Gravitational Waves cosmology: Recent results

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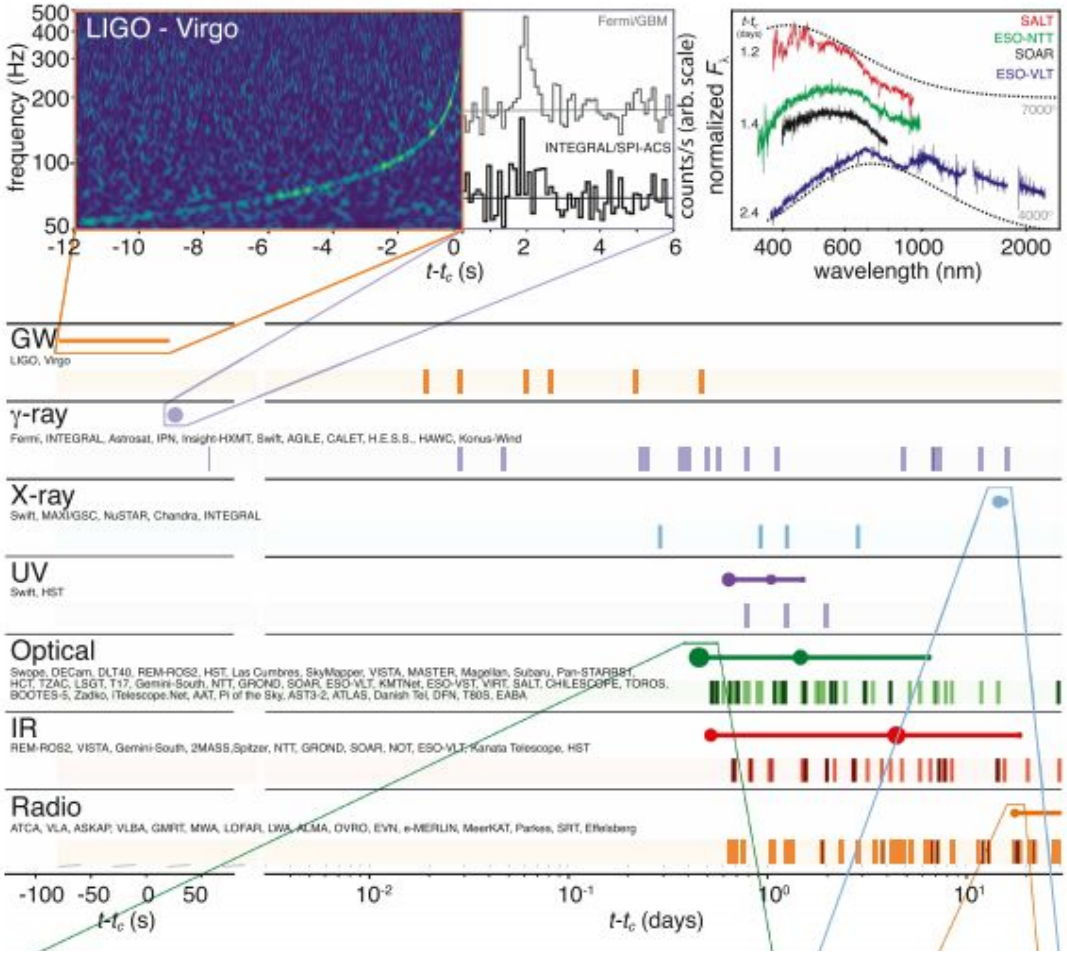
1st MaNiTou School 4-8 July

*Notes and slides are also available here

GW170817

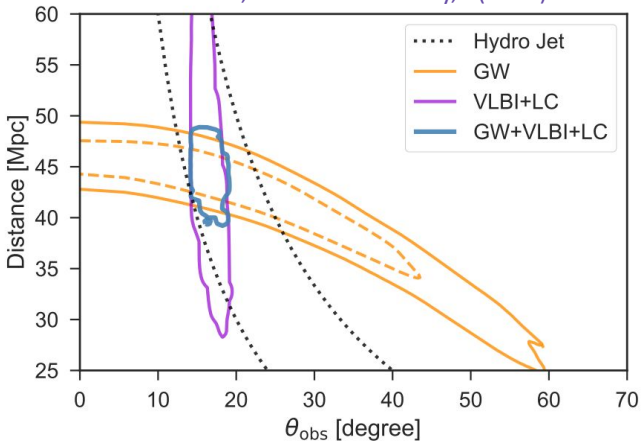
- A BNS merger at ~40 Mpc.
- The identified hosting galaxy, NGC4993, is located at redshift ~0.01.
- GW arrived 1.74s before its associated GRB.


