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Validating Fisher analysis against GWTC data

Ulyana Dupletsa

in collaboration with

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Scuola Universitaria Superiore

INFN

ET EINSTEIN TELESCOPE

LIGO VIRGO KAGRA

Increased detection rate for 3G detectors

- 1e5 BBHs
- 1e5 BNSs

Full Bayesian PE software (Bilby) is too expensive

The analysis of 1 event takes order of days

→

Fisher Matrix approximation

[Maggiore et al. 2020, Brachesi et al. 2023]

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Fisher Matrix approximation

GWFISH

[Maggiore et al. 2020, Brachesi et al. 2023]

[Dupletsa et al. 2023]

Validating Prior-informed Fisher-matrix Analyses against GWTC Data

Ulyana Dupletsa,[1,2,*] Jan Harms,[1,2] Ken K. Y. Ng,[3] Jacopo Tissino,[1,2] Filippo Santoliquido,[1,2] and Andrea Cozzumbo[1,2]

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arXiv:2404.16103

Validating Prior-informed Fisher-matrix Analyses against GWTC Data

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Prior-informed Fisher Analysis

$$p(\vec{\theta}|d) \propto \pi(\vec{\theta})\mathcal{L}(d|\vec{\theta})$$

$$\mathcal{L} \propto \exp\left[-\frac{1}{2}\left(\vec{\theta}-\vec{\theta}_{\mathrm{inj}}\right)^{\mathrm{T}} F \left(\vec{\theta}-\vec{\theta}_{\mathrm{inj}}\right)\right]$$

[Vallisneri 2008,
Iacovelli et al. 2022]

Fisher + Priors

- **Likelihood from GWFish**

Fisher + Priors

- Likelihood from GWFish
- **Sampling from truncated likelihood [Botev 2016]**

Fisher + Priors

- Likelihood from GWFish
- Sampling from truncated likelihood [Botev 2016]
- **Re-weighting by prior probability**

Fisher + Priors

- Likelihood from GWFish
- Sampling from truncated likelihood [Botev 2016]
- Re-weighting by **prior** probability

GWTC data

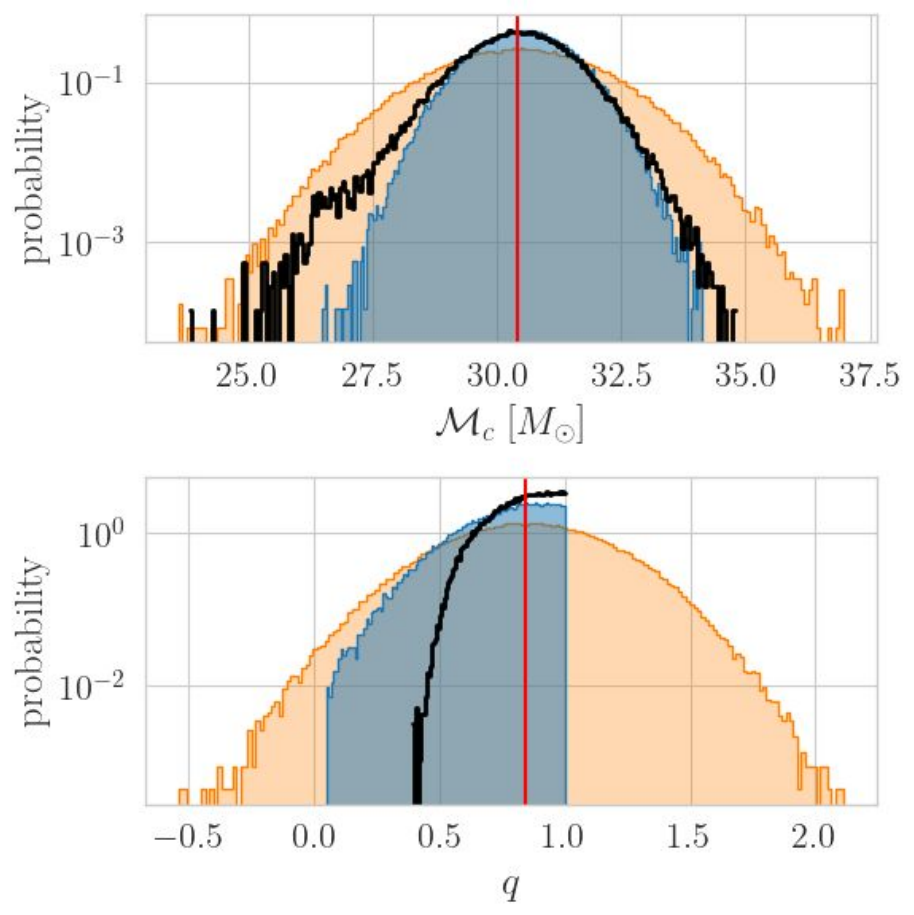
parameter	units	prior
$\mathcal{M}_c$	$M_\odot$	Uniform
q	$M_\odot$	Uniform
d_L	[Mpc]	Power Law, d_L^2
θ_{JN}	[rad]	Sine
DEC	[rad]	Cosine
RA	[rad]	Uniform
ϕ	[rad]	Uniform
Ψ	[rad]	Uniform
t_c	[s]	Uniform
a_1	-	Uniform
a_2	-	Uniform
$\mathtt{tilt}_1$	[rad]	Sine
$\mathtt{tilt}_2$	[rad]	Sine
$\mathtt{phi}_{12}$	[rad]	Uniform
$\mathtt{phi}_{JL}$	[rad]	Uniform

[LVK Collaboration, 2019, 2021 & 2023]

The role of priors

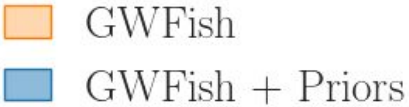
Mass estimates

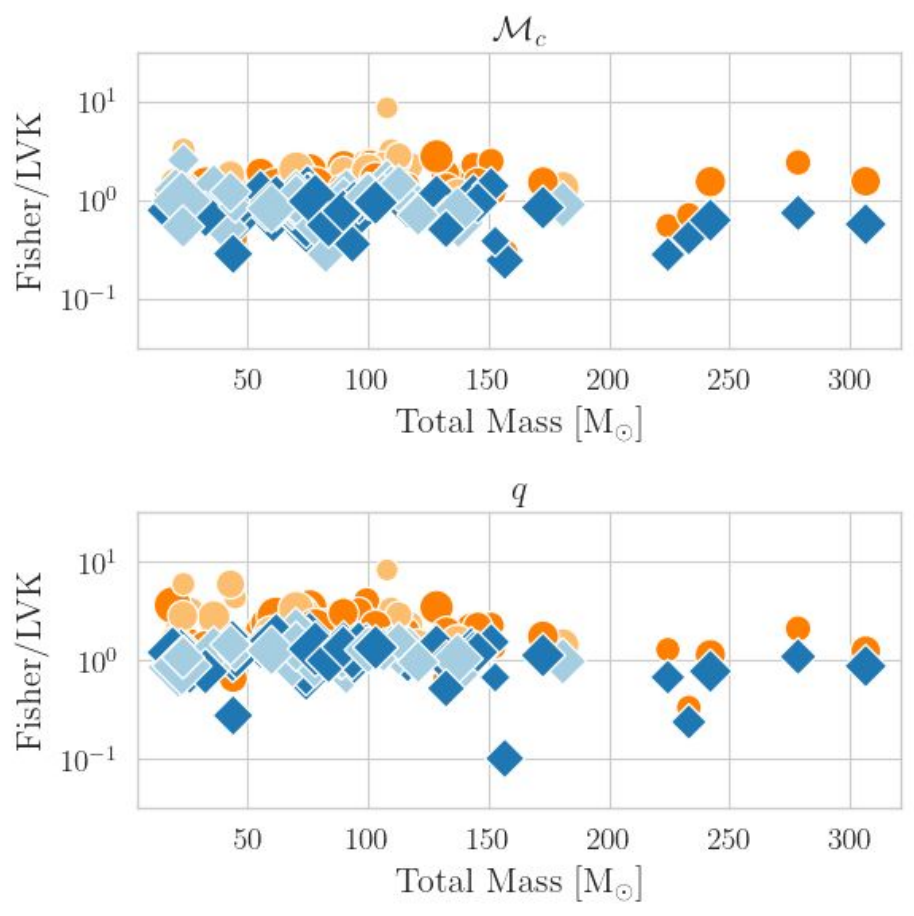
- LVK
- injection
- GWFish
- GWFish + Priors



