arXiv:2508.19331

Towards a few-% measurement of H_0 with the current network of GW detectors, without EM information

Tom Bertheas [1,2], Vasco Gennari [1], Nicola Tamanini [1]
[1] L2IT, Toulouse.
[2] LPENS, Paris

9ème Assemblée Générale
GdR Ondes gravitationnelles
October 13th 2025 — LPENS, Paris

Université de Toulouse

L2IT

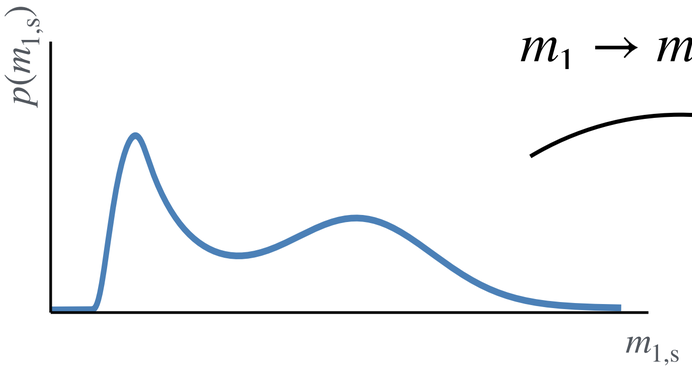
Outline

- Reminders about **spectral sirens**
- Parametric **mass models** used
- Re-analysis of **O3 data**
- **Simulations** setup
- **Forecasts** for O4 & O5

Spectral sirens

A quick reminder

Credits : V. Gennari

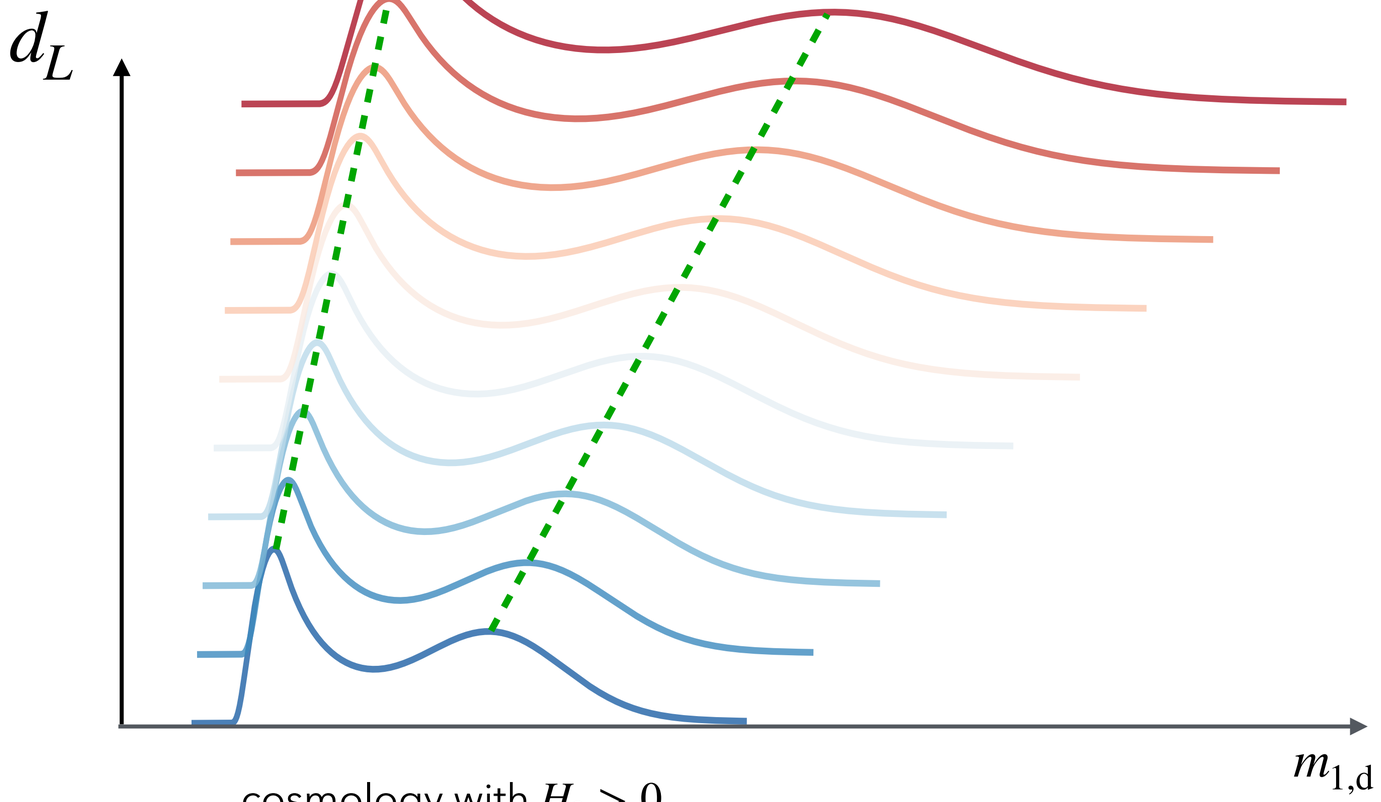


$m_1 \rightarrow m_1\,(1+z)$

Astrophysical distribution
(stationary)

Phenomenological **mass scales** in BH distribution convey **redshift information**

