Centro Brasileiro de Pesquisas Físicas

Standard Siren Cosmology with Gravitational Waves from Binary Black Hole Mergers in Active Galaxy Nuclei

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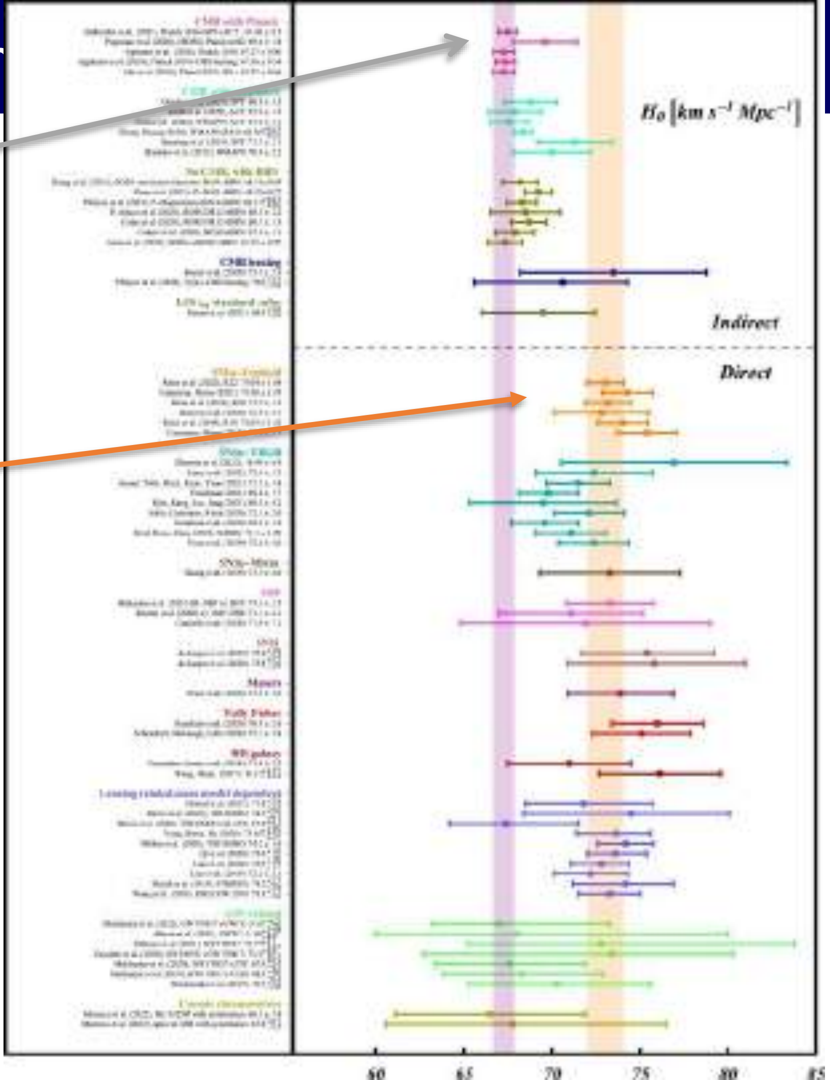
In collaboration with: Antonella Palmese