The role of priors

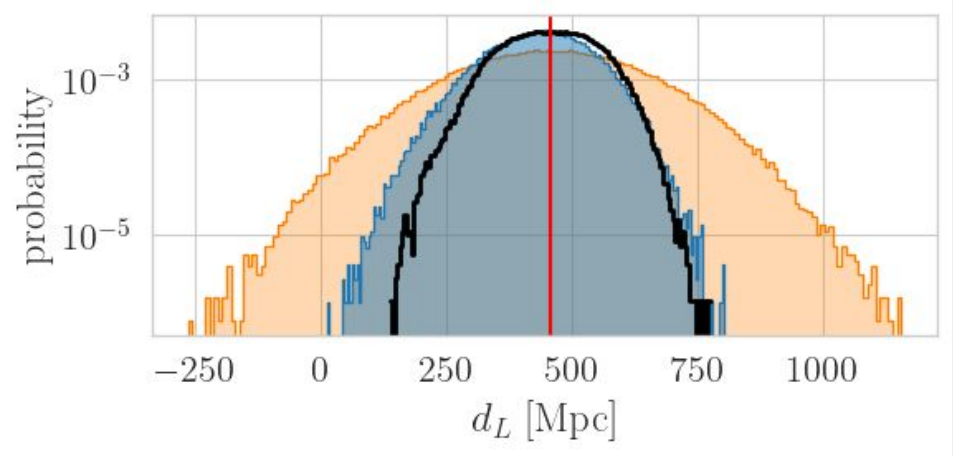
Mass estimates





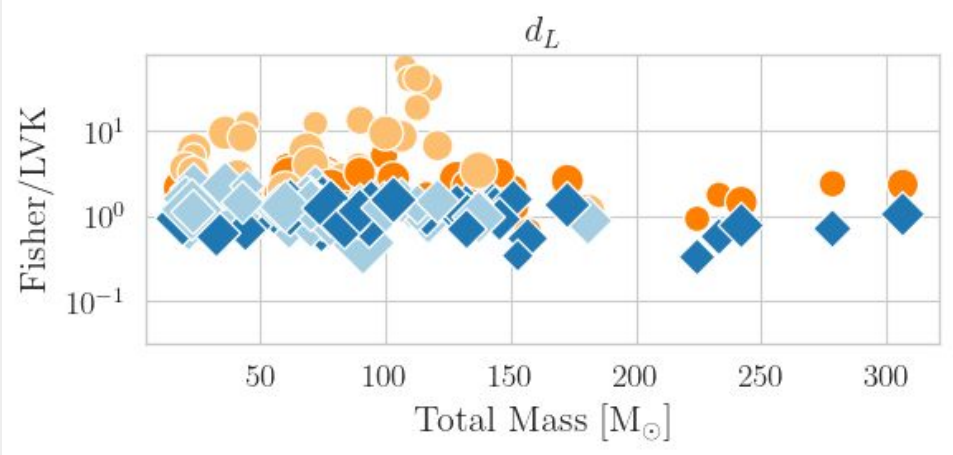
The role of priors

Luminosity Distance



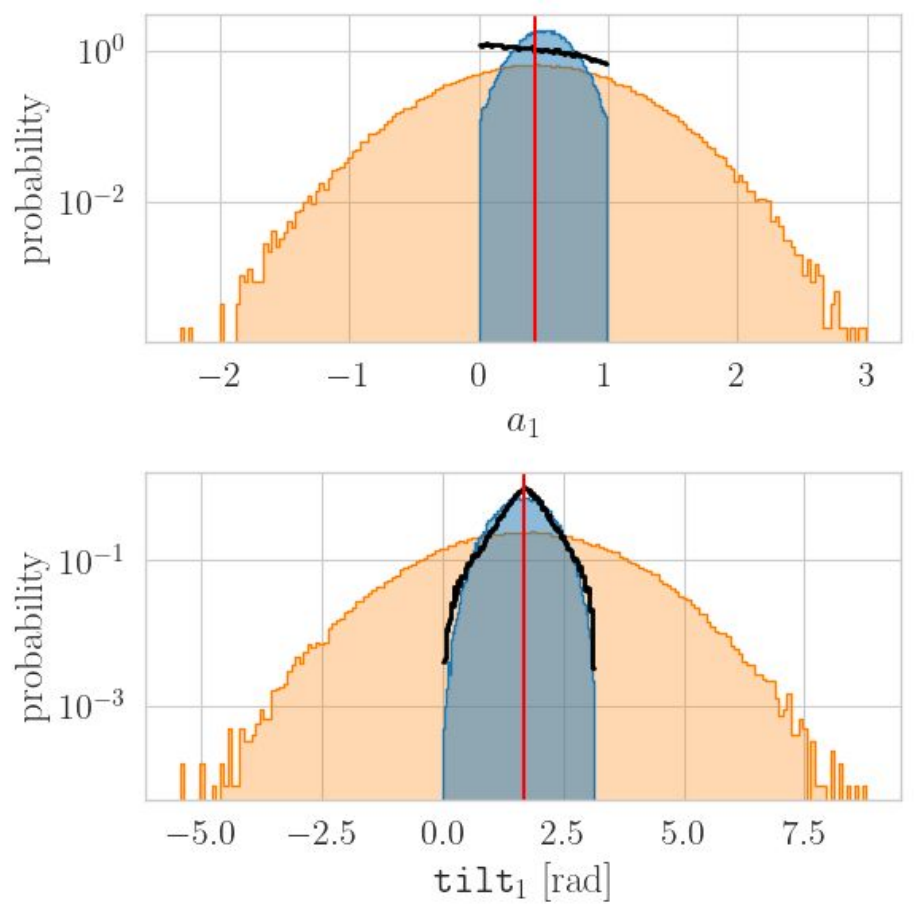
The role of priors

Luminosity Distance



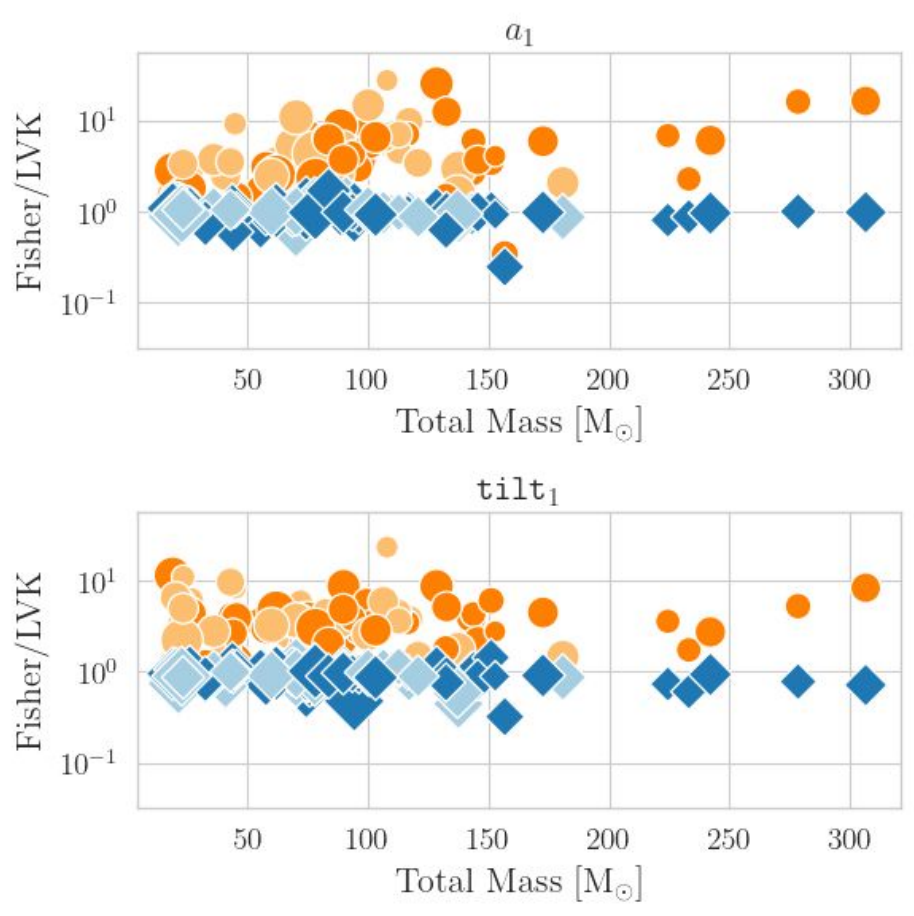
The role of priors

Spin parameters



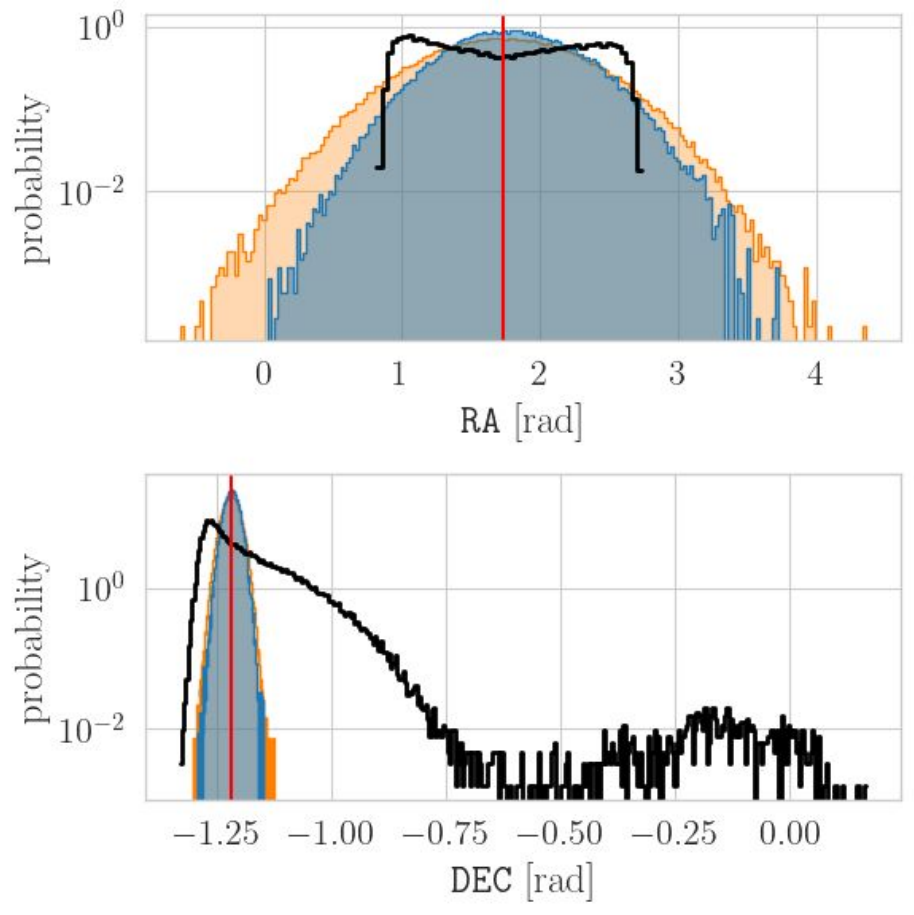
The role of priors

Spin parameters