$\sim d_L(z)$

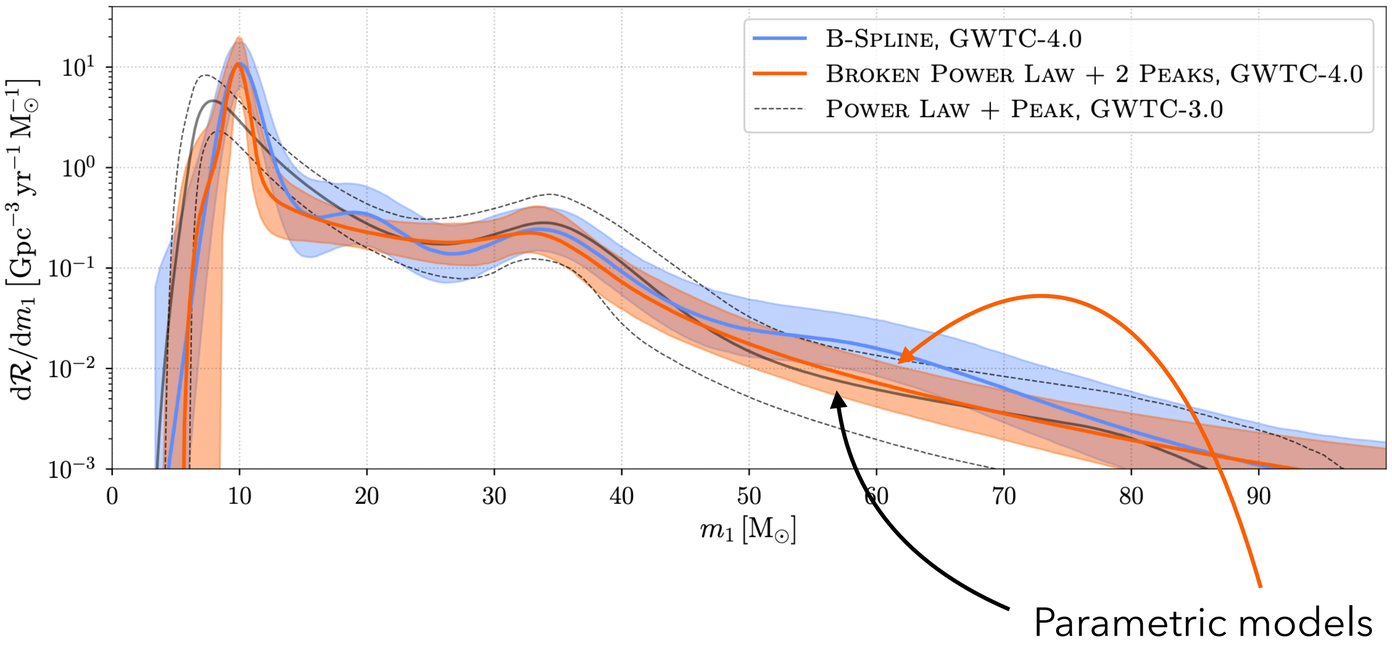


cosmology with $H_0 > 0$

Spectral sirens

Looking for anchors

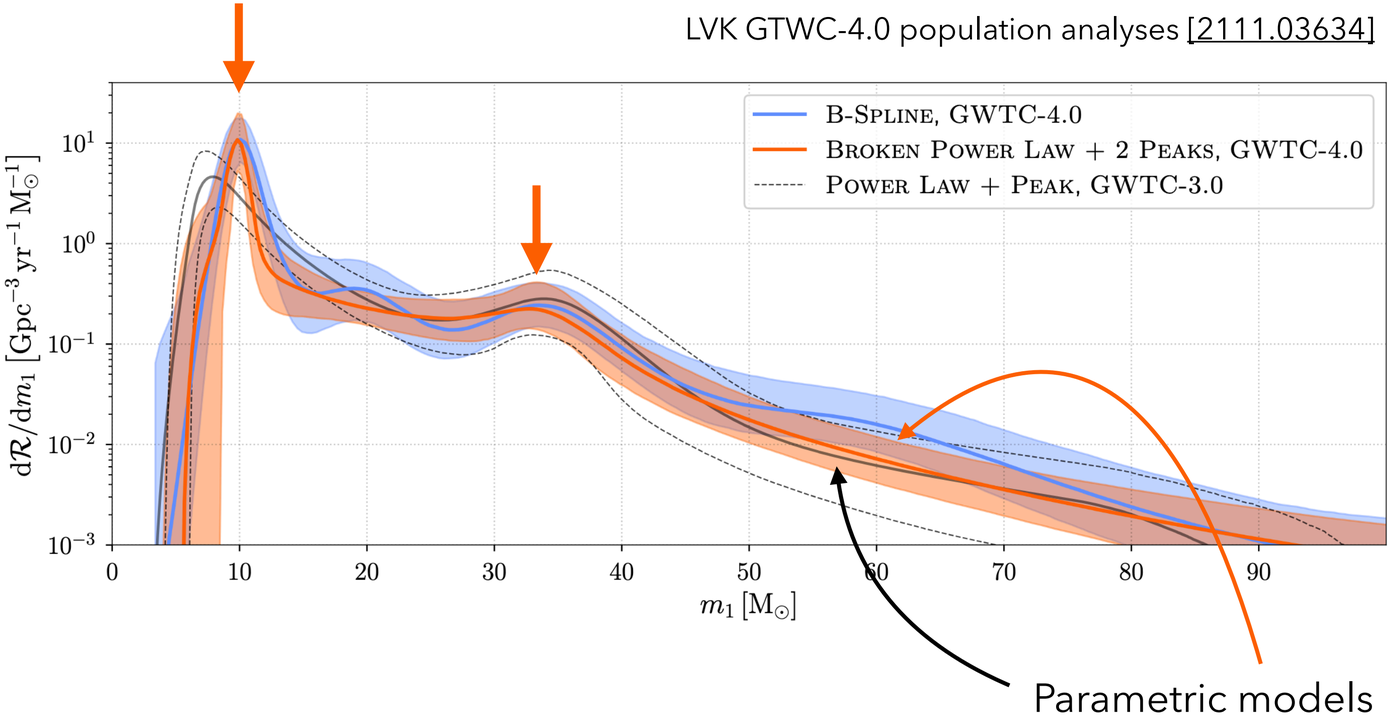
LVK GTWC-4.0 population analyses [2111.03634]



Spectral sirens

Looking for anchors

LVK GTWC-4.0 population analyses [2111.03634]

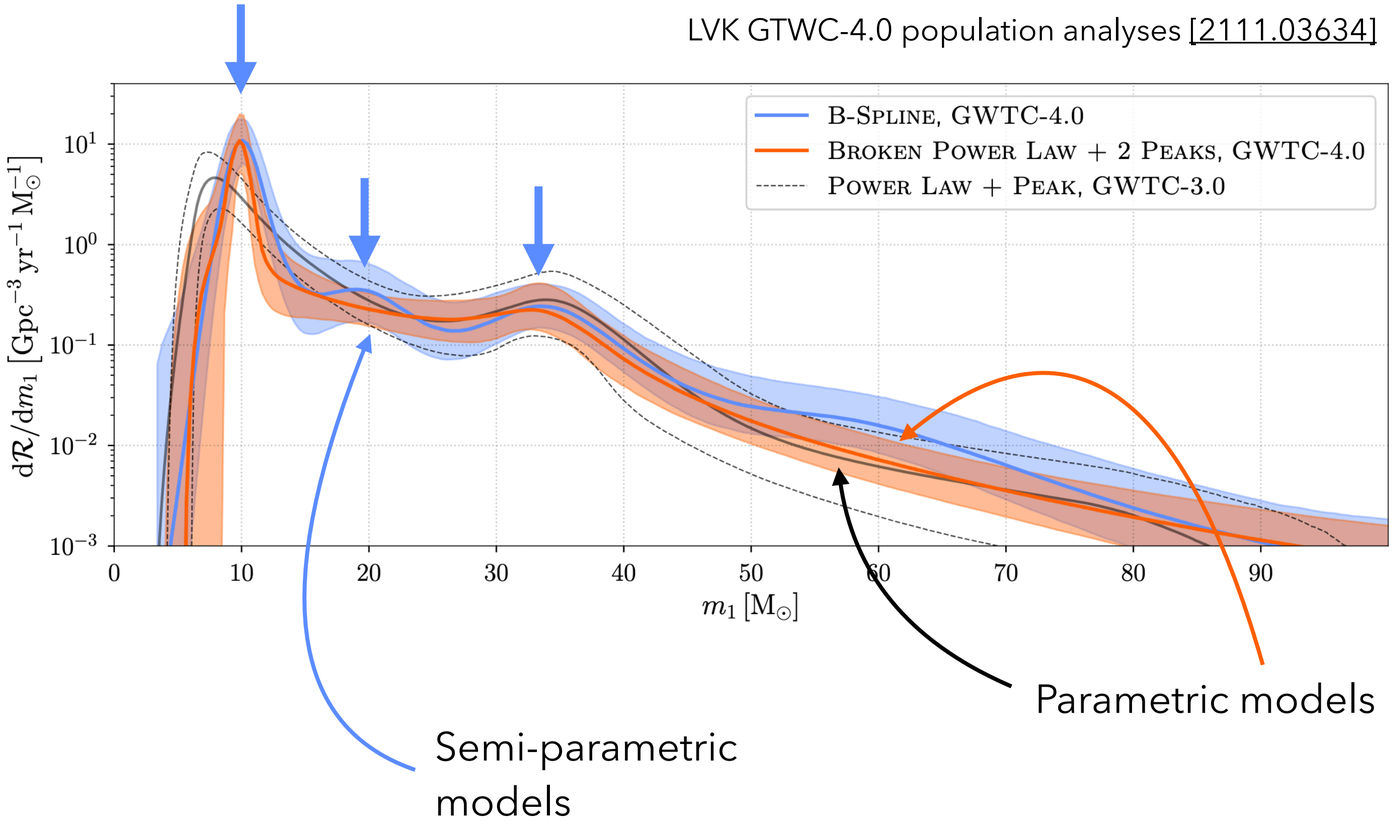


Parametric models

Spectral sirens

Looking for anchors

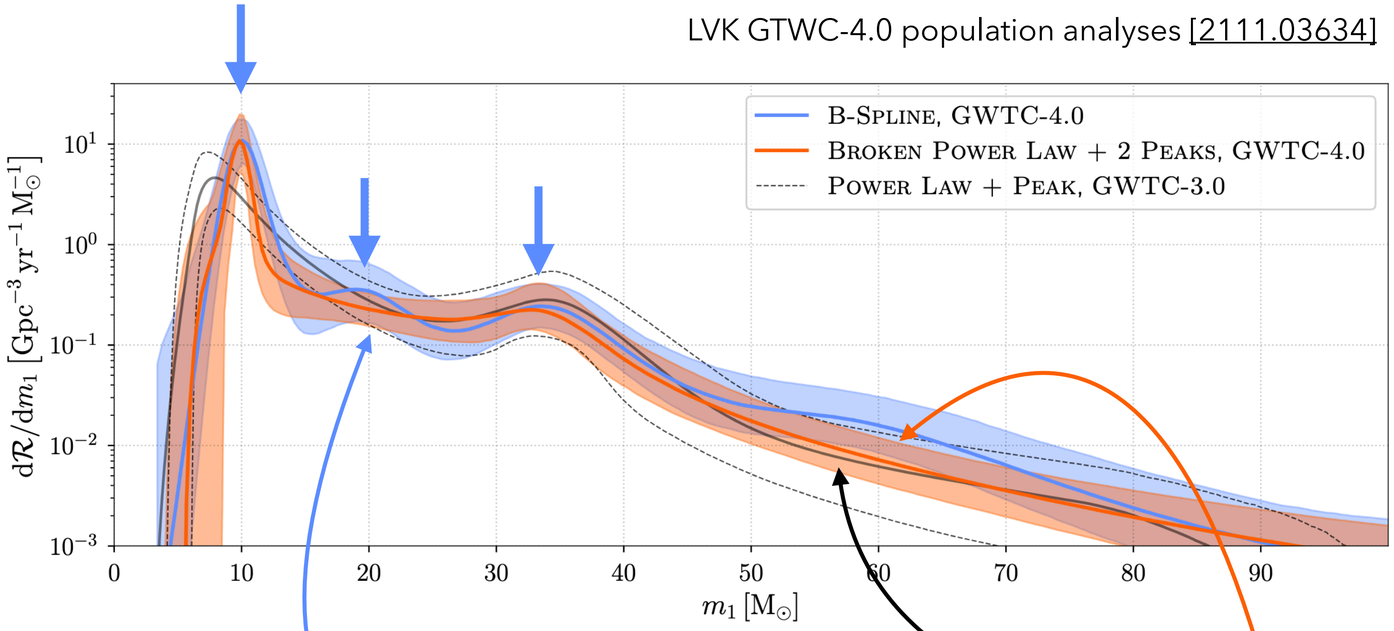
LVK GTWC-4.0 population analyses [2111.03634]