Hubble Constant Ter

CMB related

SN related

GW related

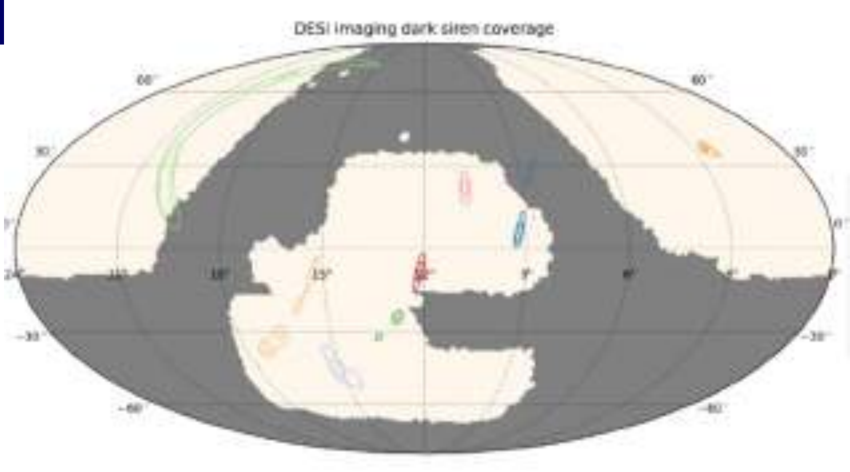


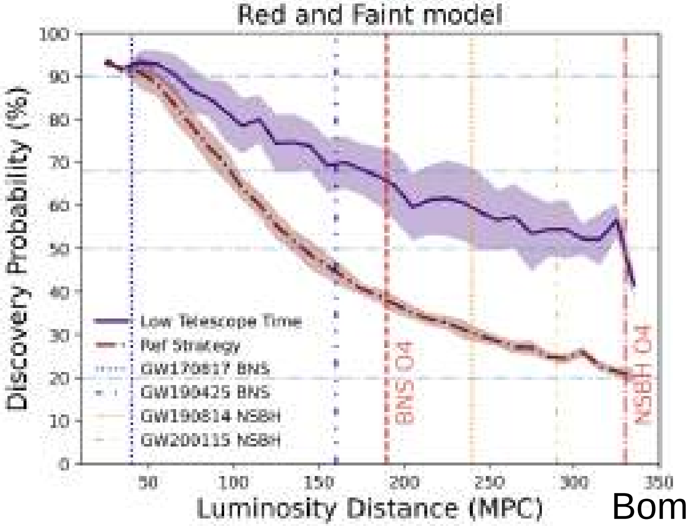
Cosmology intertwined: A review of the particle physics, astrophysics, and cosmology associated with the cosmological tensions and anomalies

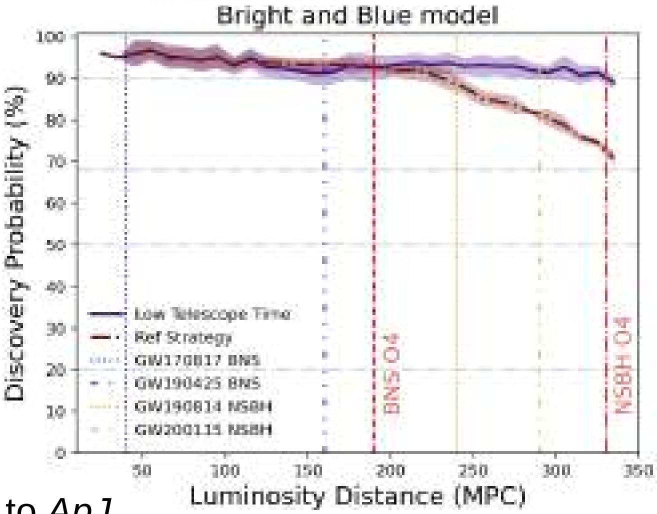
doi:/10.1016/j.jheap.2022.04.002

Bright Sirens are great but ...

- We Need to find the Kilonova! Big Areas
- Kilonovas are likely to be fainter than GW170817
- They fade fast ~1-3 days to find,
  LSST should not find many
- Inclination angle may affect ho bright they are
- Neutron-star Black holes might be even redder
- They are rarer than Binary Black holes
- We need ~50 Bright Sirens to reach ~2% H_0.







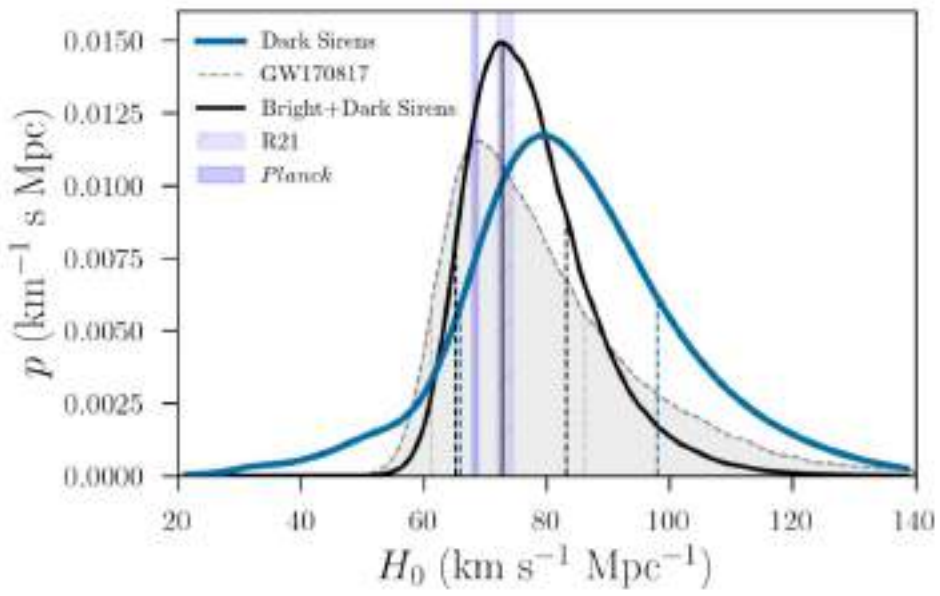
Bom et al. 2023 submitted to *ApJ*

Dark Sirens are great but ...