LIGO - Virgo
frequency (Hz)
500
400
300
200
100
50
-12
-10
-8
-6
-4
-2
0
2
4
6
t-t_c (s)
Fermi/GBM
INTEGRAL/SPI-ACS
counts/s (arb. scale)
SALT
ESO-NTT
SOAR
ESO-VLT
normalized F_λ
1.2
1.4
2.4
7000°
4000°
400
600
1000
2000
wavelength (nm)
GW
LIGO, Virgo
γ-ray
Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind
X-ray
Swift, MAXI/GSC, NuSTAR, Chandra, INTEGRAL
UV
Swift, HST
Optical
Swope, DECam, DLT40, REM-ROS2, HST, Las Cumbres, SkyMapper, VISTA, MASTER, Magellan, Subaru, Pan-STARRS1, HCT, TZAC, LSGT, T17, Gemini-South, NTT, GROND, SOAR, ESO-VLT, KMTNet, ESO-VST, WIRT, SALT, CHILESCOPE, TOROS, BOOTES-5, Zadko, iTelescope.Net, AAT, PI of the Sky, AST3-2, ATLAS, Danish Tel, OFN, T80S, EABA
IR
REM-ROS2, VISTA, Gemini-South, 2MASS,Spitzer, NTT, GROND, SOAR, NOT, ESO-VLT, Kanata Telescope, HST
Radio
ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, e-MERLIN, MeerKAT, Parkes, SRT, Effelsberg
-100
-50
0
50
t-t_c (s)
10^{-2}
10^{-1}
10^{0}
10^{1}
t-t_c (days)

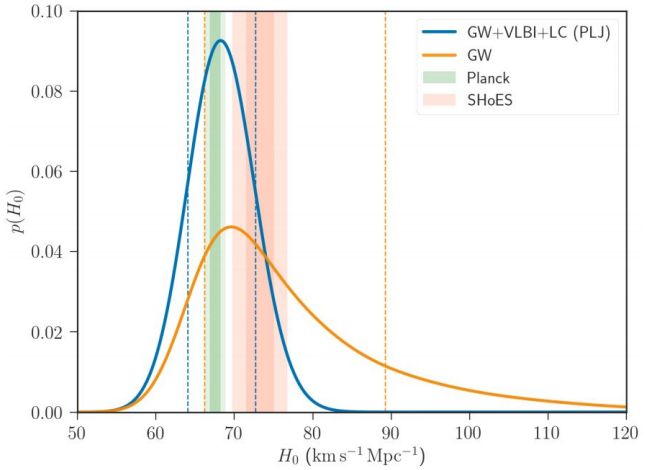
Direct EM counterpart method

- The gravitational wave event provides a direct measure of the luminosity distance
- A redshift estimation estimation is provided from the host galaxy
- Accuracy on luminosity distance can from the afterglow light curve
- By using the redshift information, the luminosity distance can be converted into a posterior on cosmological parameters

K. Hotokezaka, Nature Astronomy, 3(2019)



Luminosity distance/redshift relation



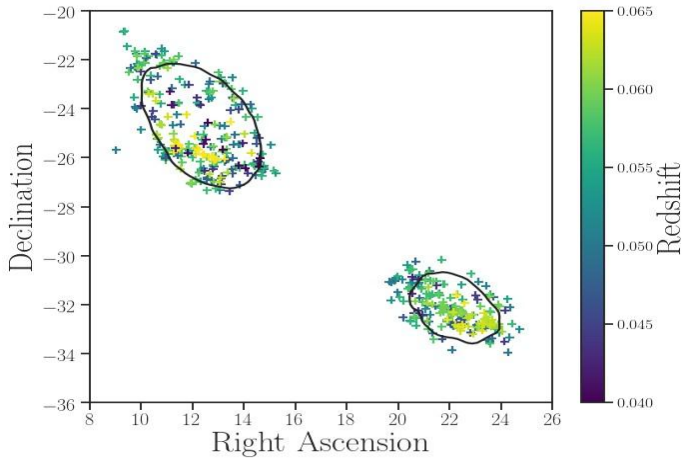
Results: Gravitational-wave cosmology with Dark Sirens

Pro: No electromagnetic counterpart needed

The galaxy catalog method

*Gray, **SM**+, 2020 PRD*

- Check the galaxy density profile w.r.t the GW localization
- **Cons:** Need to keep under control galaxy catalog completeness



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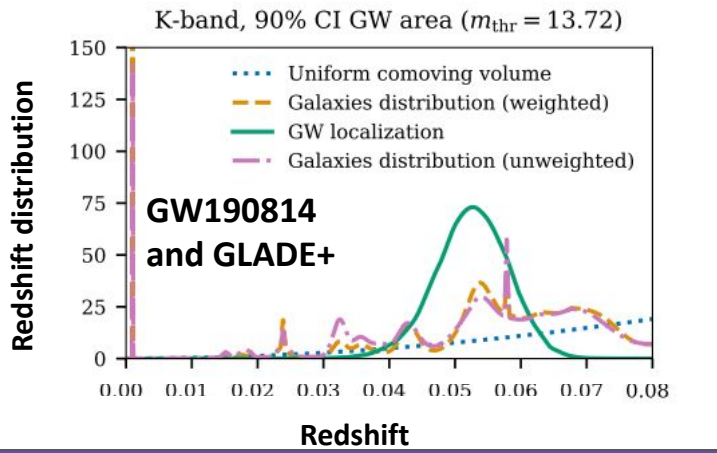
*LVK+, **SM**, arXiv:2111.03604 (ApJ)*