Spectral sirens

Looking for anchors

LVK GTWC-4.0 population analyses [2111.03634]

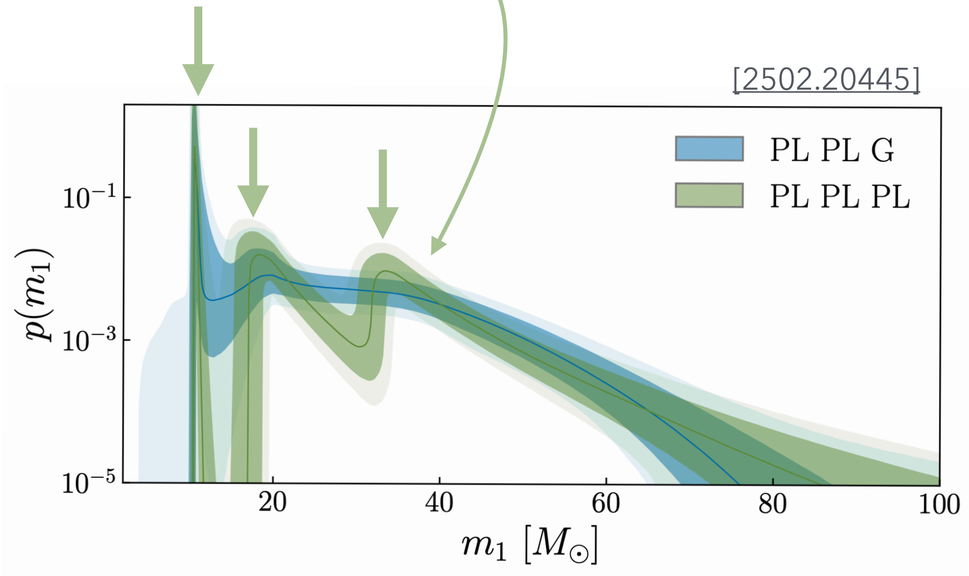


Parametric models

Semi-parametric models

3 (sharp) features parametric models

[2502.20445]



Methods

Mass models

Fiducial :

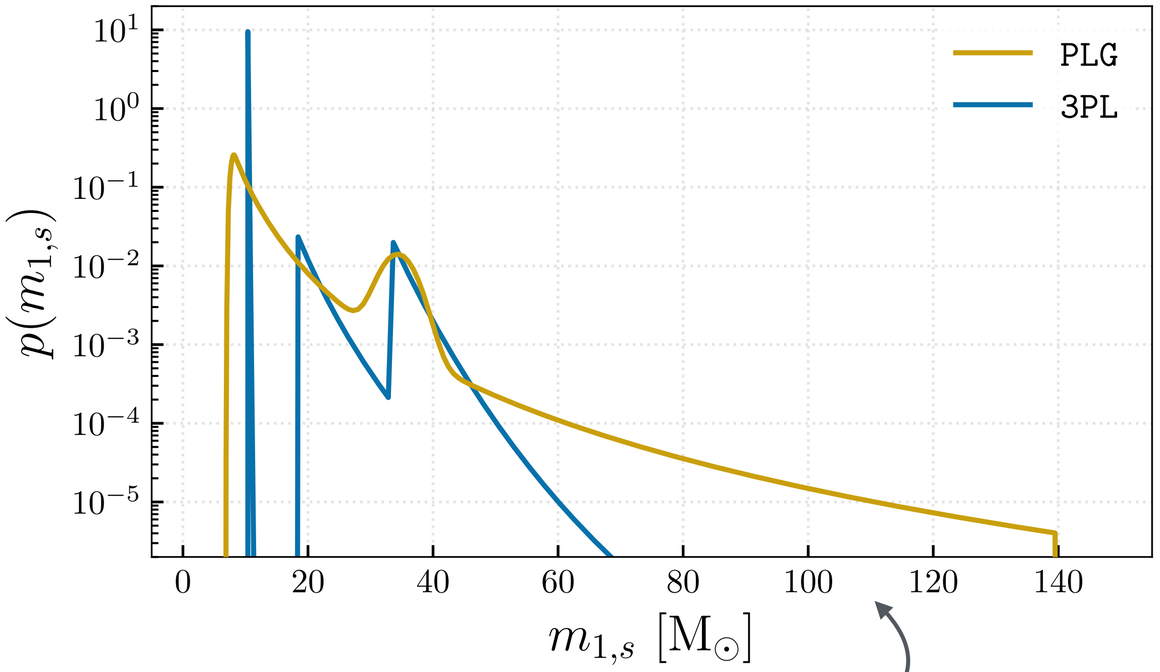
`PowerLaw-Gaussian (PLG)`

$$p(m_1) \sim PL + G$$

More (and sharper) features :

`PowerLaw-PowerLaw-PowerLaw (3PL)`

$$p(m_1) \sim PL_1 + PL_2 + PL_3$$



This is max $\mathscr{L}$ from O3

Methods

Mass models

Fiducial :

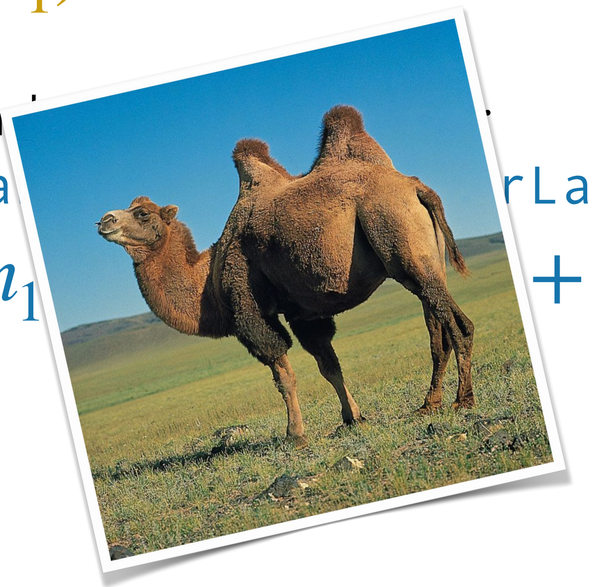
PowerLaw-Gaussian (PLG)

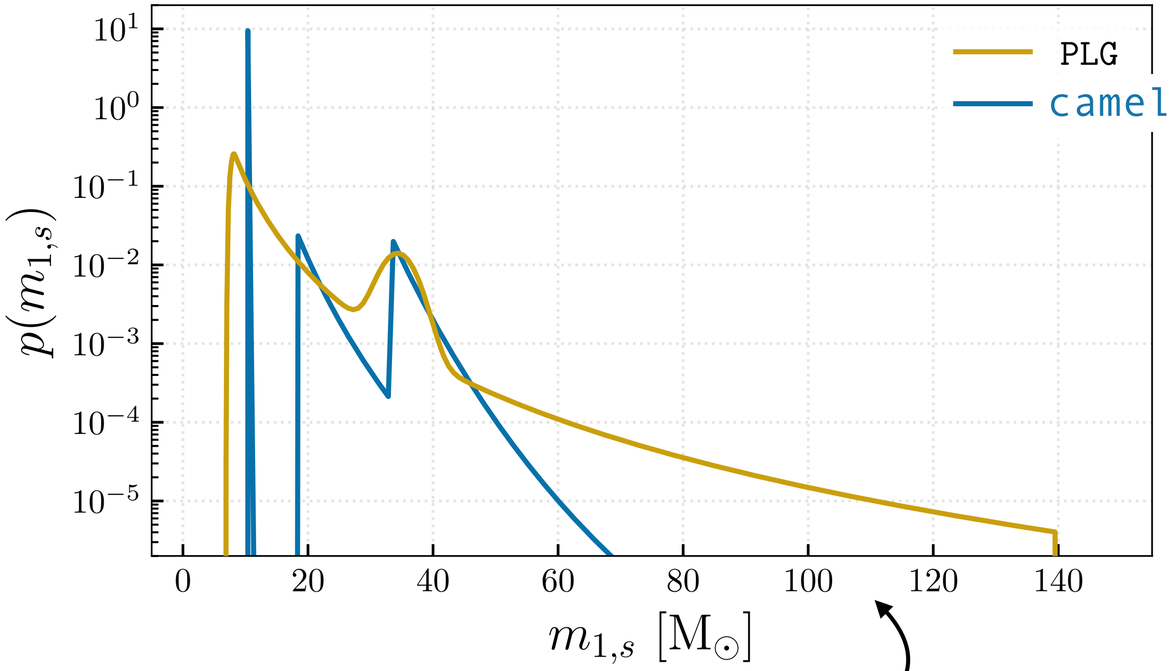
$$p(m_1) \sim PL + G$$

More (an

PowerLa rLaw (camel)

$p(m_1$ $+ PL_3$





This is max $\mathscr{L}$ from O3

Methods

Mass models

Fiducial :