- Require highly complete catalogs
- Photo-z must be good
- Unobservable areas in the sky.
- Systematics & selection effects

$$p(H_0|\{d_{\mathrm{GW},i}\},d_{\mathrm{EM}}) \propto p(H_0)\prod_j p(d_{\mathrm{GW},j},d_{\mathrm{EM}}|H_0).$$

Palmese & Bom et al. 2023 *ApJ*



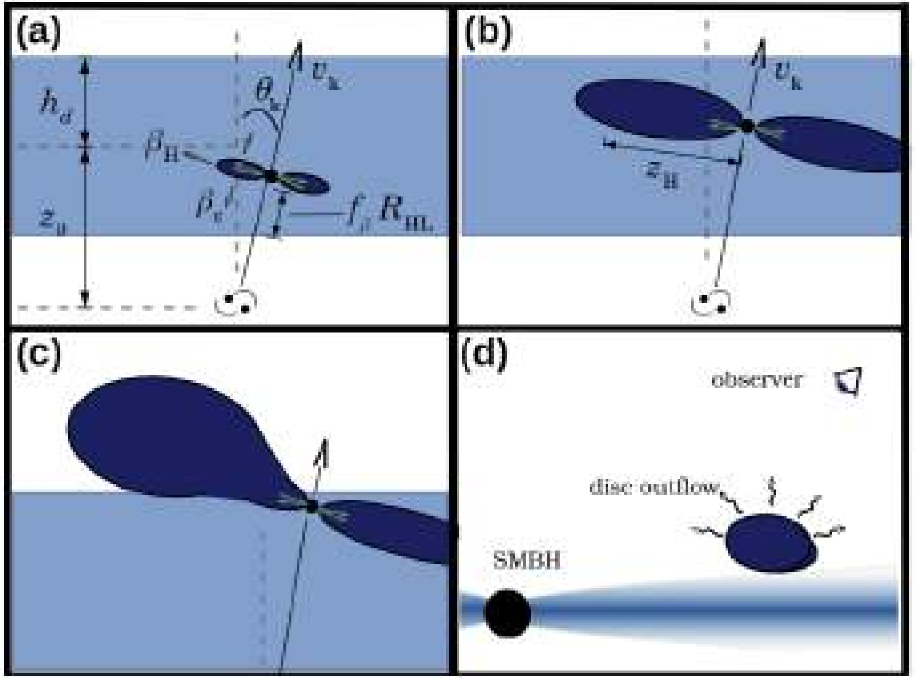
Palmese & Bom et al.

Event(s)	Prior	H_0	σ_{H_0}/H_0	$\sigma_{H_0}/\sigma_{\mathrm{prior}}$	Reference
GW170817 - bright	[20, 140]	$68.80^{+17.3}_{-7.63}$	18%	31%	Adapted from Nicolaou et al. (2020)
F21 O1-O3a – dark	[30, 140]	$67.3^{+27.6}_{-17.9}$	34%	61%	Finke et al. (2021)
O1-O3 – dark	[20, 140]	$79.8^{+19.1}_{-12.8}$	20%	39%	This work
O1-O3 – all	[20, 140]	$72.77^{+11.0}_{-7.55}$	12%	22%	This work

Does Binary Black Holes produces AGN optical flares?

There was a recent claim of AGN flare association to GW190521 (Graham et al. 2020) and 8 Other candidates (Graham et al. 2023).

We propose a novel model (Rodriguez-Ramirez et al. 2023, submitted). Together with Kimura et al. 2021 We propose a cocoon around the BBH merger kicked out AGN disk merger would produce a flare that might have EM counterpart from Gamma rays to optical.



Rodriguez-Ramirez & Bom et al. submitted

DOI: 10.48550/arXiv.2304.10567

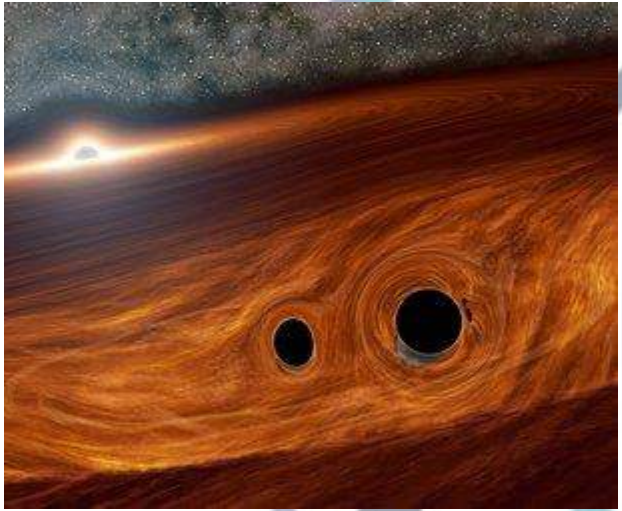
Not so Bright, but not in totally dark, AGN Flares?

Binary Black Hole Mergers (BBHs) s are more common than Binary Neutron Stars (BNS) Kilonovas (During O4: ~10 BNS and ~80 BBH) .

BBH mergers in AGN disks can produce EM counterparts (e.g. McKernan et al. 2012; Bartos et al. 2017b; McKernan et al. 2019; Kimura et al. 2021).