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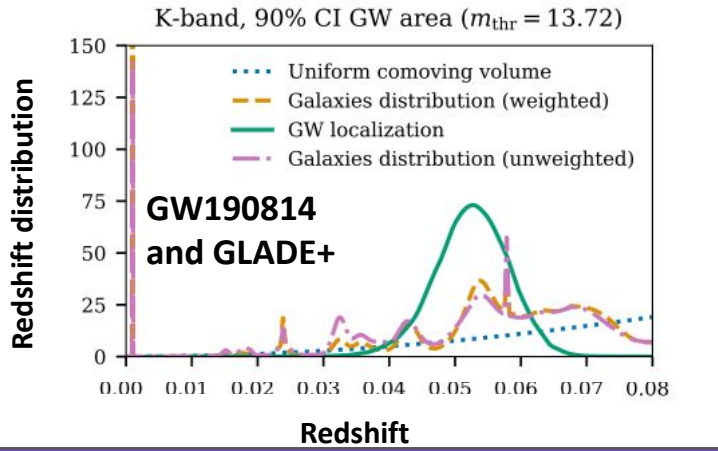
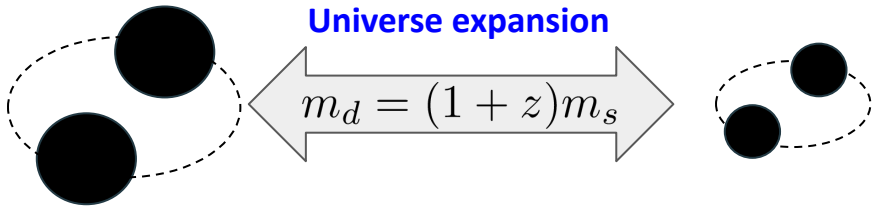


The Mass distribution method

- Infer redshift from *redshifted masses* and mass features in the BBHs mass spectra



***SM**, Karathanasis+, 2021 PRD*

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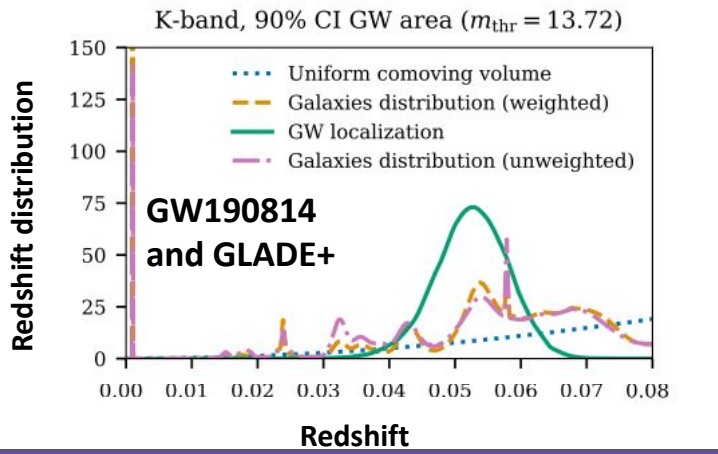

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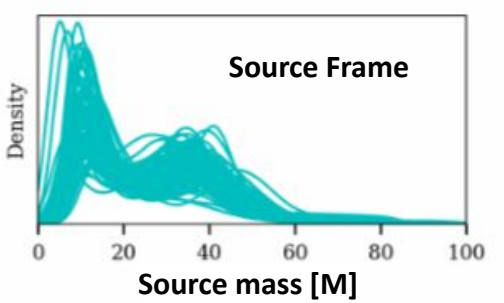
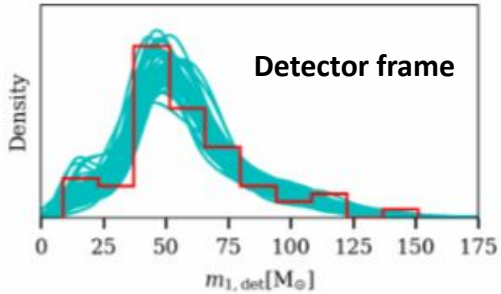


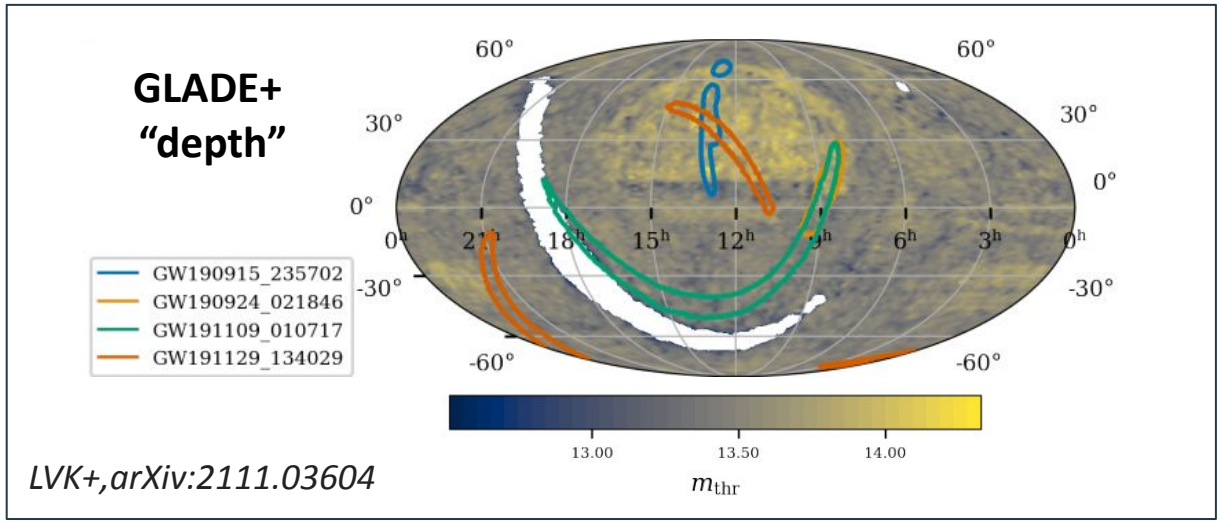
Selection bias
+
Cosmology
+
Bayesian inference