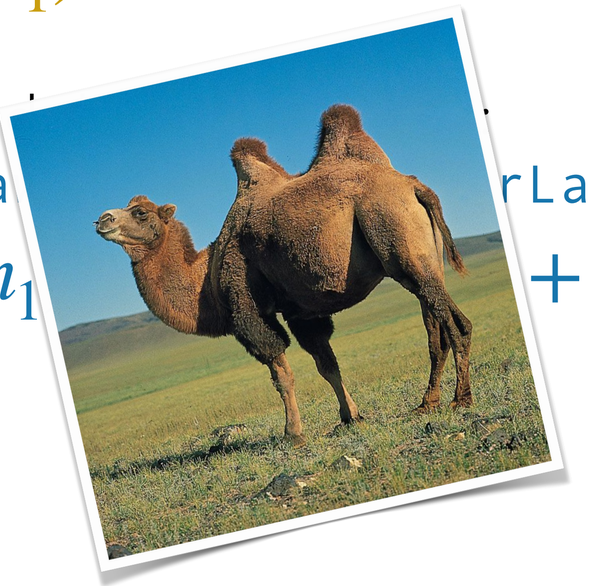
PowerLaw-Gaussian (PLG)

$$p(m_1) \sim PL + G$$

More (an

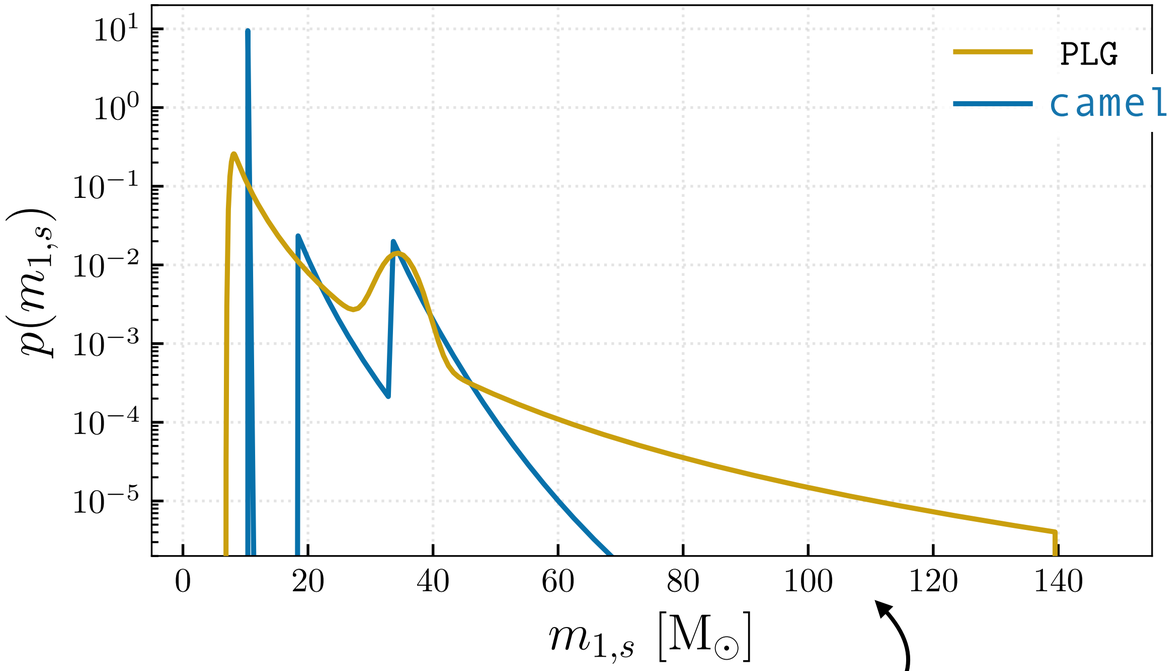
PowerLa rLaw (camel)

$p(m_1$ $+ PL_3$



O3 data shows strong bayes evidence in favour of 3PL over PLG:

$$\ln \mathscr{B}_{\mathrm{3PL/PLG}} > 5$$



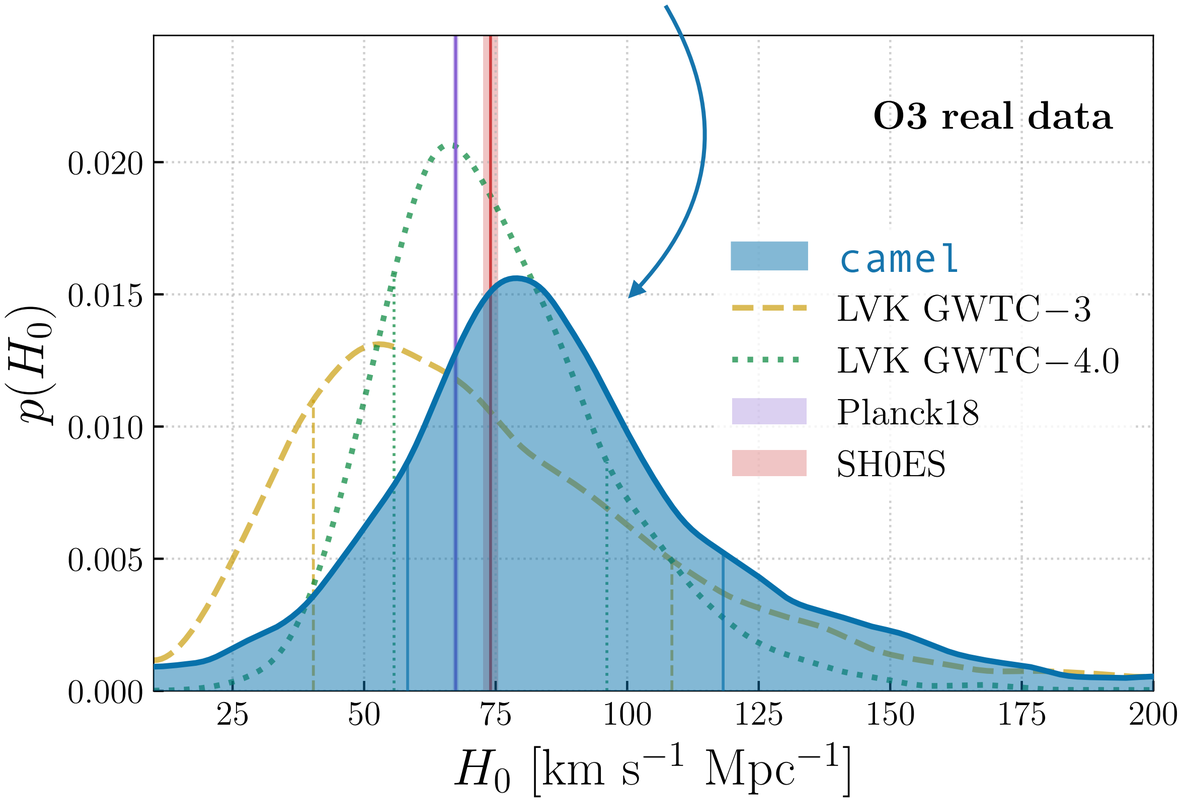
This is $\max \mathscr{L}$ from O3

Results

O3 real data

- `3PL` = 30% accuracy improvement compared to (LVK) O3 PLG
- O3 H_0 measurement competitive with current GWTC-4.0 results

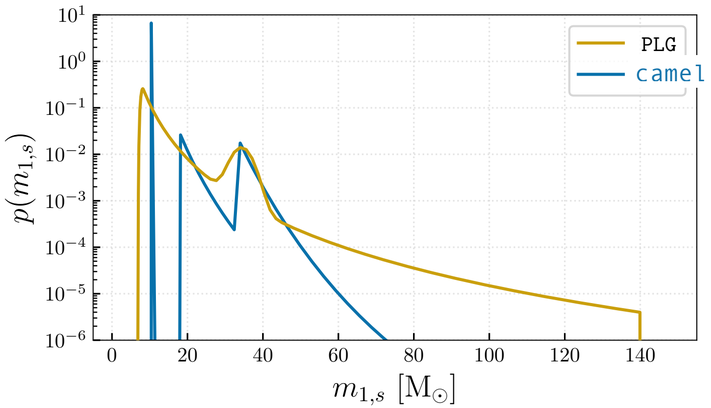
$$H_0 = 84^{+35}_{-25}\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$$



Methods

Simulating mock data sets

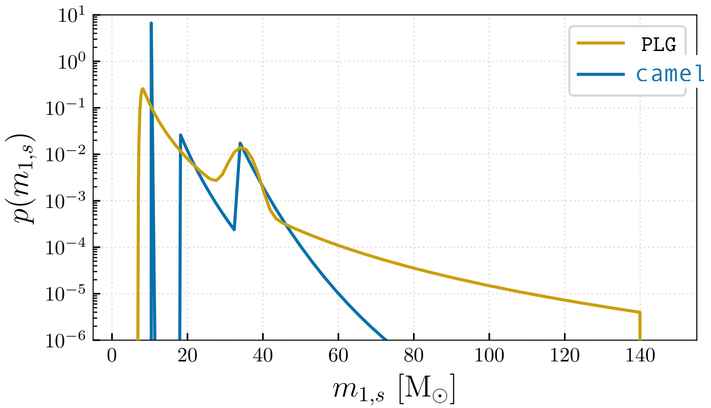
1. **Draw events** (m_1, m_2, z) from O3 max $\mathscr{L}$ rates



