Detecting binary neutron stars in Einstein Telescope

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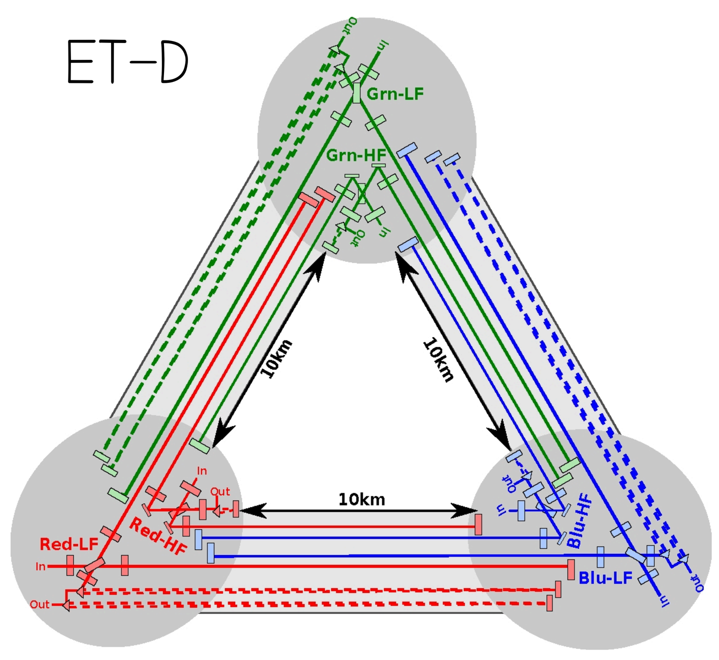
Full text

ET-D



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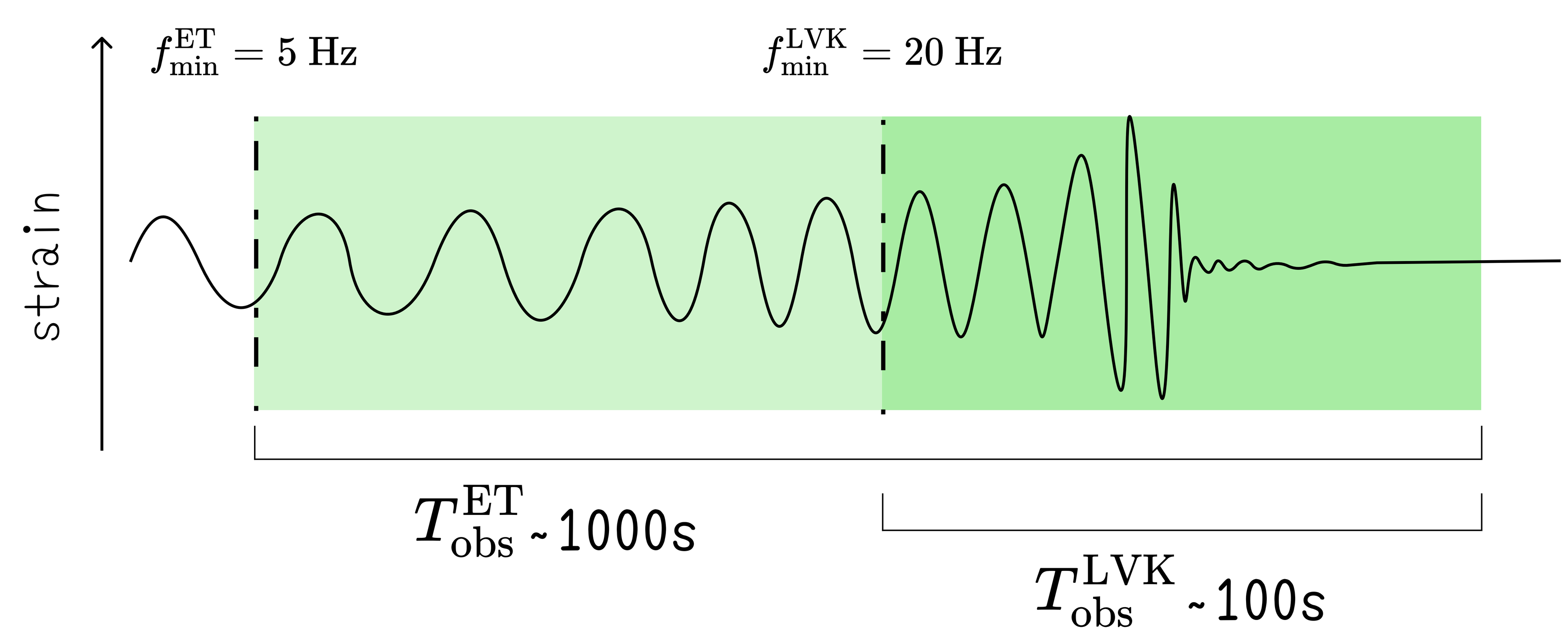
ET-D is a proposed configuration of the future Einstein Telescope (ET) with 3 colocated interferometers in triangular shape with an arm length of 10 km.