Latest results with O3 from the LVK collaboration

We presented two analyses to infer cosmological parameters with Dark Standard Sirens in *[LVK+,arXiv:2111.03604]*

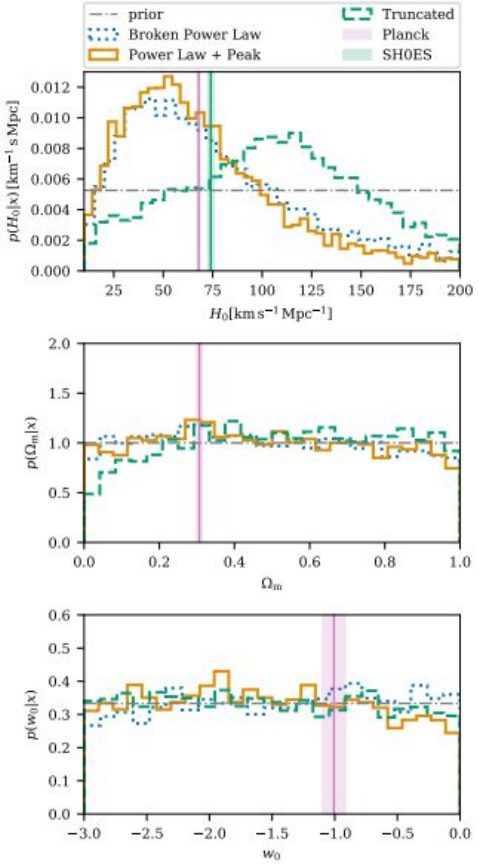
- **Joint cosmological and source mass analysis:** We use 42 confident BBHs with detected SNR>11.
- **Dark siren analysis with the GLADE+** *[G. Dalya+,arXiv:2110.06184]* **catalog:** All the 47 Compact binaries events with SNR>11.



Latest O3 results from the LVK collaboration: source mass

SNR>11

- We inferred jointly the source mass distribution of BBHs and the value of the Hubble constant, Dark Matter fraction and and Dark Energy Equation of State parameter.
- We employed 3 phenomenological mass models: A truncated power law, a power law+peak and a broken power law.
- We obtain that the truncated power law model is disfavored w.r.t the other two by a factor of ~100.
- For the two preferred models we obtain consistent constraints on the Hubble constant.



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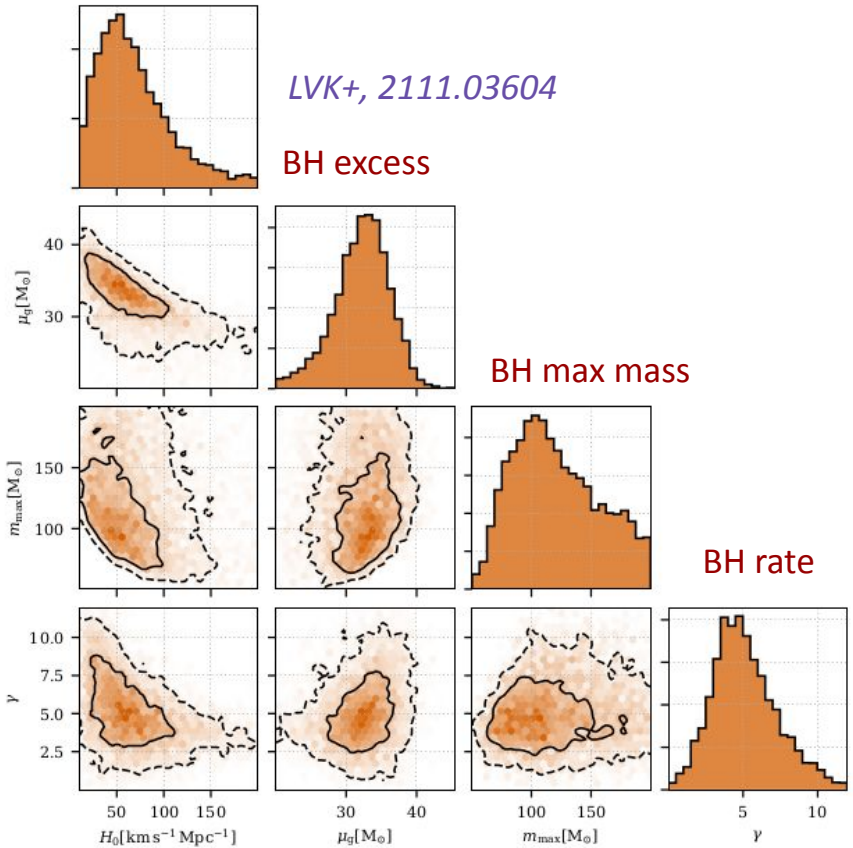
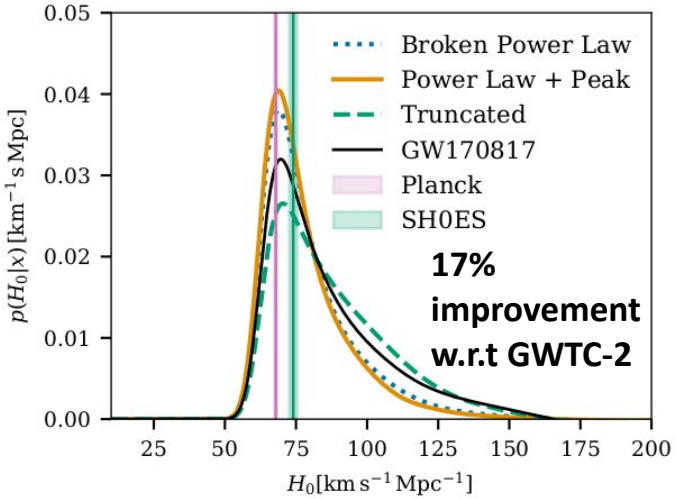