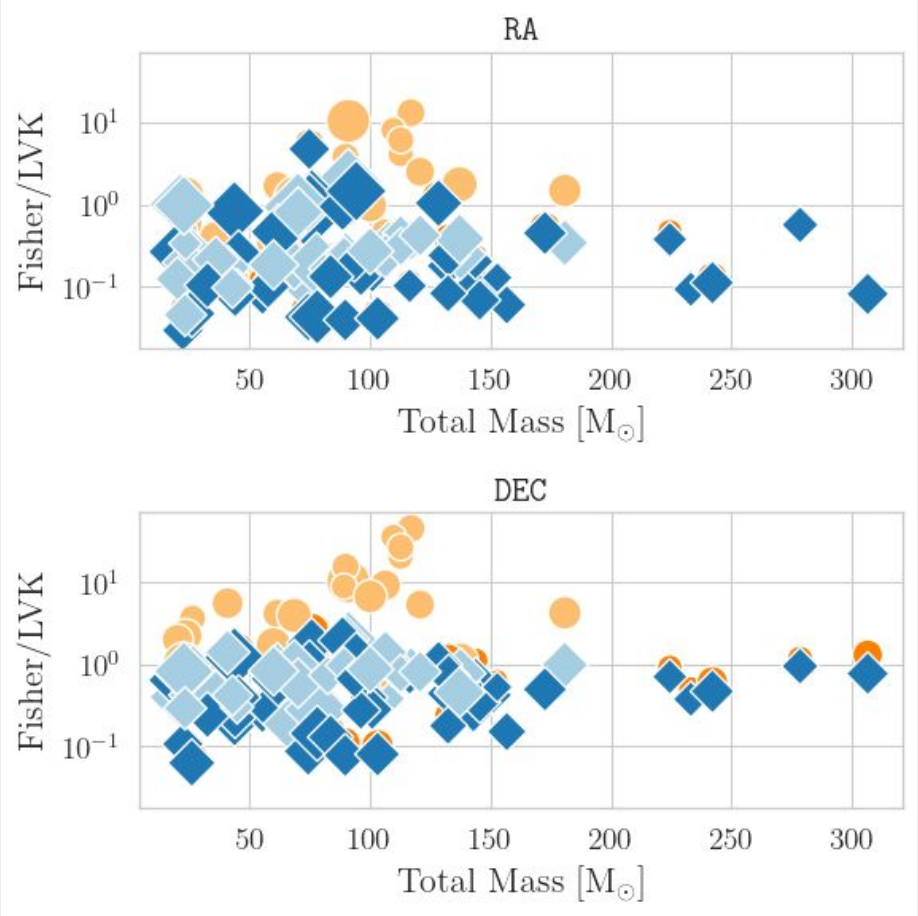
The role of priors

Angular parameters and multi-modality

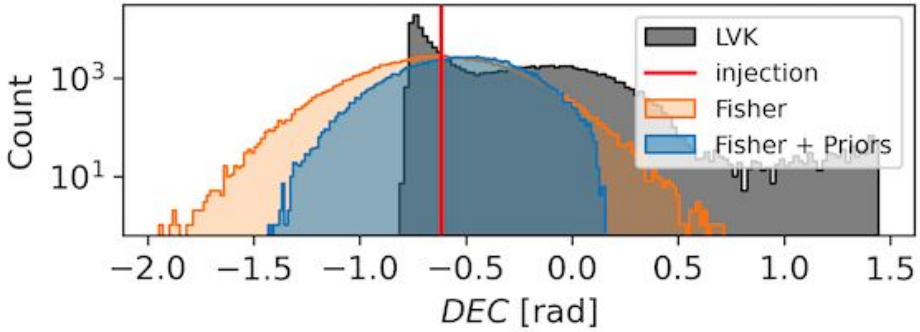


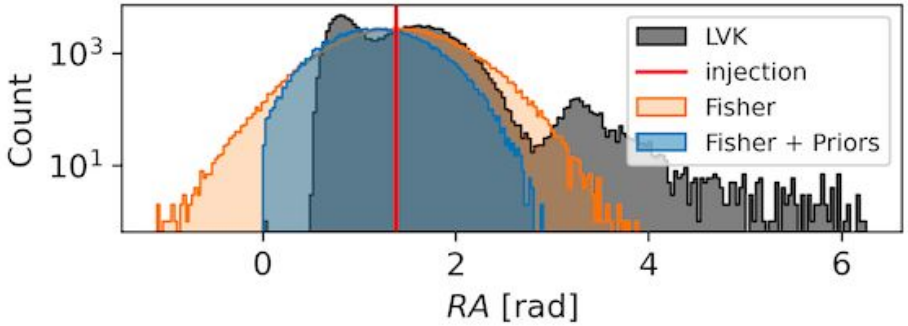
The role of priors

Angular parameters and multi-modality



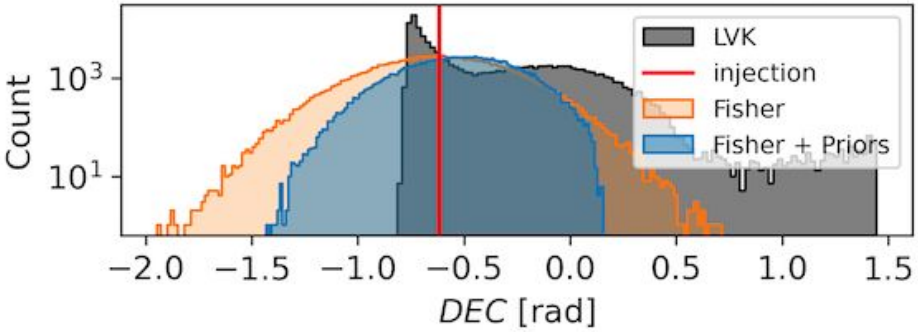
GW191204 SNR ~ 16.4

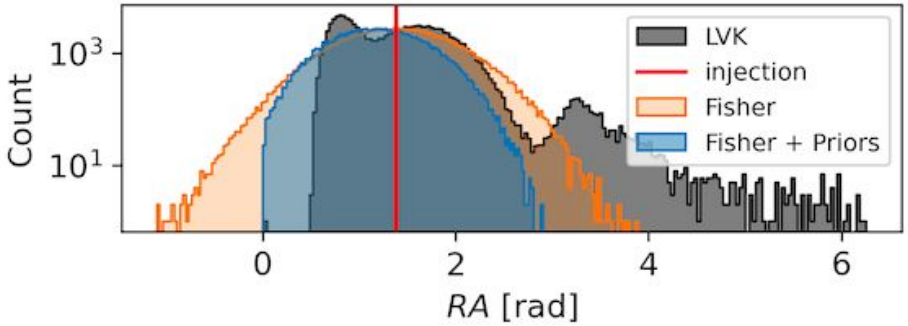




H1 + L1

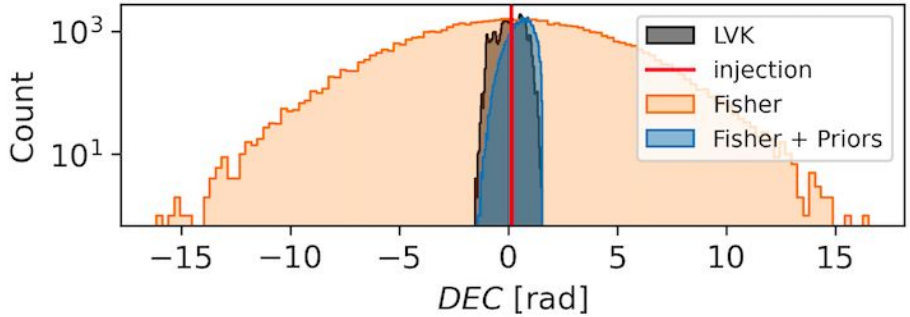
GW191204 SNR ~ 16.4