LF - low frequency interferometer
HF - high frequency interferometer

LVK	LIGO-Virgo-KAGRA network
ET	Einstein Telescope
—	signal



With ET-D sensitivity we expect to see up to 10^5 binary neutron star mergers per year. That opens new perspectives in studying the nuclear equation of state and interior physics of neutron stars through observing tidal effects correction to the phase of the gravitational wave.

The observed waveform of a binary neutron star merger depends on 12 parameters of the source, such as masses of the component stars, sky coordinates, luminosity distance, tidal deformability parameters.

Duration of the observed signal, T_{obs}, depends on a low frequency cut-off of the detector, $f_{\min}$.

If Einstein Telescope sensitivity allows the detection of longer and fainter signals, then can we accurately infer the parameters of sources?

How accurately we can estimate the parameters of sources?

With long-duration signals of >1000 s full Bayesian inference methods could be expensive. Instead, a Fisher matrix approach is commonly used to quantify uncertainties of the parameter estimation.

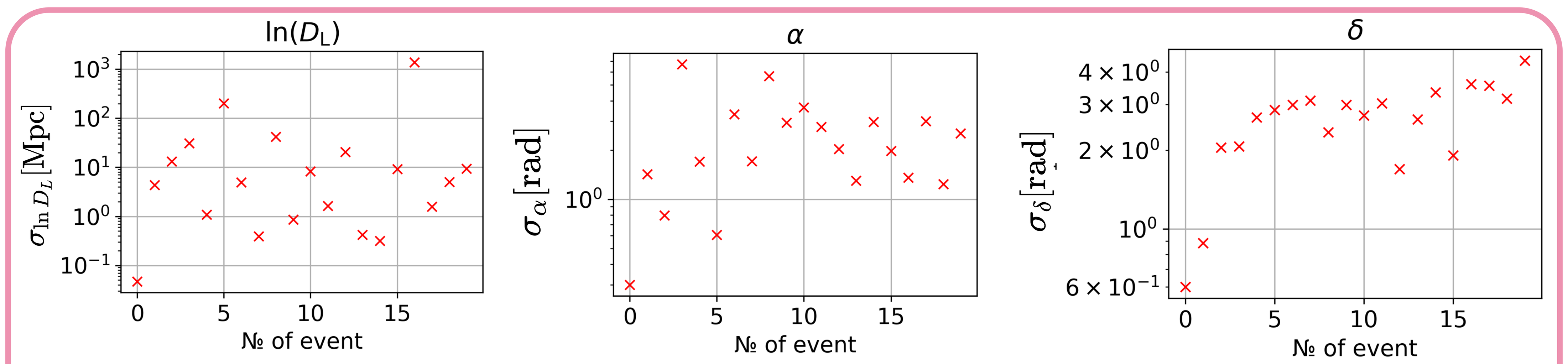
$$\Gamma_{\kappa\sigma} = -\mathbb{E}\left[\frac{\partial^2 \boxed{\ln\mathcal{L}}}{\partial\boxed{\lambda^\kappa\lambda^\sigma}}\right] \qquad \Gamma^{-1}_{\kappa\sigma} = \begin{bmatrix} \mathrm{Var}(\lambda_1) & \dots\dots & \mathrm{Cov}(\lambda_n,\lambda_1) \\ \vdots & \cdot & \vdots \\ \mathrm{Cov}(\lambda_n,\lambda_1) & \dots\dots & \mathrm{Var}(\lambda_n) \end{bmatrix} = C$$