Methods

Simulating mock data sets

1. **Draw events** (m_1, m_2, z) from O3 max $\mathscr{L}$ rates



2. Realistic **detection** simulation:

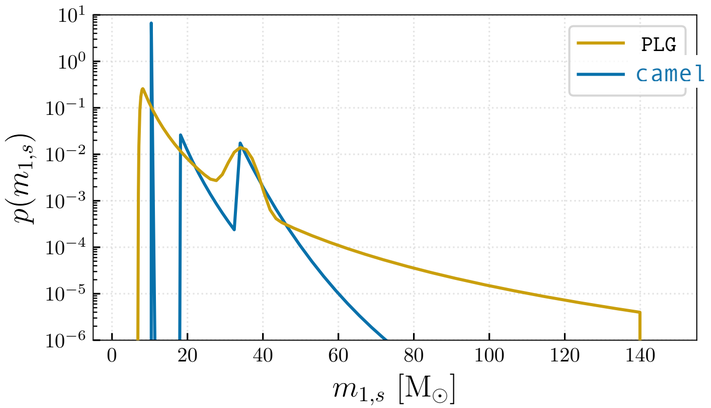
- Duty cycles based on observing plans (O4 1.5yrs / O5 3yrs)
- Coloured gaussian noise from design PSDs
- Signal with `IMRPhenomXHM`
- Matched-filter $\mathrm{SNR} > 12$

	O4	O5
`PLG`	142	1823
`3PL`	149	1862

Methods

Simulating mock data sets

1. **Draw events** (m_1, m_2, z) from O3 max $\mathscr{L}$ rates



2. Realistic **detection** simulation:

- Duty cycles based on observing plans (O4 1.5yrs / O5 3yrs)
- Coloured gaussian noise from design PSDs
- Signal with `IMRPhenomXHM`
- Matched-filter $\mathrm{SNR} > 12$

	O4	O5
`PLG`	142	1823
`3PL`	149	1862

3. Realistic **parameter estimation**:

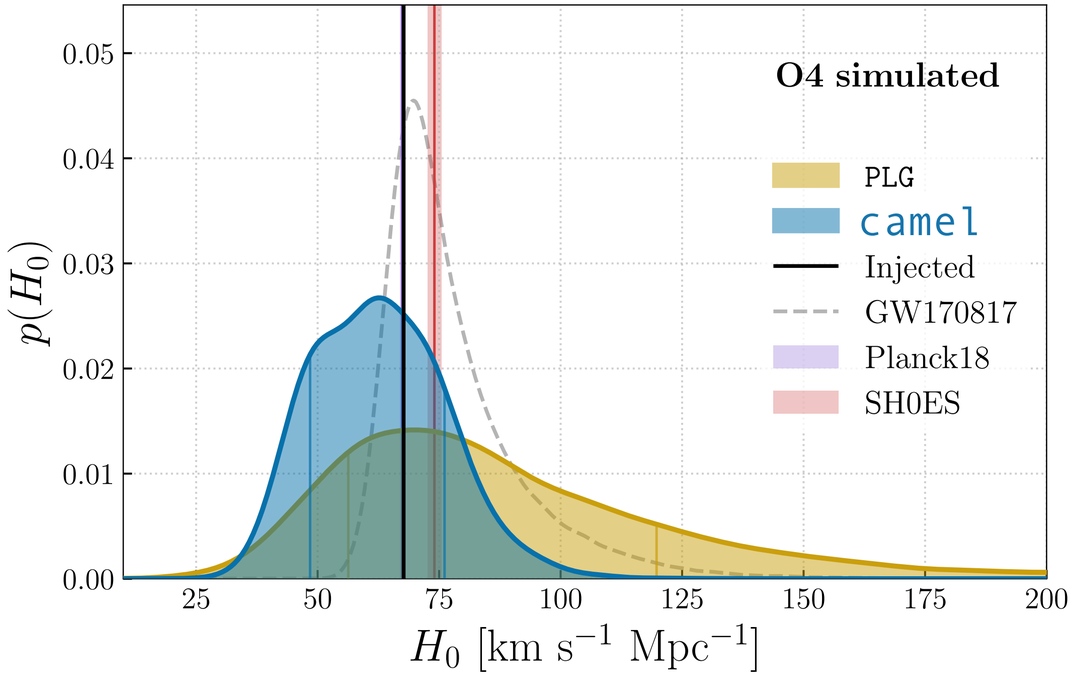
- Full realistic PE procedure on each event
- Gaussian likelihood
- samples generated with the `nessai` sampler from `bilby`

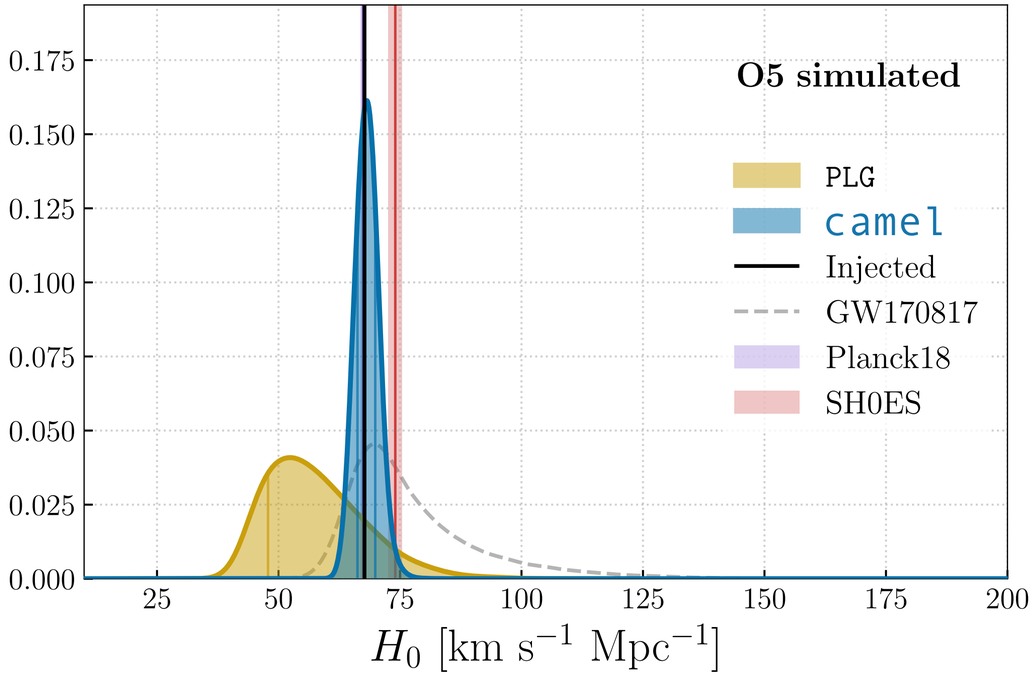
Similar procedure as LVK's MDC study [2412.14244]

*median ± 68%CI (±90%CI)

Results

H_0 constraints forecasts





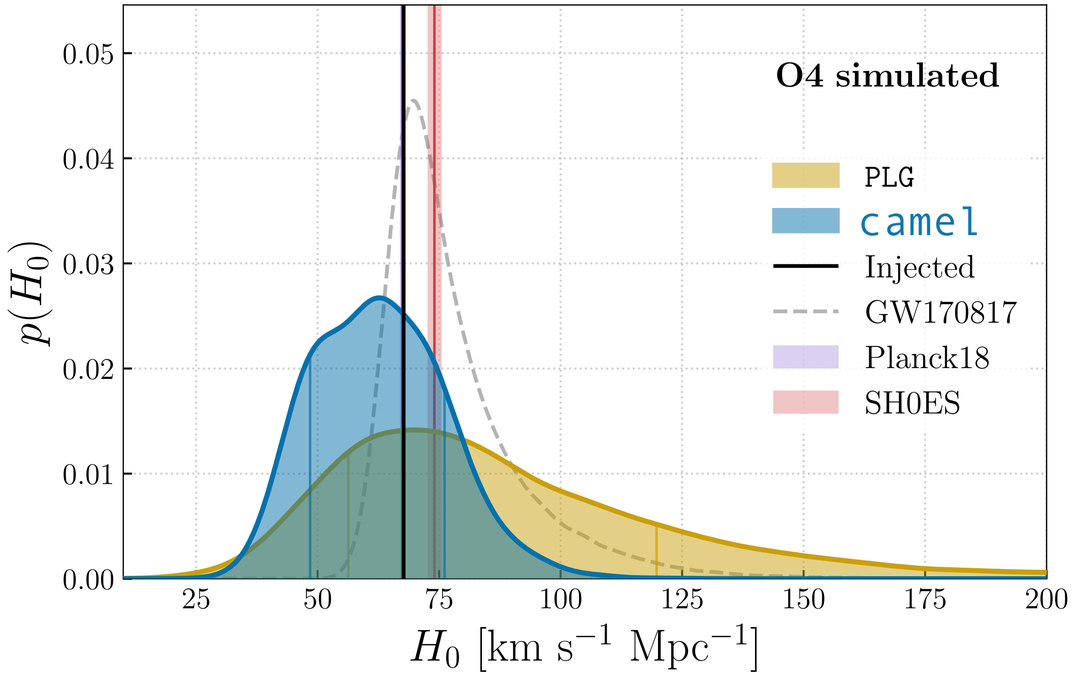
O4	H_0 [km s^{-1} Mpc^{-1}]
PLG	$80^{+39\,(73)}_{-24\,(36)}$
camel	$62^{+14\,(23)}_{-14\,(20)}$