25% of BBHs during LVC (O2) preferred an AGN disk origin model (Gayathri et al. 2021).

Between 20%-80% of BBHs are likely to happen in AGN disks (Ford & McKernan, 2021) .



Credit: Caltech/R. Hurt (IPAC)

Not so Bright, not in total darkness, AGN Flares?

We modelled the problem as a signal versus background problem: for each GW event from a BBH in an AGN disk we have N expected background flares and N + 1 total expected flares.

Fraction of AGN that host flares induced by BBH

$$\frac{dN_i}{d\Omega dz}\left(\Omega, z \mid \Omega_i^{\rm GW}, z_i^{\rm GW}, \lambda, T, \frac{dB}{d\Omega dz dt}\right) = \lambda\delta(\Omega_i^{\rm GW} - \Omega)\delta(z_i^{\rm GW} - z) + T\frac{dB}{d\Omega dz dt}(\Omega, z),$$

$$R_B = T\frac{dB}{d\Omega dz dt}$$

$$\mu_i \equiv \int \frac{dN_i}{d\Omega dz} P_{\rm det}^{\rm AGN}(\Omega, z) d\Omega dz$$

Cosmological parameters

The likelihood is given by inhomogeneous Poisson process

$$\mathcal{L}_i(\vec{\theta}, \lambda) \propto \prod_{j=1}^{k}\left[\lambda p(x_i^{\rm GW} \mid \Omega_{ij}^{\rm AGN}, d_L(z_{ij}^{\rm AGN}, \vec{\theta})) p_0(\Omega_{ij}^{\rm AGN}, z_{ij}^{\rm AGN}) + R_B\left(\Omega_{ij}^{\rm AGN}, z_{ij}^{\rm AGN}, \vec{\theta}\right)\right] e^{-\mu_i}$$

Palmese et al. 2021 – doi:10.3847/2041-8213/ac0883

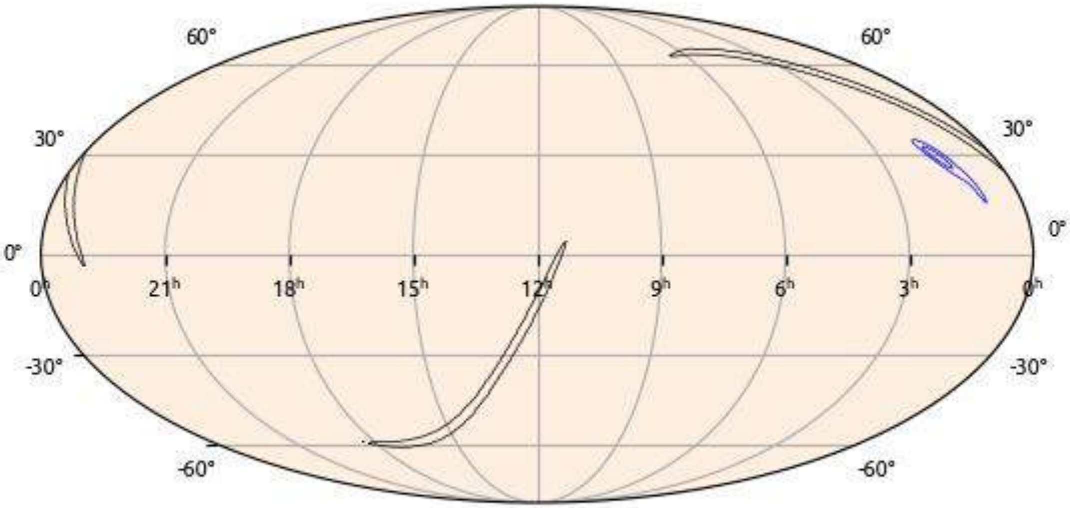
Not so Bright, not in total darkness, AGN Flares?

We produce a full simulation of the detections of BBHs mergers expected in the upcoming LVK O4 observing run with Bayestar assuming 70% duty cycle for O4 (LVK) and O5 (LVK A+).

We consider the scenarios:

1 – Fiducial number density of AGN per volume $n=10^{-4.75}$, and alternatively high number of background AGN, $n=10^{-4.5}$.

2 – The number of AGNs that flare in the time frame of weeks, 10^{-4} (Palmese et al. 2021) and a less restrict scenario 10^{-3}.