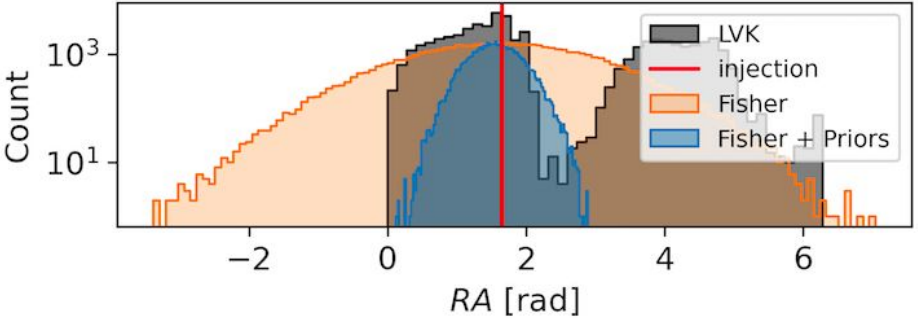




H1 + L1

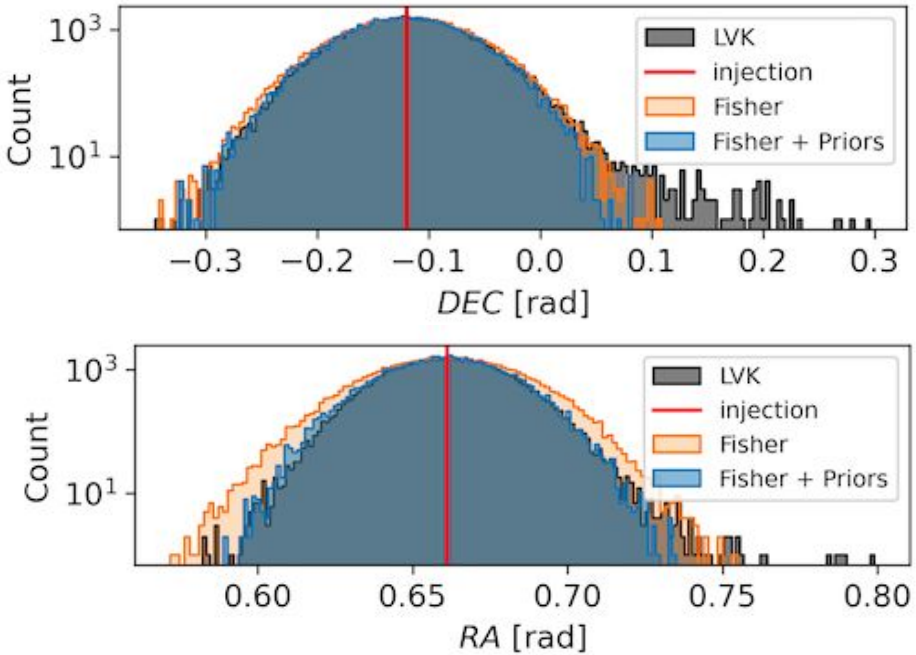
GW190910 SNR ~ 8.8





L1 + V1

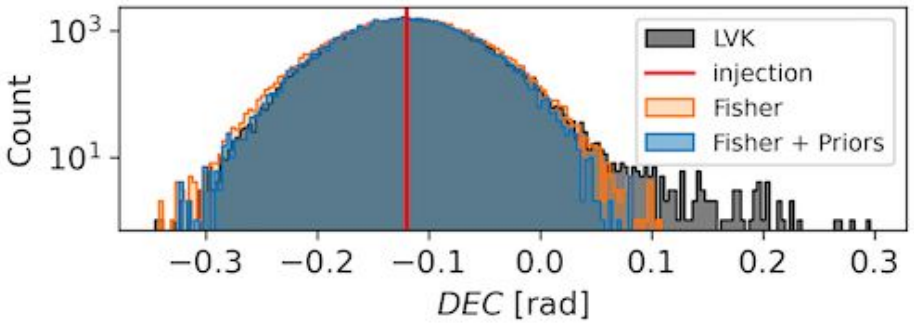
GW190701 SNR ~ 9.3

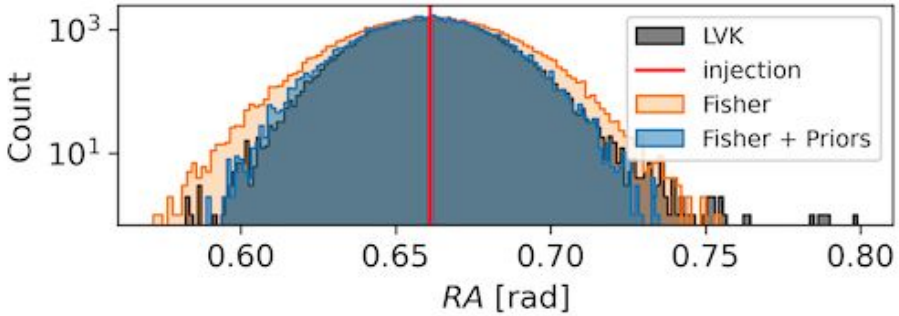


H1 + L1 + V1

SNR: 4.3 + 6.8 + 4.7

GW190701 SNR ~ 9.3

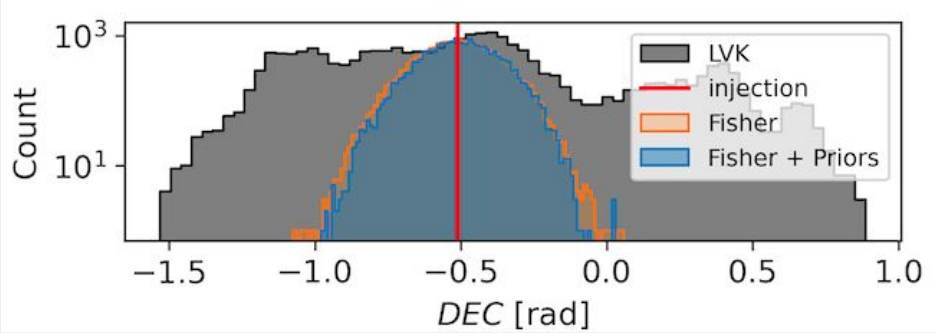


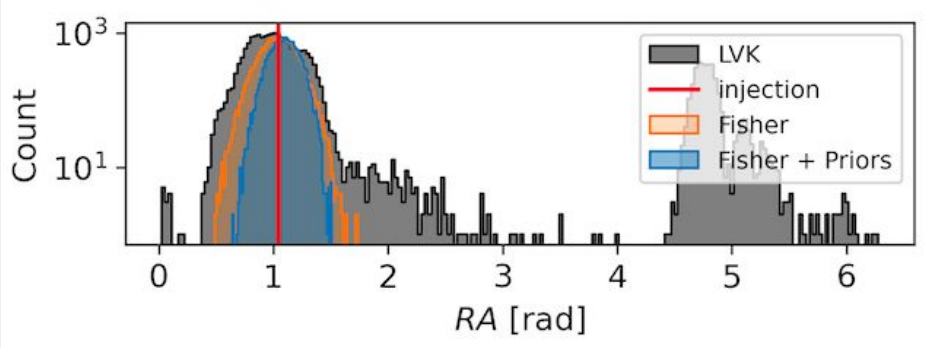


H1 + L1 + V1

SNR: 4.3 + 6.8 + 4.7

GW191230 SNR ~ 7





H1 + L1 + V1

SNR: 5.0 + 4.6 + 1.2

Conclusions & Remarks

- **Reliability of Fisher matrix results**

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- **Role of SNR vs multi-modality**

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Conclusions & Remarks

- Reliability of Fisher matrix results
- Role of SNR vs multi-modality
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GWFISH

Thank you!