log-likelihood
parameters

Fisher Information Matrix (FIM)   variance-covariance matrix

Using the brightest sources of ET Mock Data, we can compute the uncertainty of the parameter measurement from the inverse of the FIM (the variance-covariance matrix).

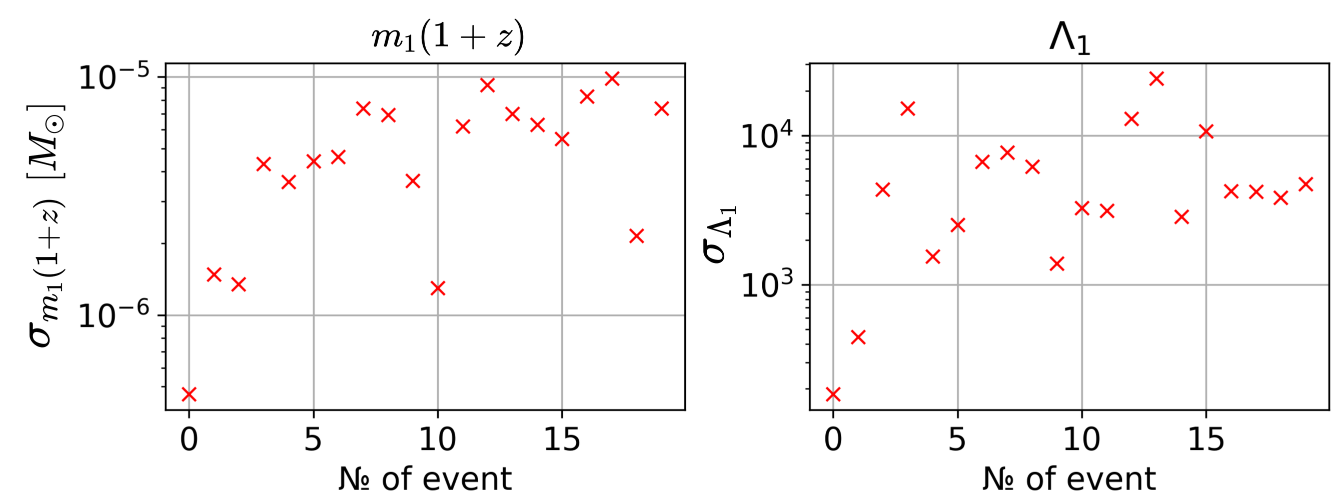
By construction FIM assumes Gaussian distribution of uncertainties and cannot handle multimodality.