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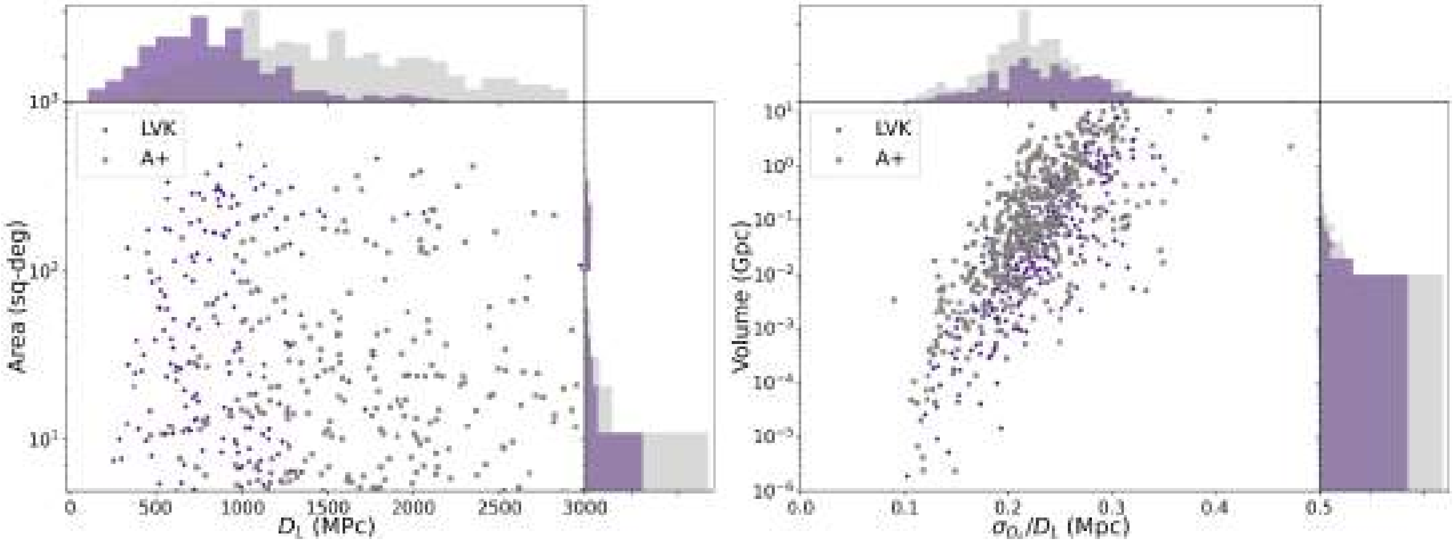
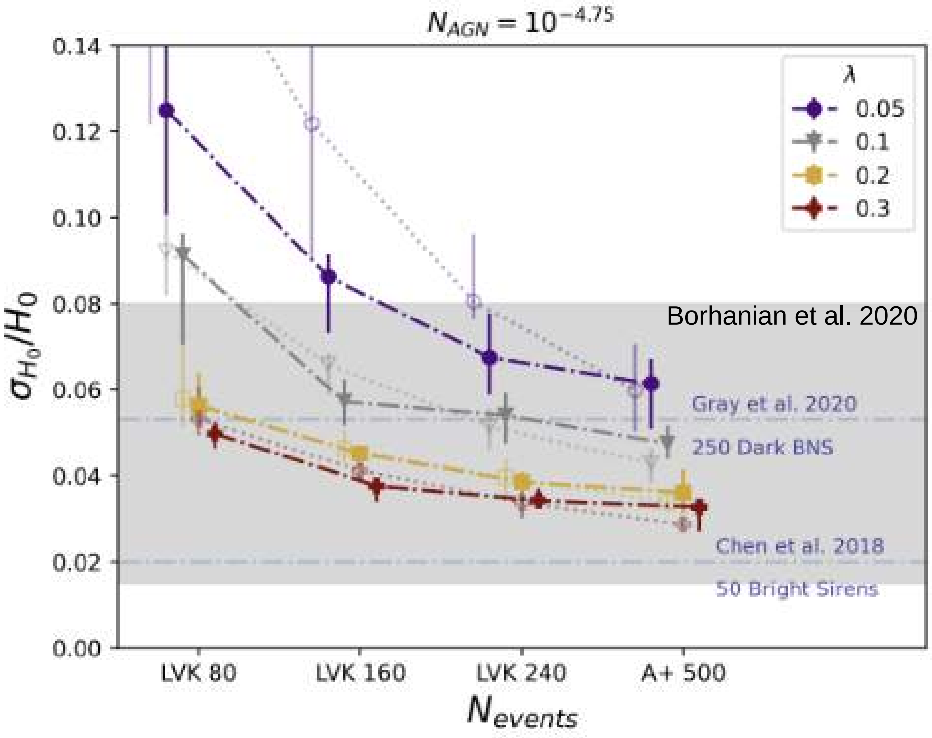