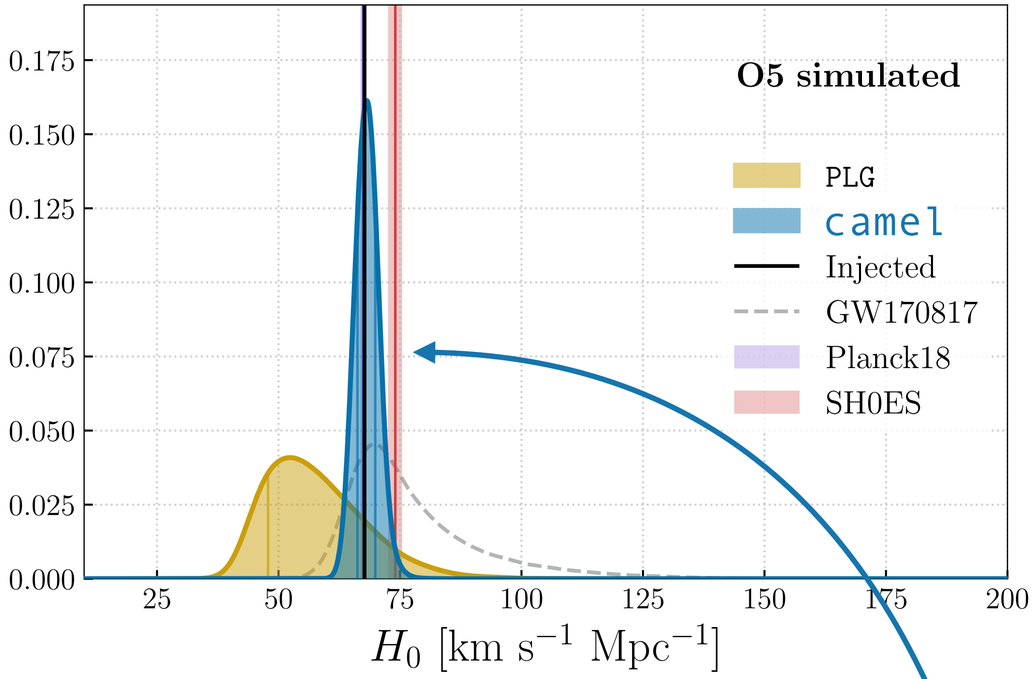
O5	H_0 [km s^{-1} Mpc^{-1}]
PLG	$56^{+12\,(20)}_{-8\,(11)}$
camel	$68.2^{+1.7\,(3.1)}_{-2.0\,(2.9)}$

*median ± 68%CI (±90%CI)

Results

H_0 constraints forecasts





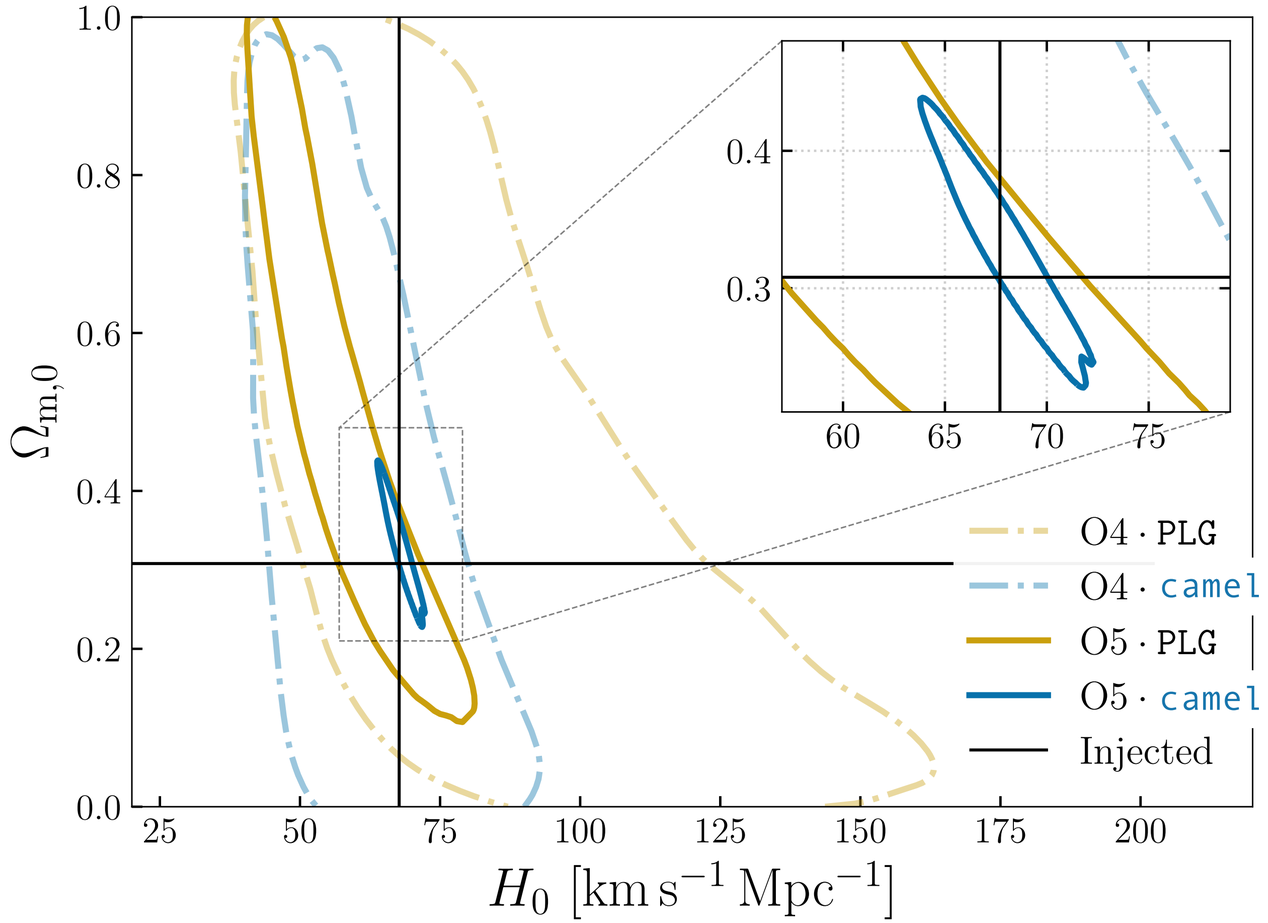
O4	H_0 [km s^{-1} Mpc^{-1}]
PLG	$80^{+39\,(73)}_{-24\,(36)}$
camel	$62^{+14\,(23)}_{-14\,(20)}$

O5	H_0 [km s^{-1} Mpc^{-1}]
PLG	$56^{+12\,(20)}_{-8\,(11)}$
camel	$68.2^{+1.7\,(3.1)}_{-2.0\,(2.9)}$

2.7% accuracy !

Results

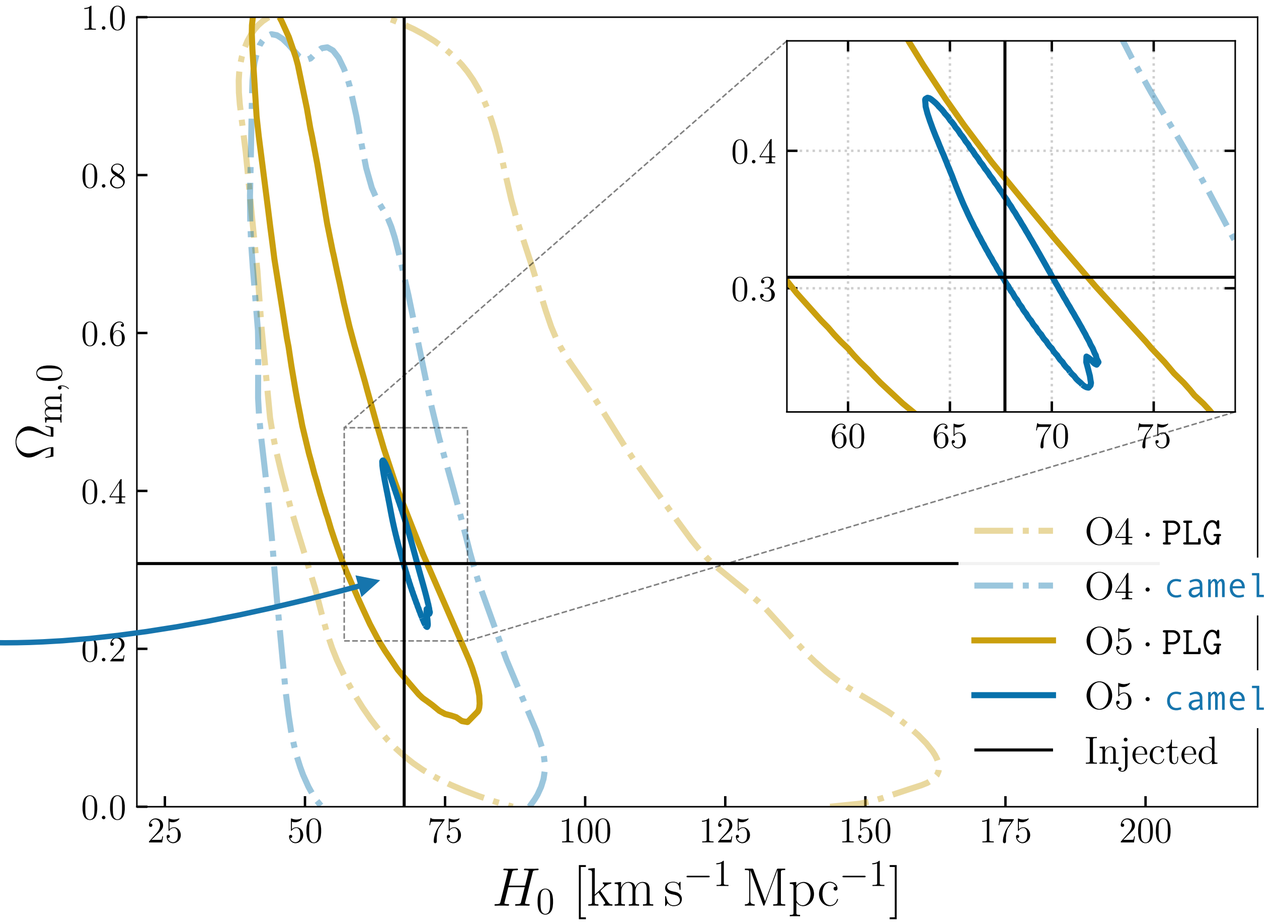
Beyond H_0 : constraining $\Omega_{m,0}$