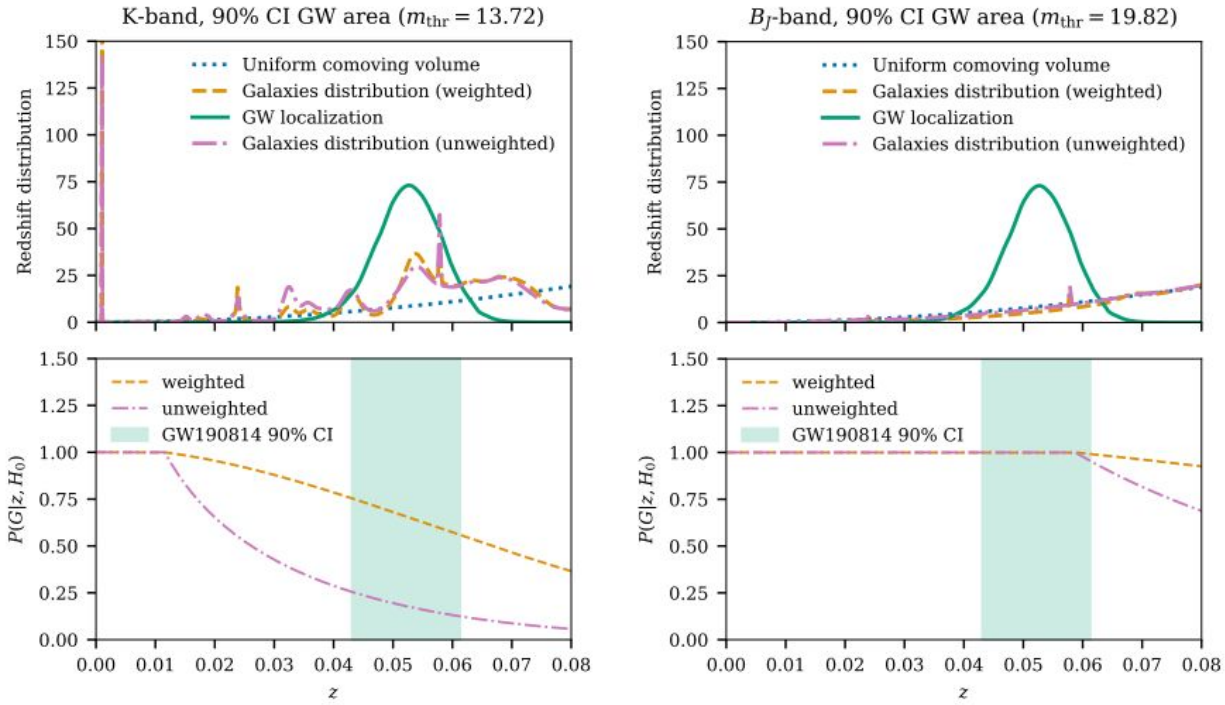
- BBHs population parameters that correlate with the determination of the Hubble constant are parameters governing source mass features in the spectrum and the rate evolution parameter.

Combining with GW170817



Latest O3 results from the LVK collaboration: Galaxy catalogs

- The best localized event from O1, O2 and O3 without EM counterpart is GW190814.
- Apart from G190814, GLADE+ is highly incomplete for most of the GW events considered.