$$\boxed{\sigma_\kappa^{\mathrm{FIM}} = C_{\kappa\kappa}^{1/2}}$$

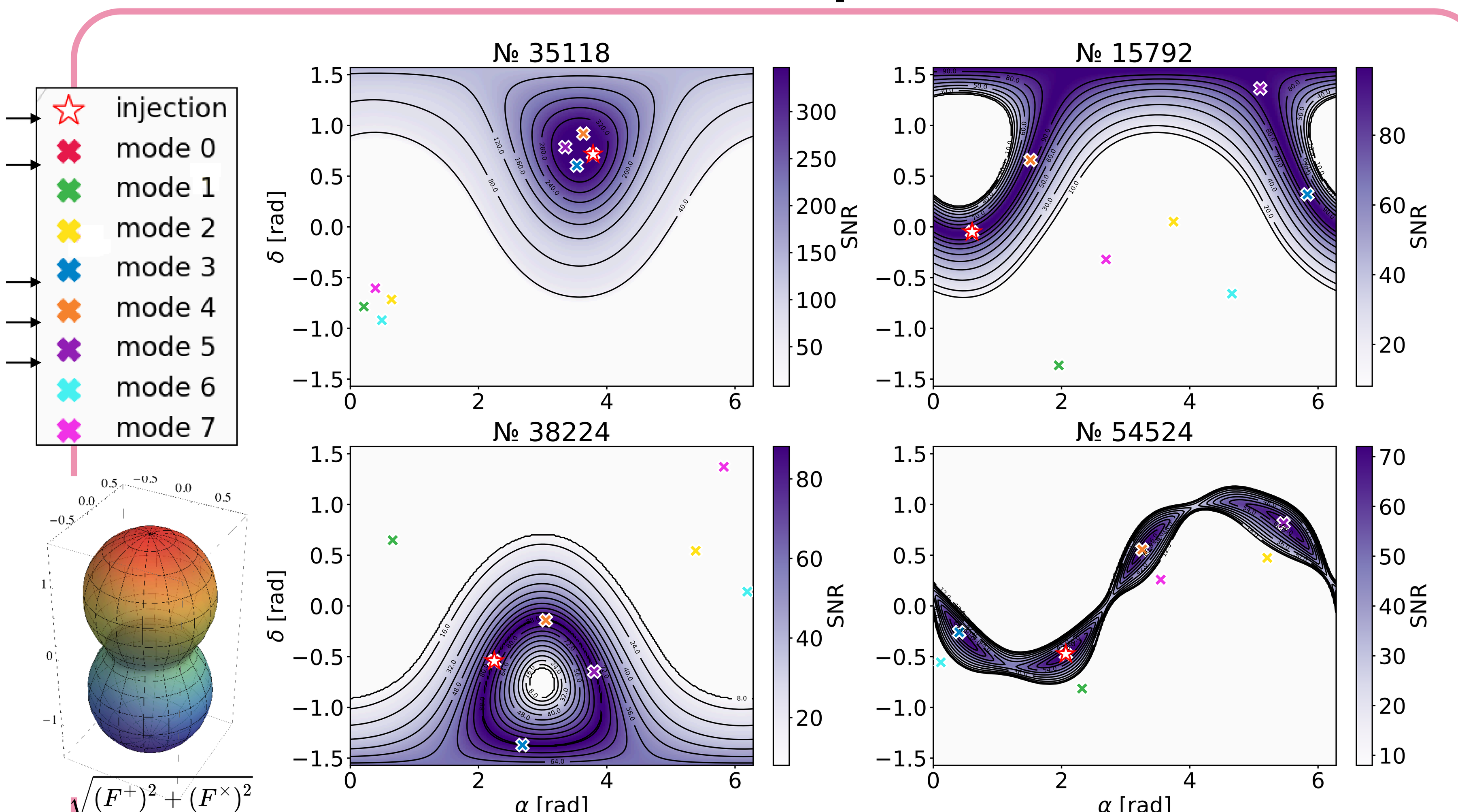
standard deviation

$m_1(1+z)$	redshifted mass
Λ_1	tidal deformability parameter
D_L	luminosity distance



The uncertainties predicted by the FIM for some parameters are larger than their true values, while the uncertainties in the sky coordinates cover the entire sky.