Hubble Constant precision



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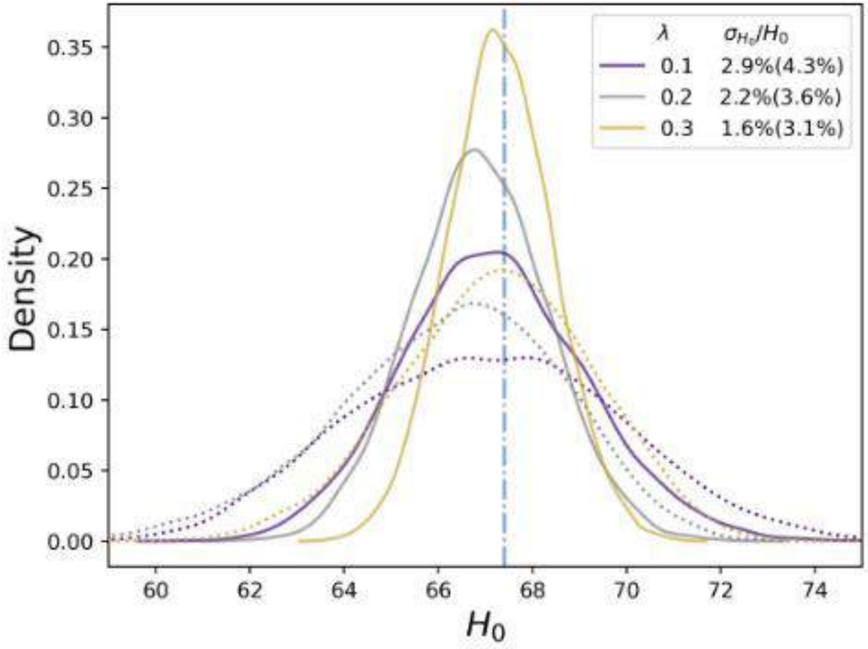
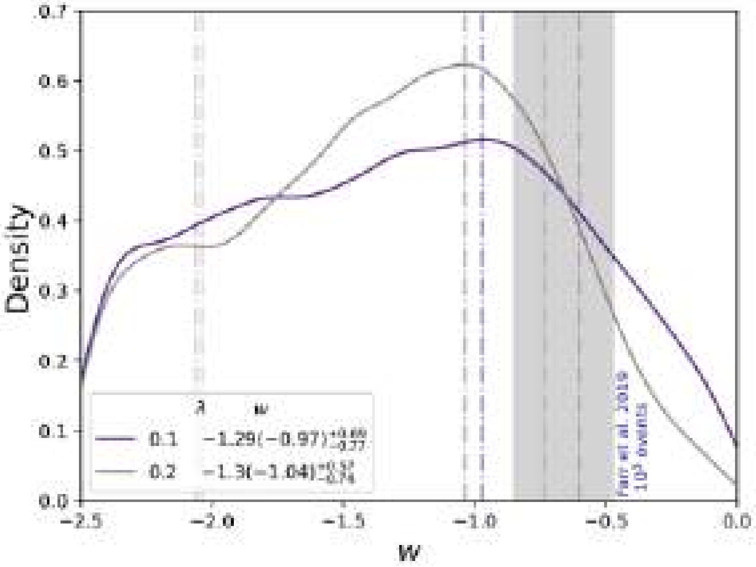
$$\Omega_m \in [0.0, 1.0]$$