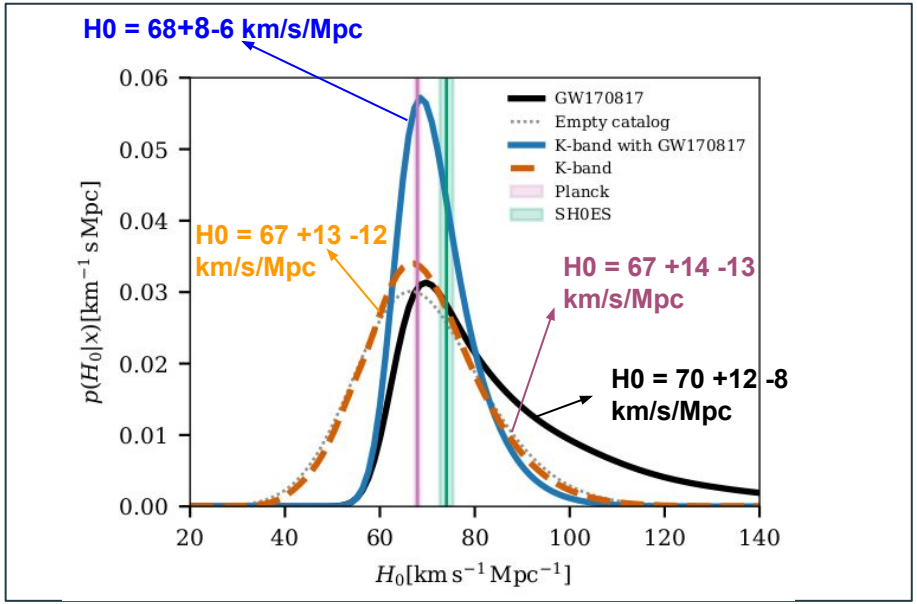
LVK+,arXiv:2111.03604

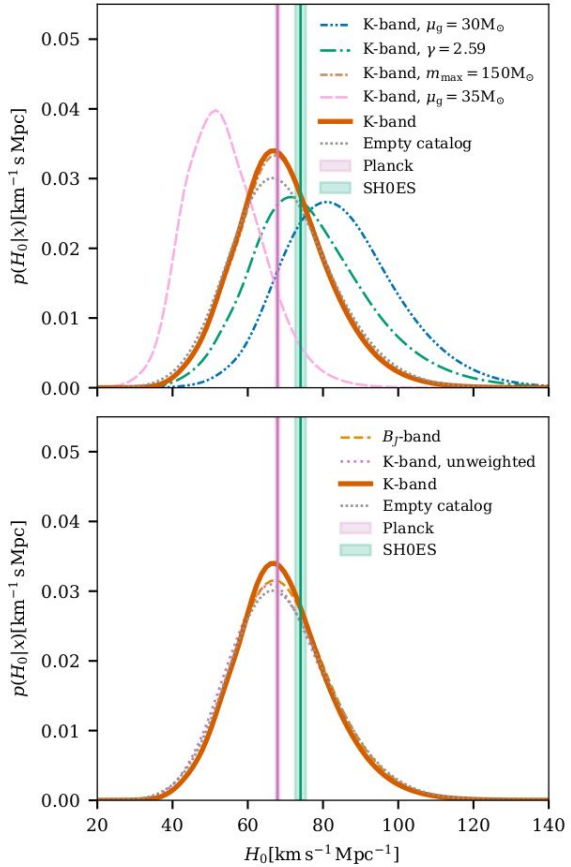
Latest O3 results from the LVK collaboration: Galaxy catalogs

LVK+, 2111.03604

- The galaxy catalog results are dominated by the BHs population assumptions.

- This is due to the incompleteness of the galaxy catalog and the large localization error for the GW events.

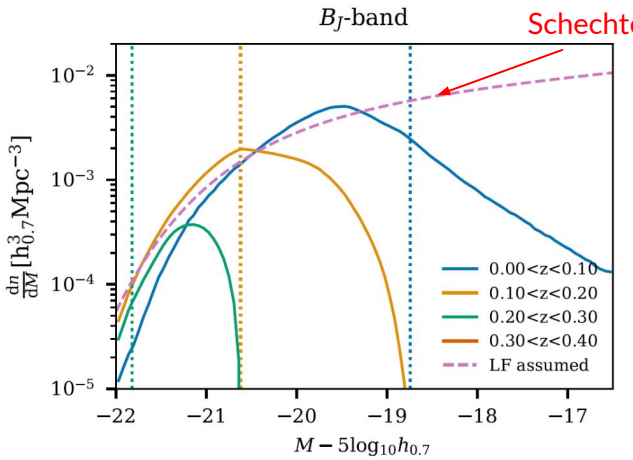


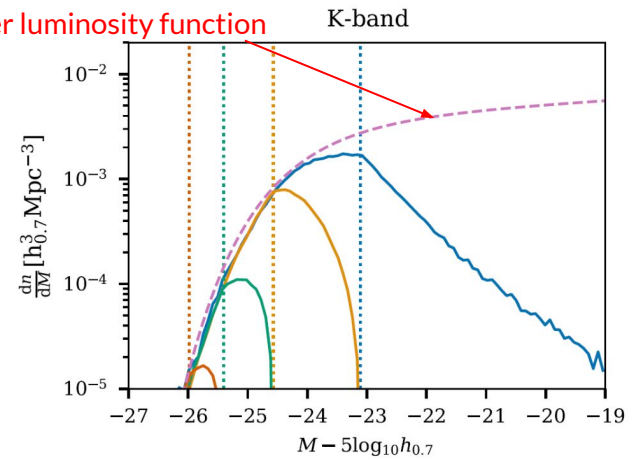


Latest O3 results from the LVK collaboration: Robustness of assumptions

Observed vs **predicted** abs mag distributions, binned by redshift

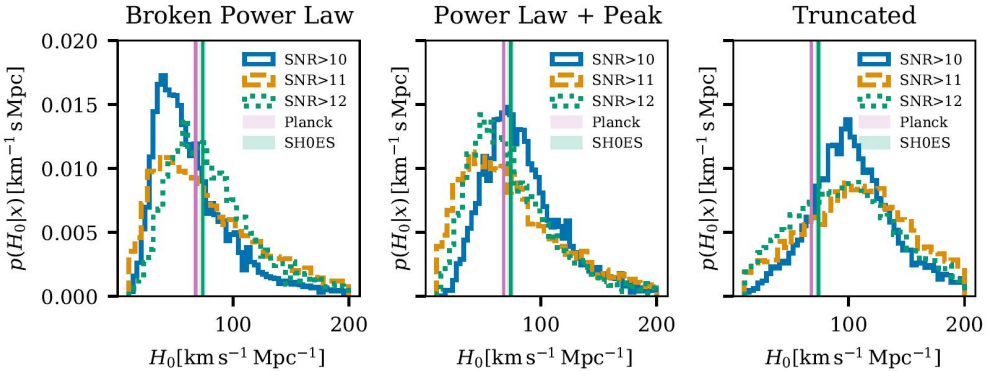
Motivates choice of K-band for our main results