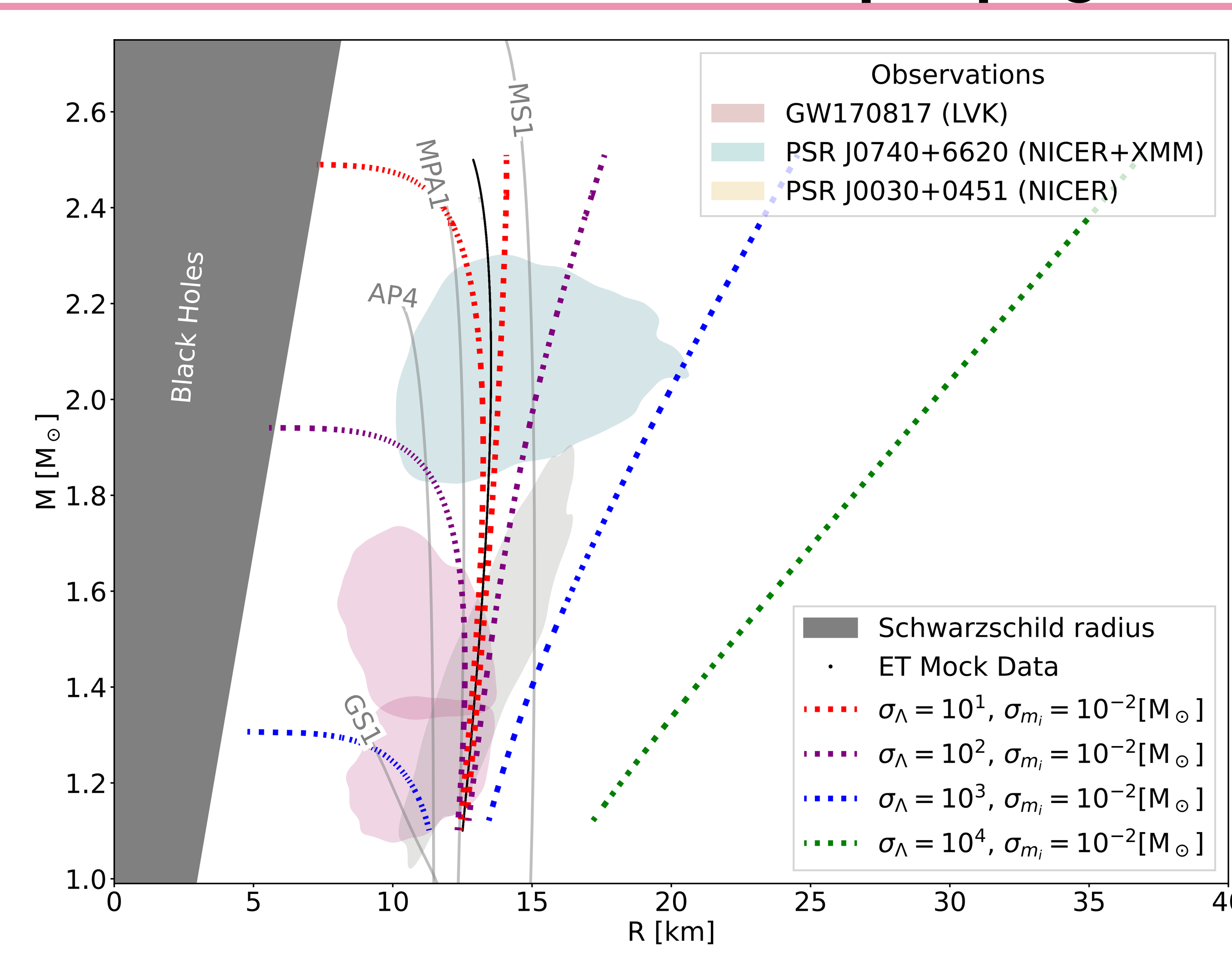
Can we trust FIM predictions?



The signal-to-noise ratio (SNR) maps have 8 symmetry-induced modes because of the directional sensitivity, $\sqrt{(F^+)^2 + (F^\times)^2}$, of the triangular detector.

The maps of the SNR distribution show, that the distributions are not Gaussian and multimodal, so the FIM predictions will be incorrect.

How do uncertainties propagate?



The uncertainty of mass and distance propagates to the source masses of the component stars and radii: $\sigma_{m_1} \in (10^{-2}, 10^{-1})M_\odot$, $\sigma_{R_1} \in (10^0, 10^1)$km.

With the predicted uncertainties of FIM we would not be able to constrain the family of models of equations of state.