Results

Beyond H_0 : constraining $\Omega_{m,0}$

$$\Omega_m = 0.32^{+0.06}_{-0.04}$$



Conclusions

Main **assumptions**:

- Negligible redshift evolution of the mass function
- Likely over constraining features in the mass spectrum

- **O3: 30% accuracy increase** with 3PL compared to LVK's PLG
- **Forecasts**: accuracy on H_0 by 3PL (resp. PLG) (X% accuracy at 68% CL)

  O4: 20% (resp. 40%)

  O5: 2.7% (resp. 18%)

- Our results are optimistic (for spectral sirens) **but** in reality we expect **EM counterparts** + contribution from **galaxy catalogs**

→ **towards %-level measurement of H_0 with O5 !**

- **Next ?** Extend to: GWTC-4.0, beyond ΛCDM cosmology, etc.

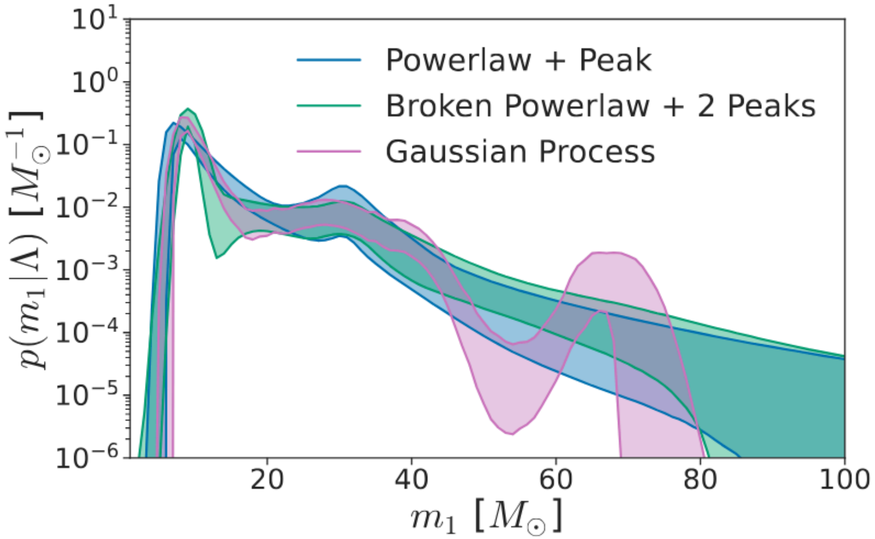
Thanks for your attention !

backup

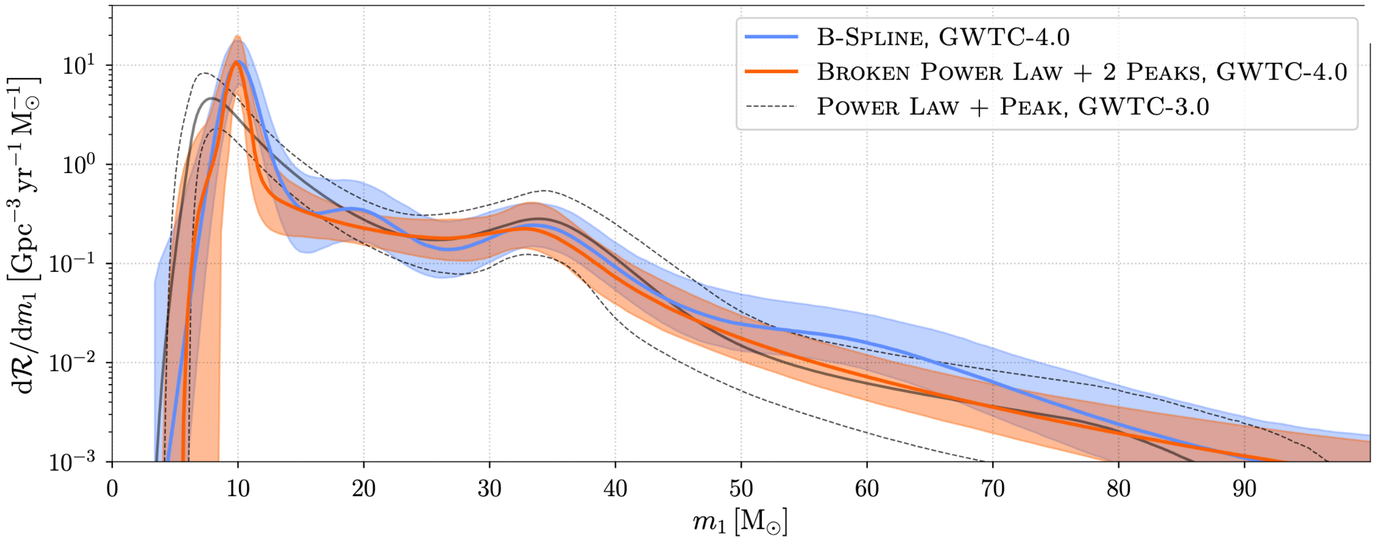
Spectral sirens

Non parametric studies

[2509.03607]



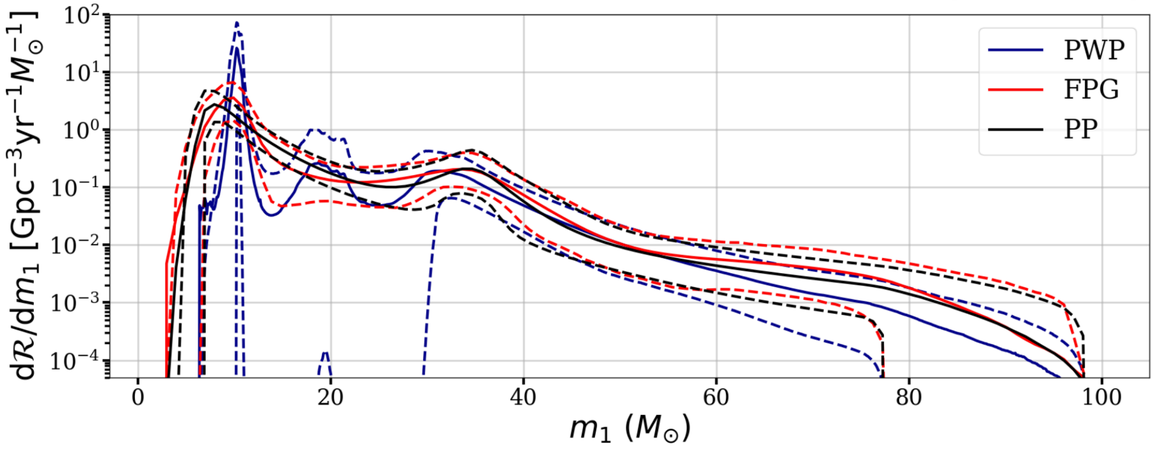
LVK GTWC-4.0 population analyses [2111.03634]