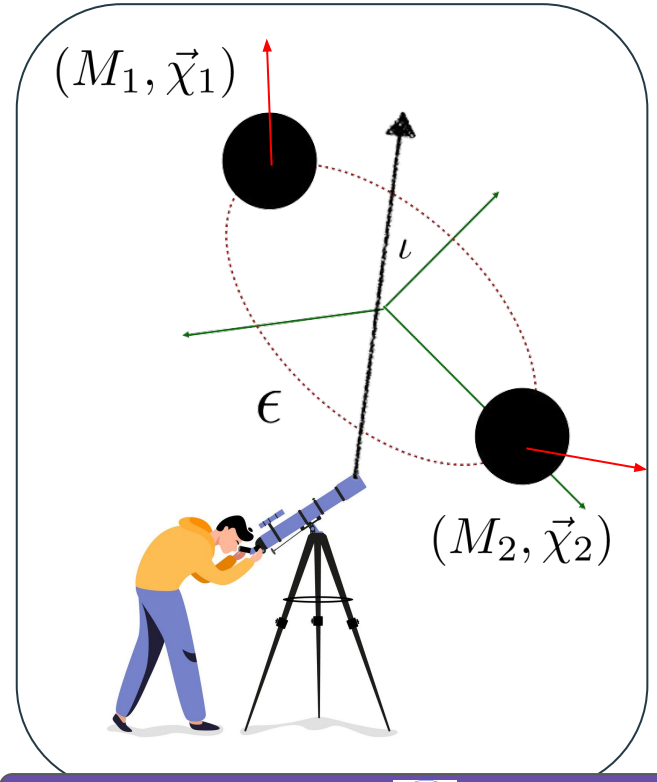


Changing SNR cut produces **consistent H_0 posteriors**.

Population excess at ~ **35 solar masses** observed for each SNR cut

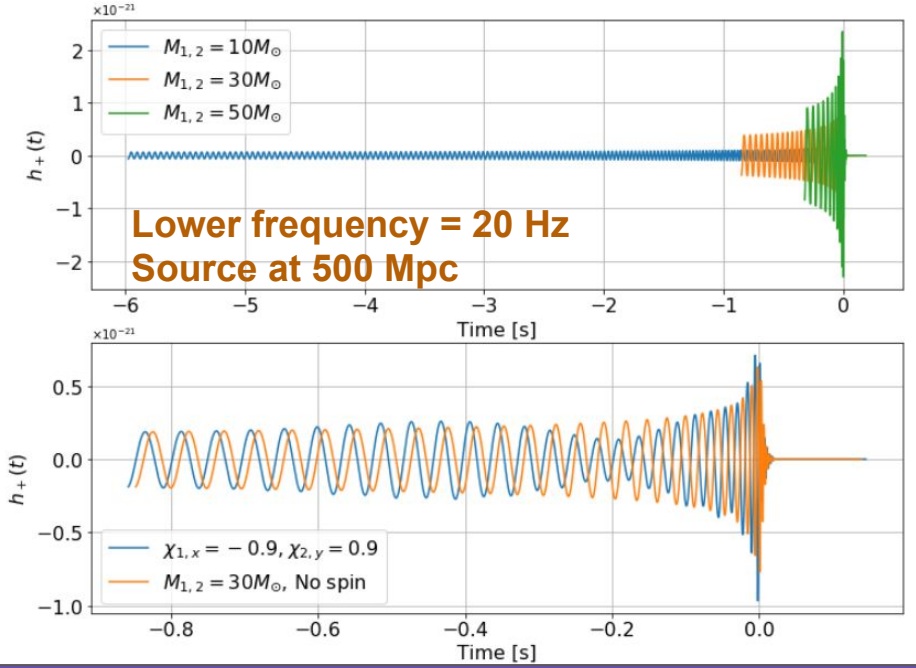


What do we measure?



The parameters:

- **Intrinsic:** Spins, masses, tidal deformability, eccentricity
- **Extrinsic:** Time, reference phase, sky position, luminosity distance, orbital orientation