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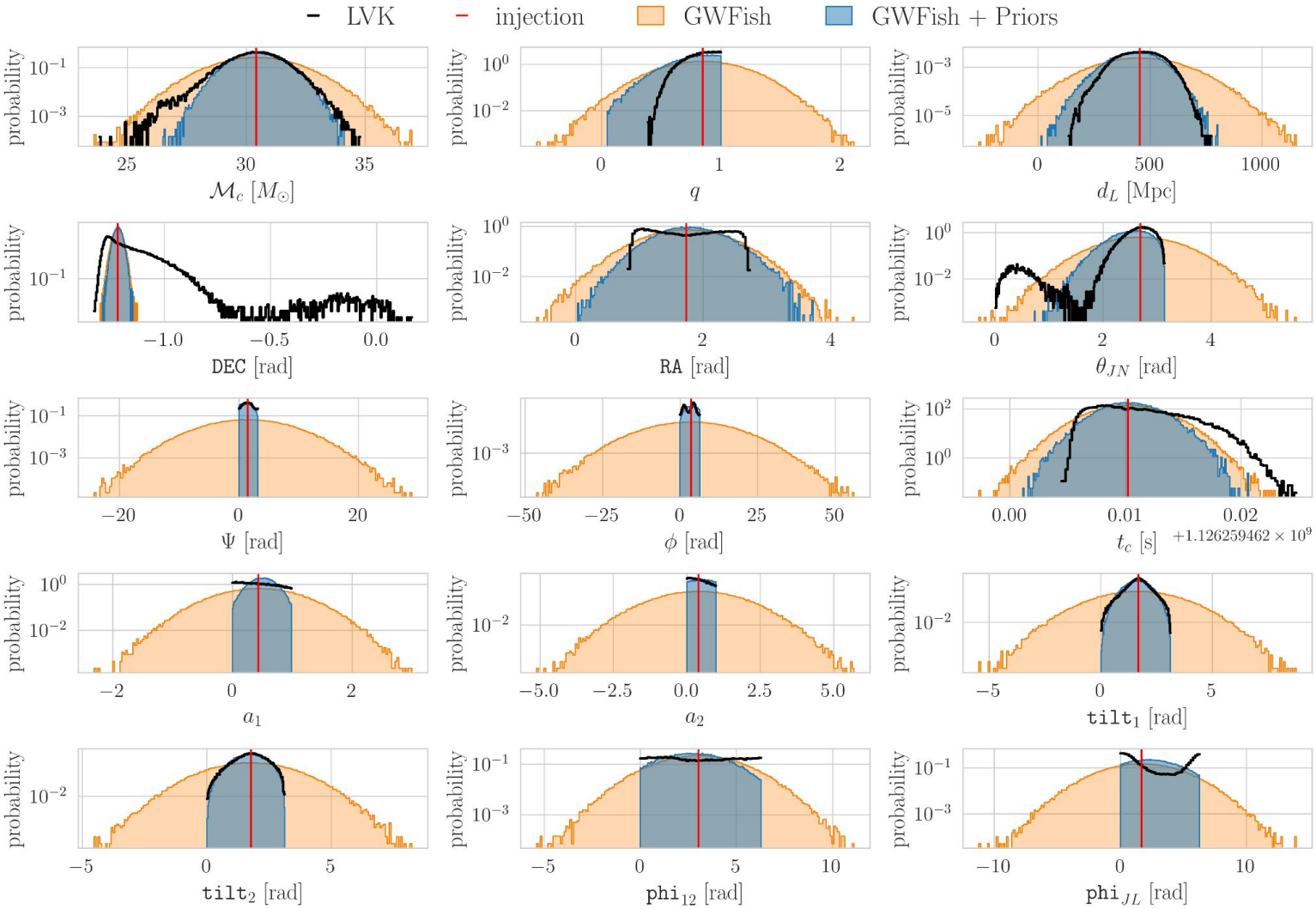