Spectral sirens

Non parametric studies

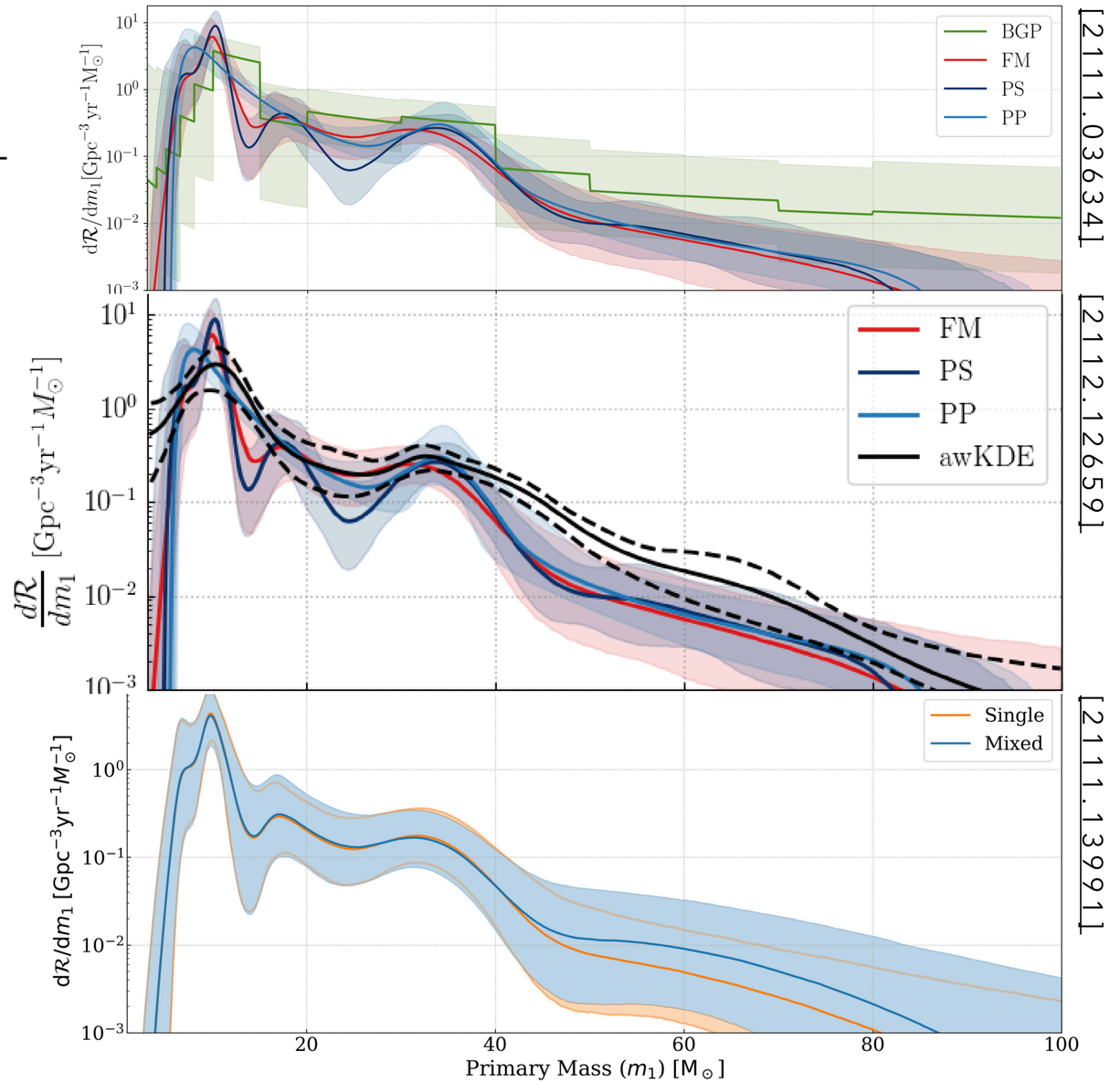
[2305.08909]



[2111.03634]

[2112.12659]

[2111.13991]



Numerical stability

[icarogw (2305.17973)]

- # of (detected) **injections** for selection effects:
  - O4 : 500,000
  - O5 : 6,000,000
- Numerical stability indicators:
  - **Effective number of injections**
  - **Effective number of PE samples** (per event)
- We had to remove some 3PL events because of numerical stability. We checked that it does not affect the results (it is negligible wrt Poisson noise)

Neffinj / 4*Nobs	O4	O5
3PL	13	12
PLG	220	211

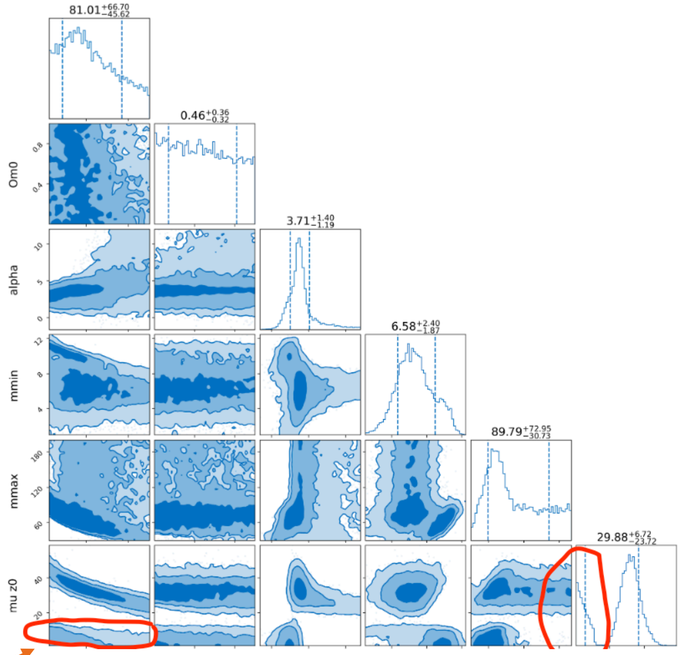
(min) NeffPE	O4	O5
3PL	19	15
PLG	81	103

PLG results

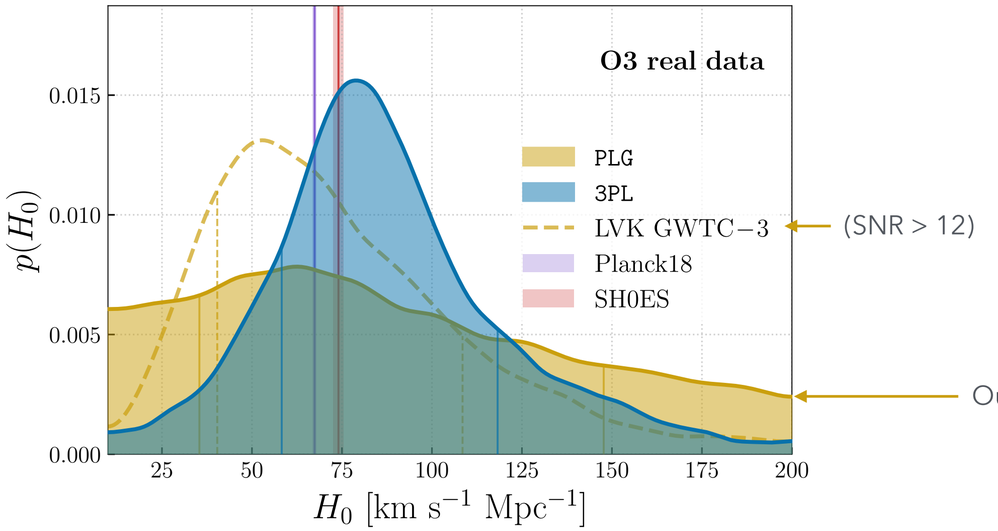
LVK's vs ours

We use :

- wider priors for some parameters ($\mu_g, m_{\rm min}, \ldots$)
- different dataset (IFAR > 4yr, 50 events)

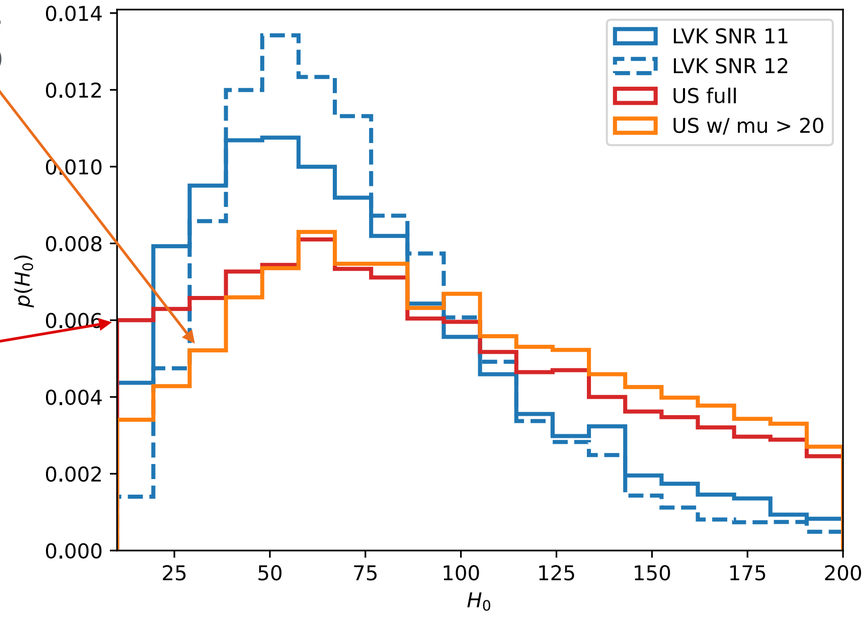


Our results removing the samples with $\mu_g < 20$



(SNR > 12)

Our results



Additional checks

- **Stability of results** (in particular for 3PL)
- For O4 :
  - multiple realisations (estimate Poisson noise in the # of detected events)
  - deterministically sampled population