Posteriors and priors

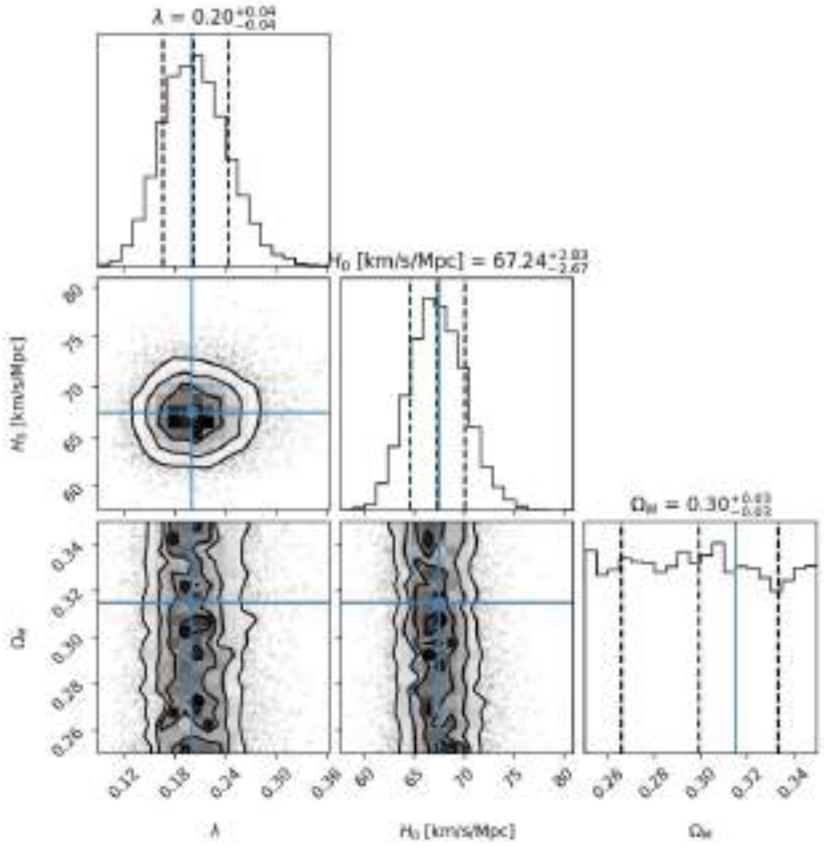




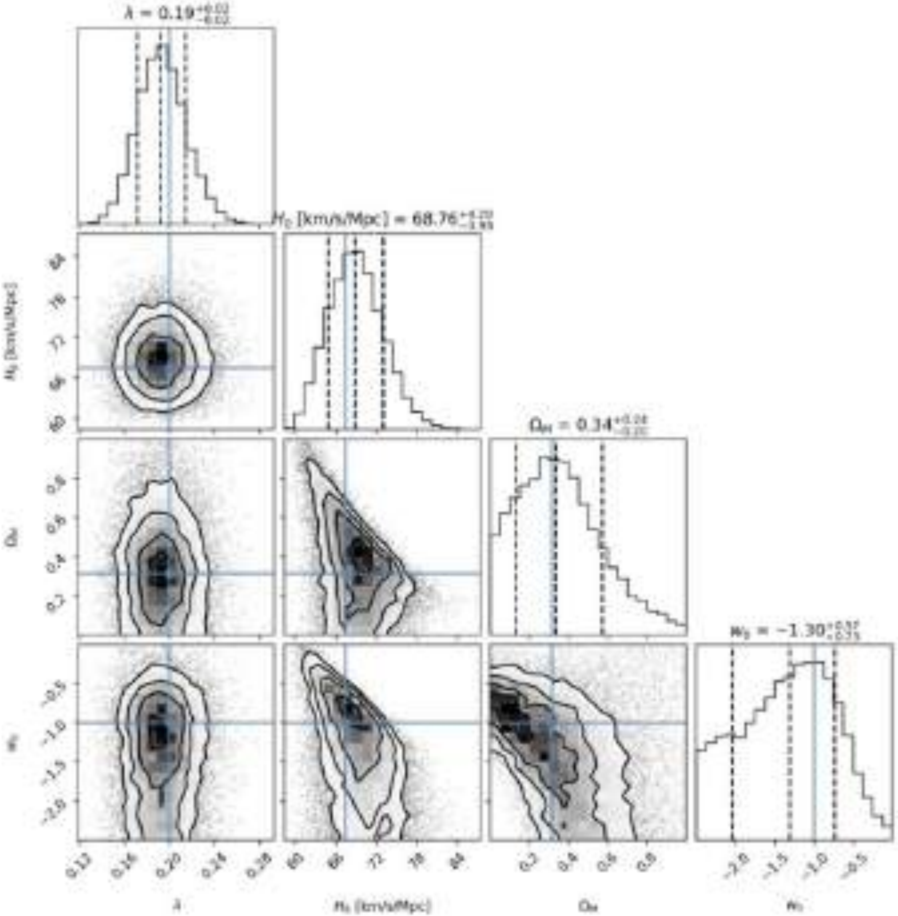
$\Omega_m \in [0.25, 0.35]$

What can be obtained in the next 1-2 years

160 events ~ 1 O4
Narrow prior on Omega matter [0.25,0.35], the fraction of BBHs inducing flares is set to 0.2