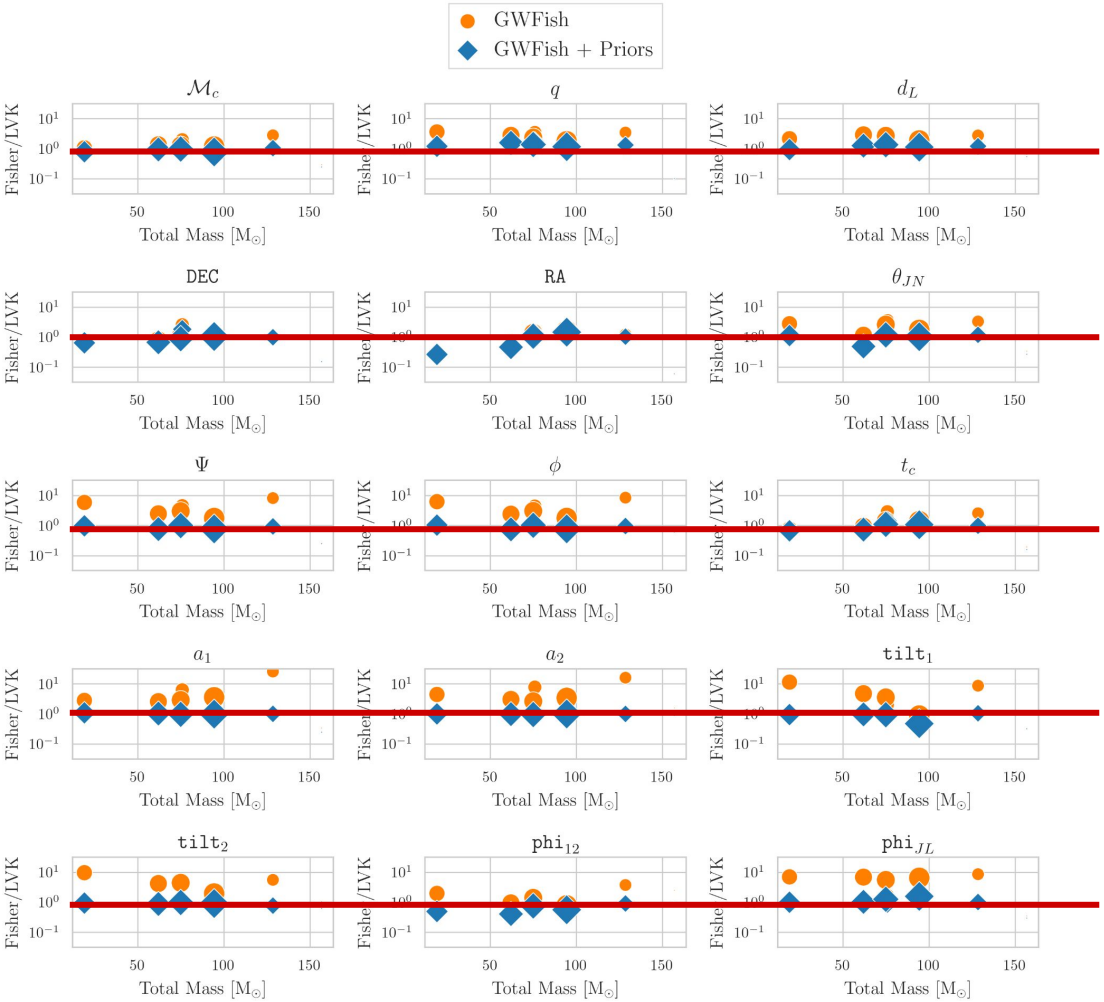
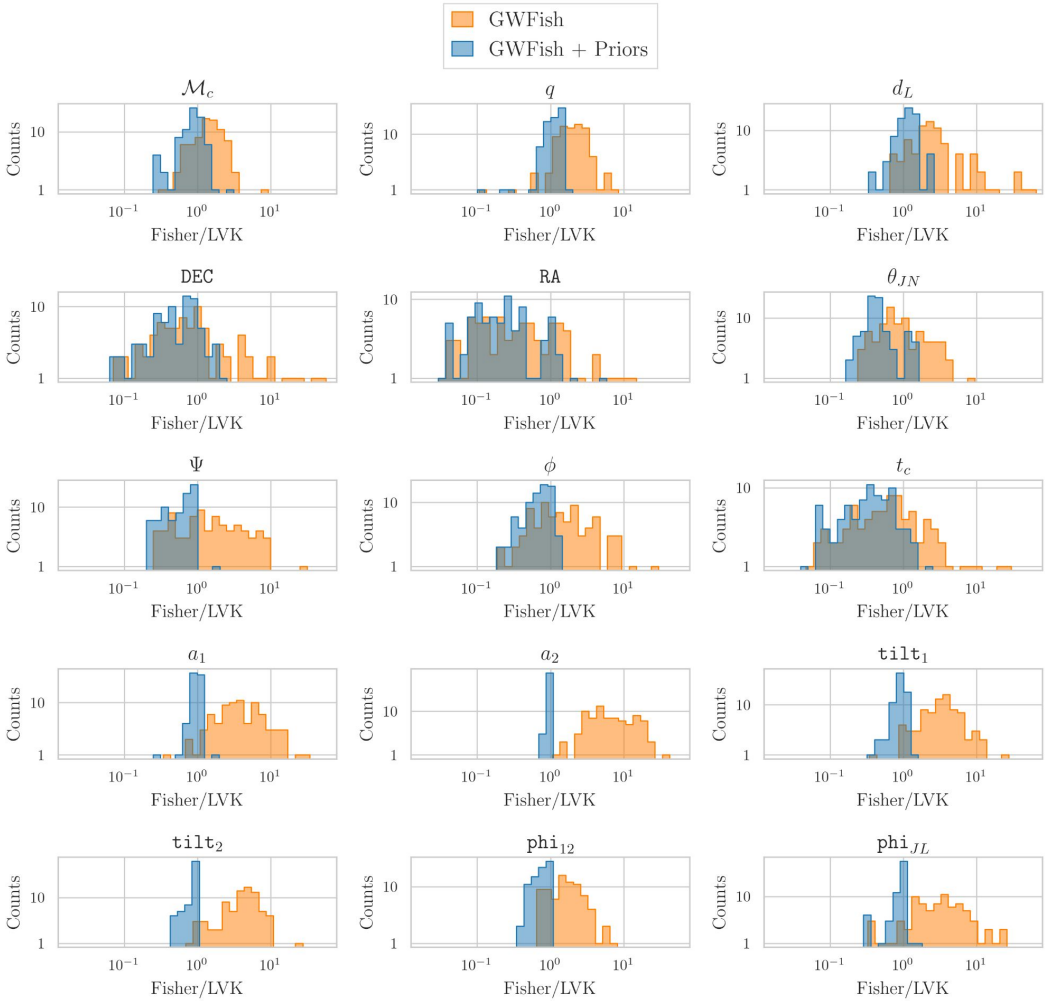
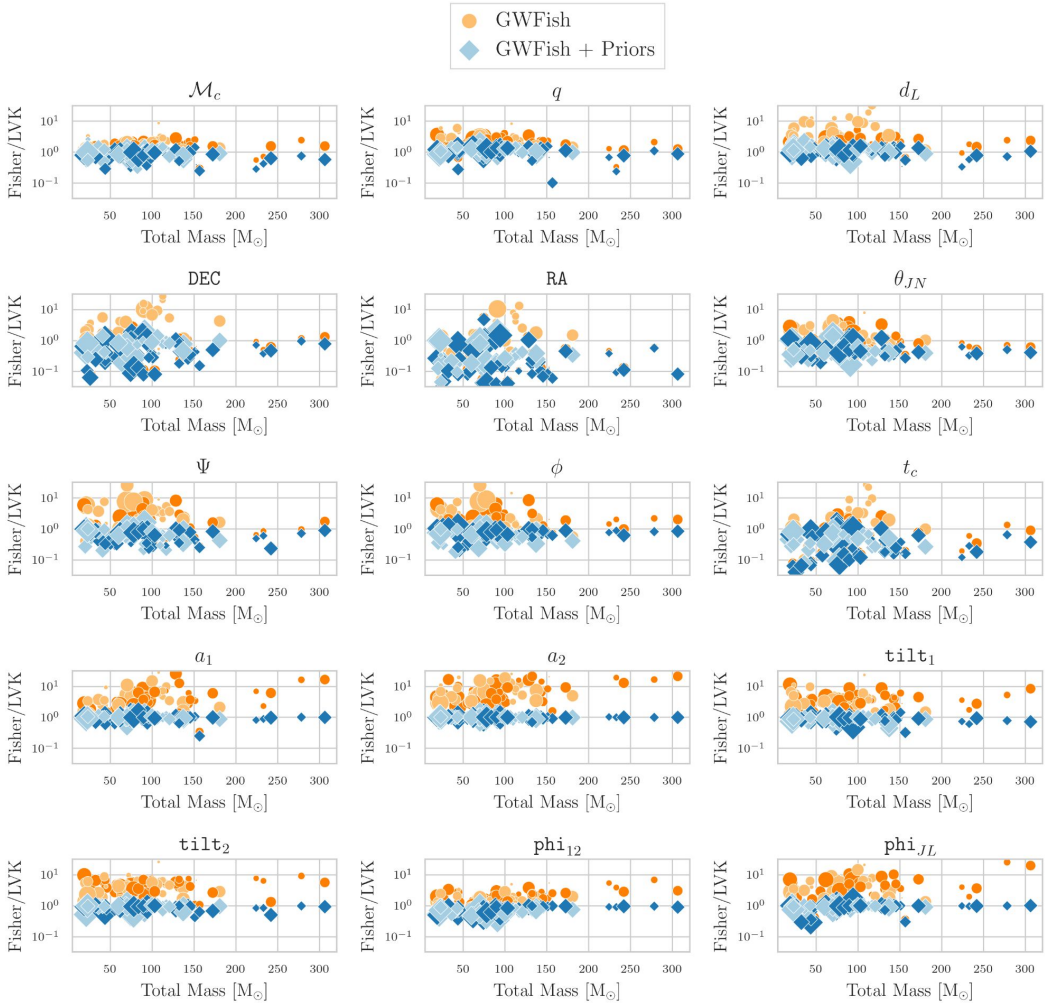

