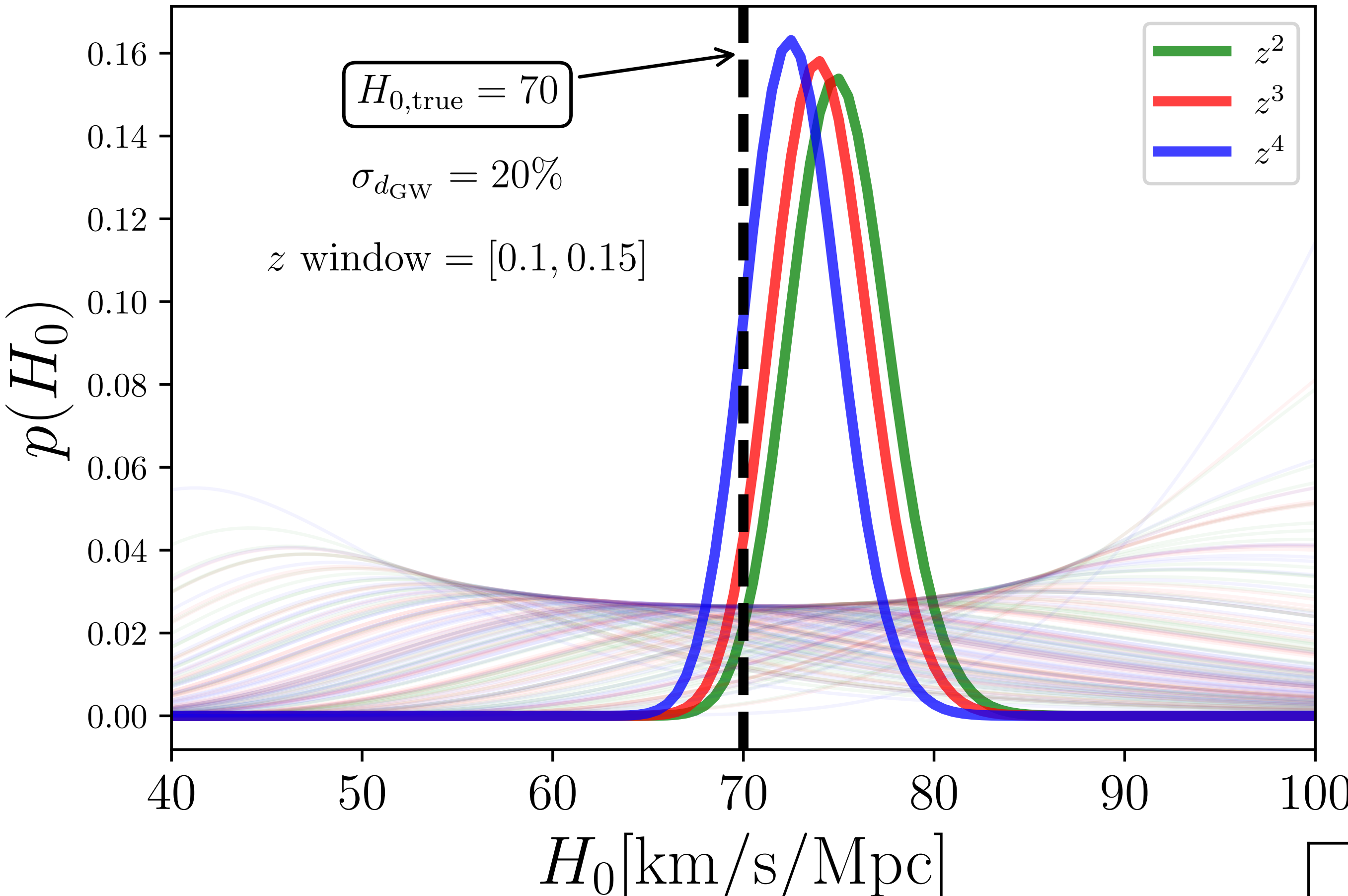


Dependence on z range of galaxies:

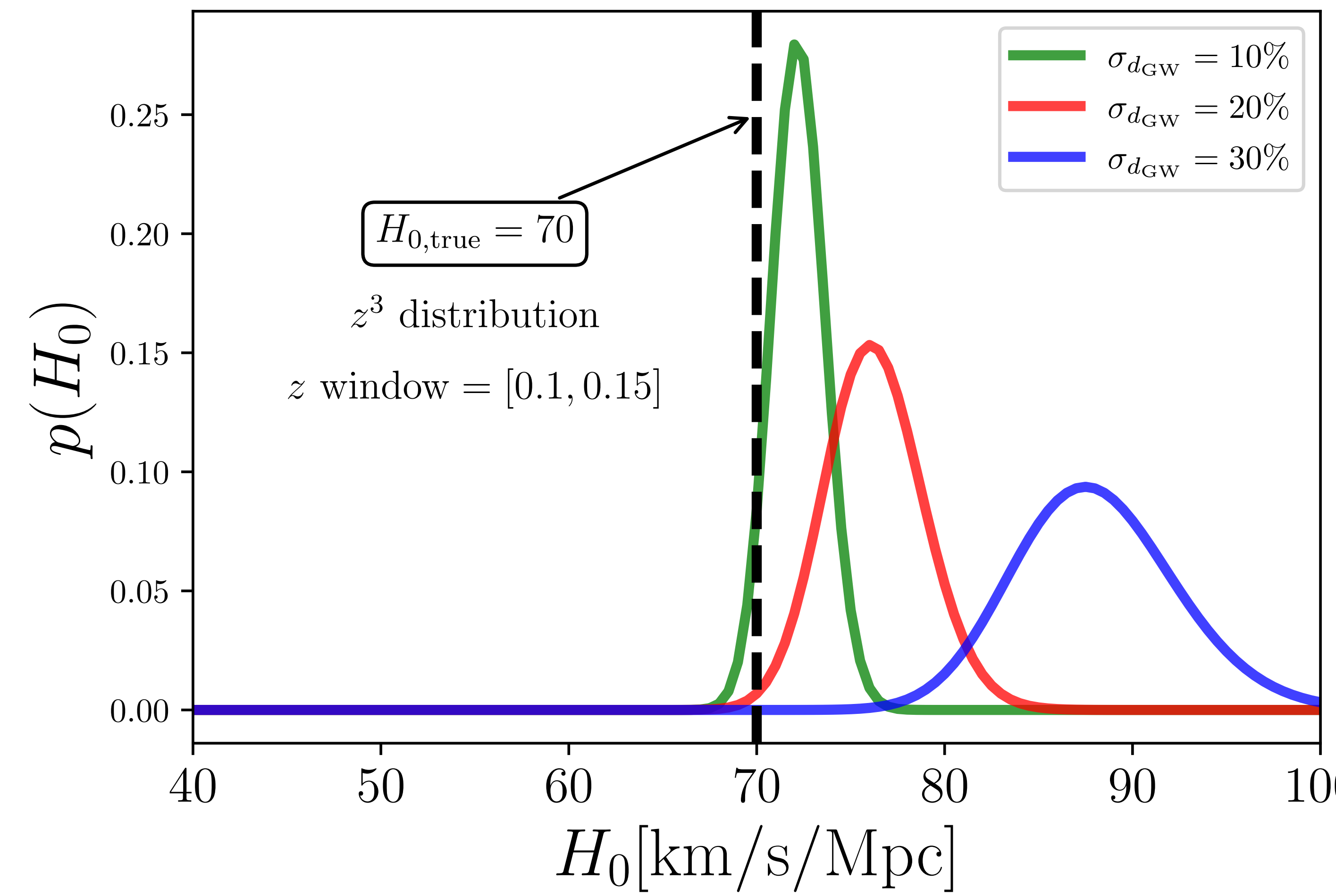


Trott & Huterer, arXiv:2112.00241

Dependence on N(z) of population:



Dependence on error in GW d:



Takeaways

- Don't get me wrong, standard sirens are <u>great</u> 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 H_0
- 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**