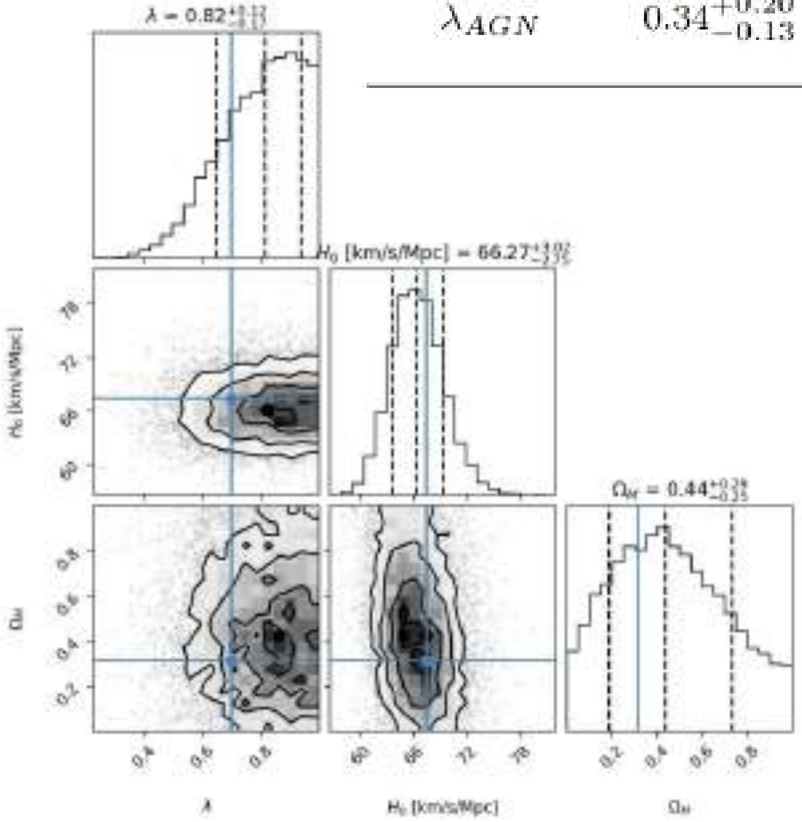
What can be obtained in O5 for wcdm



500 events ~ flat uninformative priors

Informed Dark Sirens

λ_{AGN}	0.3	0.4	0.5	0.6	0.7	0.8
$\sigma_{H_0}/H_0(\%)$	$11.1^{+9.5}_{-4}$	$10.1^{+8.2}_{-3.6}$	$10.8^{+1.6}_{-4.0}$	$6.2^{+1.6}_{-0.7}$	$6.0^{+2.3}_{-0.3}$	$5.0^{+2.2}_{-0.5}$
λ_{AGN}	$0.34^{+0.20}_{-0.13}$	$0.41^{+0.21}_{-0.17}$	$0.49^{+0.23}_{-0.17}$	$0.61^{+0.22}_{-0.18}$	$0.70^{+0.21}_{-0.17}$	$0.80^{+0.18}_{-0.14}$

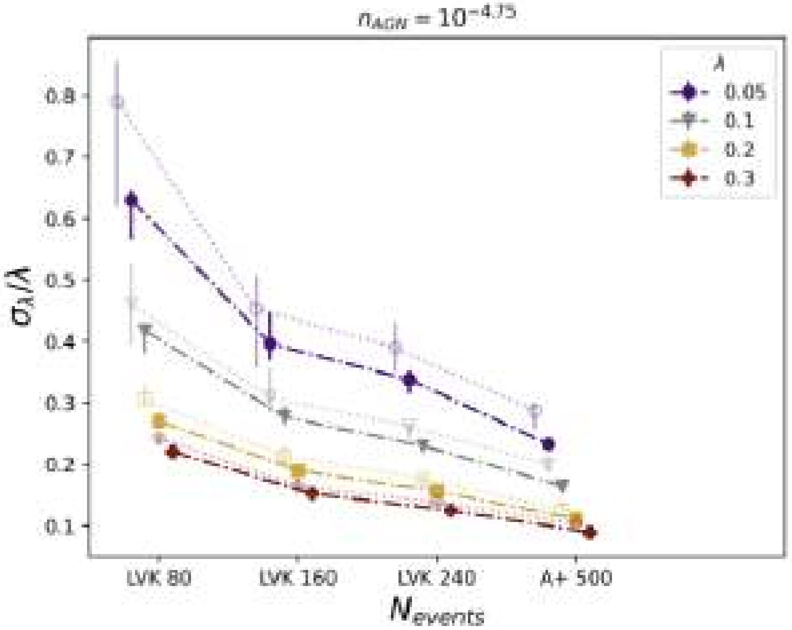


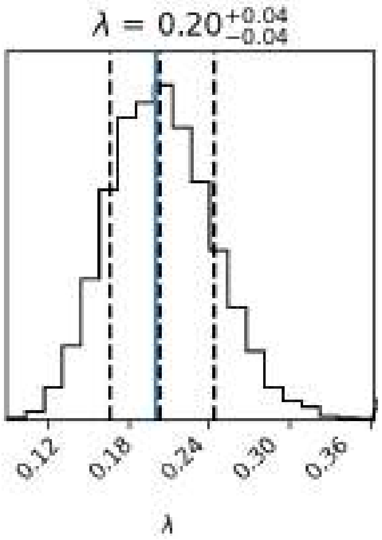
No Flares, All AGNS in the GW region

80 events – 1 year

Optimistic scenario, the fraction is 0.7.
Spectroscopic redshifts in all AGNs.
95% of the events have less than 70 AGNs.
Feaseble for multifiber spectrographs (e.g. DESI has 5000 fibers).

Contraints into the fraction of BBHs inducing flares





Concluding remarks

Binary Black Hole Mergers (BBHs) from AGNs are a promising probe for H0 and Standard Sirens,. It could reach ~3.5%-7% level after 160 events of LVK and 2.5% to 5% after 500 events in O5 using wide uninformative priors.

50 bright Sirens are likely to be found during O5. But we might not detect them (1 out of 2 Neutron Stars mergers found in GTC O3 catalog. No need of golden events (Borhanian et al. 2020). No need of highly complete catalogs (Gray et al. 2020).

There is no need to identify the host.

For the BBH flares we need imaging in time domain (e.g. Vera Rubin, LSST) but not ToO spectroscopy. BBHs may flare in a scale of weeks or months after GW.

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