LVK
injection
GWFish
GWFish + Priors
probability
$\mathcal{M}_c$ [$M_\odot$]
q
d_L [Mpc]
DEC [rad]
RA [rad]
θ_{JN} [rad]
Ψ [rad]
ϕ [rad]
t_c [s]
$+1.126259462 \times 10^9$
a_1
a_2
tilt$_1$ [rad]
tilt$_2$ [rad]
phi$_{12}$ [rad]
phi$_{JL}$ [rad]

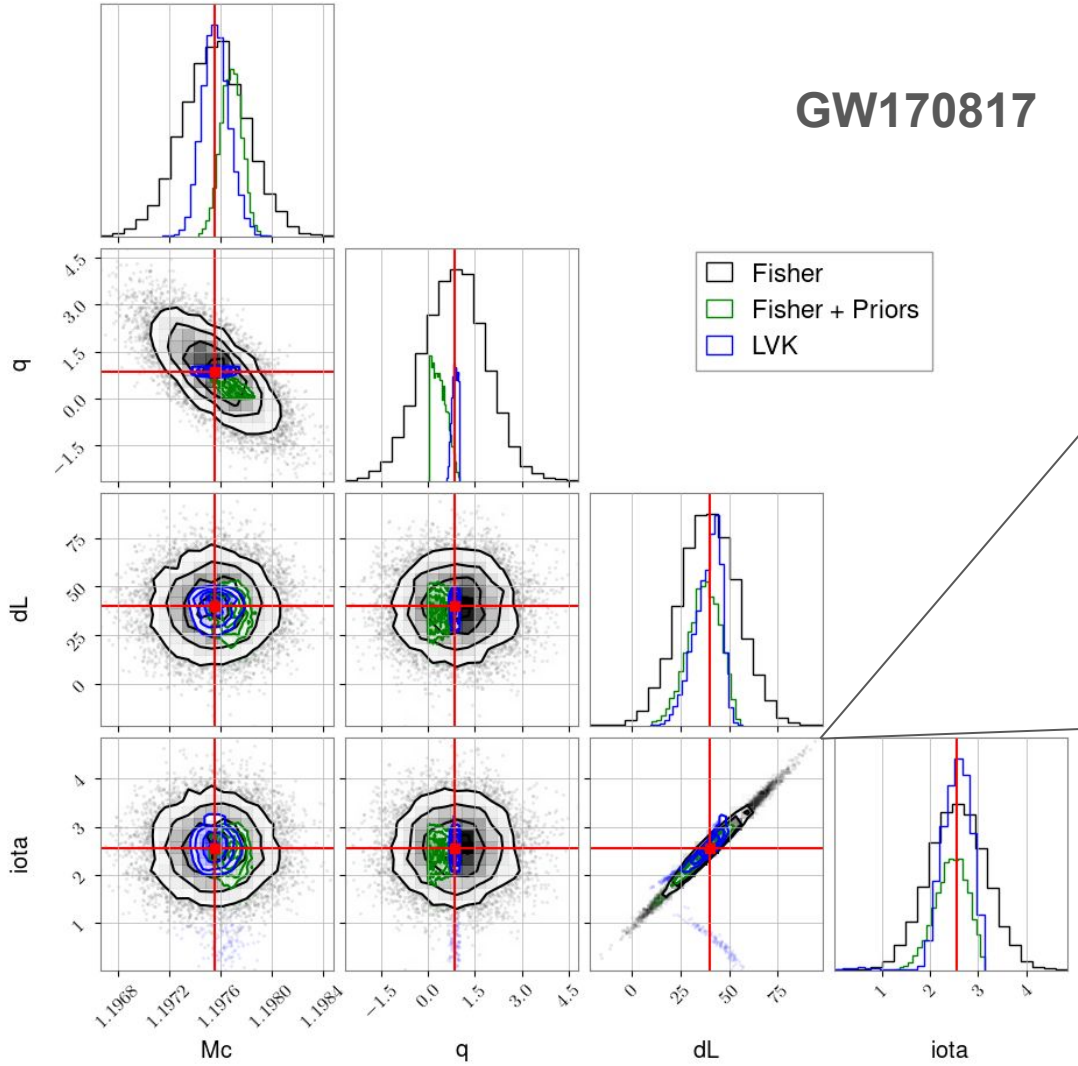
H1 + L1 + V1

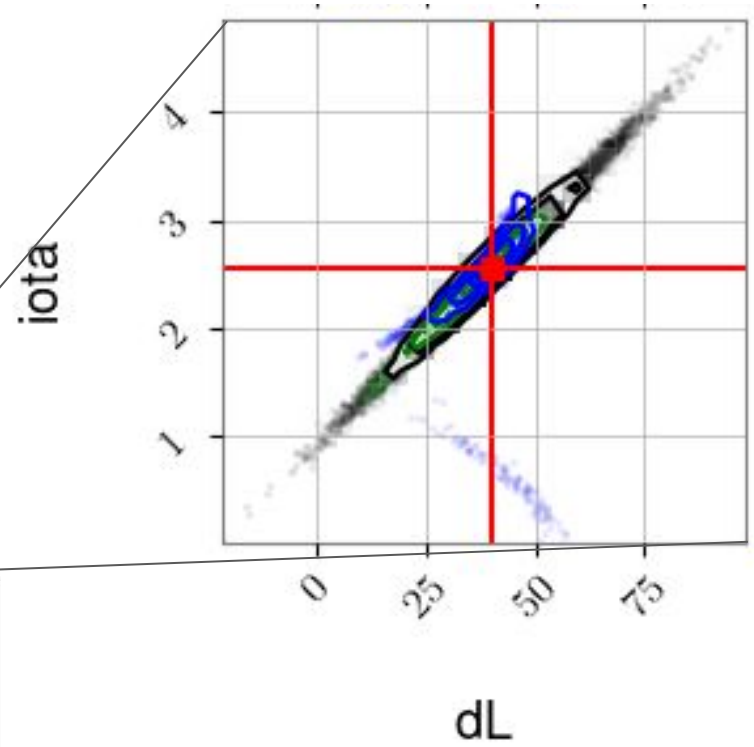

GWFish
GWFish + Priors
$\mathcal{M}_c$
q
d_L
DEC
RA
θ_{JN}
Ψ
ϕ
t_c
a_1
a_2
tilt$_1$
tilt$_2$
phi$_{12}$
phi$_{JL}$
Fisher/LVK
10^1
10^0
10^{-1}
50
100
150
Total Mass [$M_\odot$]


GWFish
GWFish + Priors
$\mathcal{M}_c$
q
d_L
DEC
RA
θ_{JN}
Ψ
ϕ
t_c
a_1
a_2
tilt$_1$
tilt$_2$
phi$_{12}$
phi$_{JL}$
Counts
Fisher/LVK
1
10
10^{-1}
10^{0}
10^{1}


GWFish
GWFish + Priors
$\mathcal{M}_c$
q
d_L
DEC
RA
θ_{JN}
Ψ
ϕ
t_c
a_1
a_2
tilt_1
tilt_2
phi_{12}
phi_{JL}
Fisher/LVK
10^1
10^0
10^{-1}
50
100
150
200
250
300
Total Mass [$M_\odot$]

GW170817


Fisher
Fisher + Priors
LVK
Mc
q
dL
iota
1.1968
1.1972
1.1976
1.1980
1.1984
−1.5
0.0
1.5
3.0
4.5
0
25
50
75
1
2
3
4


iota
dL
0
25
50
75
1
2
3
4