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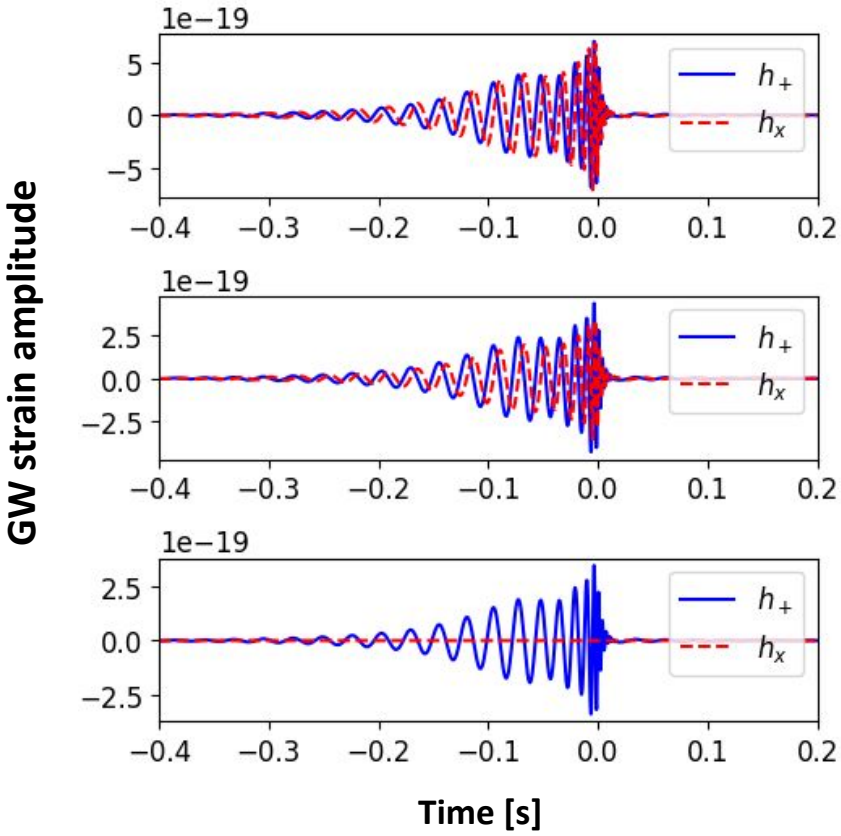
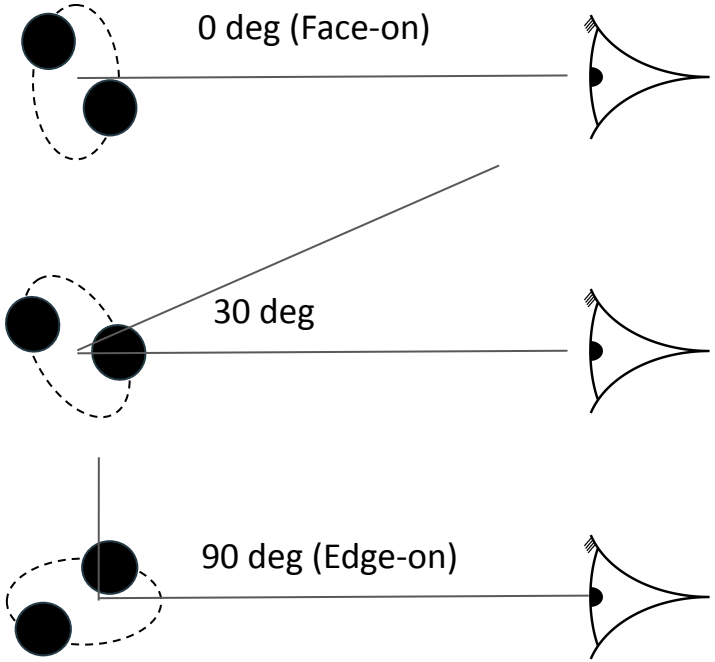
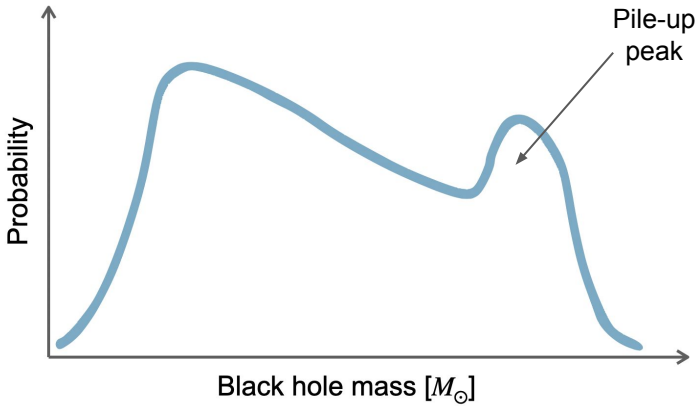
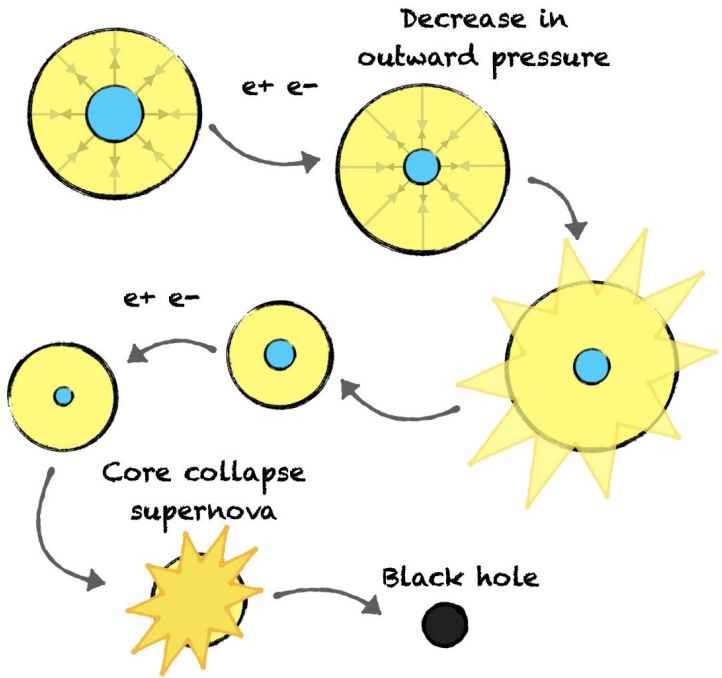




Pulsational pair instability: black hole pile up

- Massive stars shed mass in ‘pulses’.
- Produce stars of similar mass, which collapse to form black holes around ~ 35 to 45 $M_\odot$





Stars of masses $\sim 80M_\odot \rightarrow 130M_\odot$ at ZAMS

(ZAMS = Zero Age Main Sequence ~ original mass of star)

Extreme deconvolution of noisy, heterogeneous and incomplete data