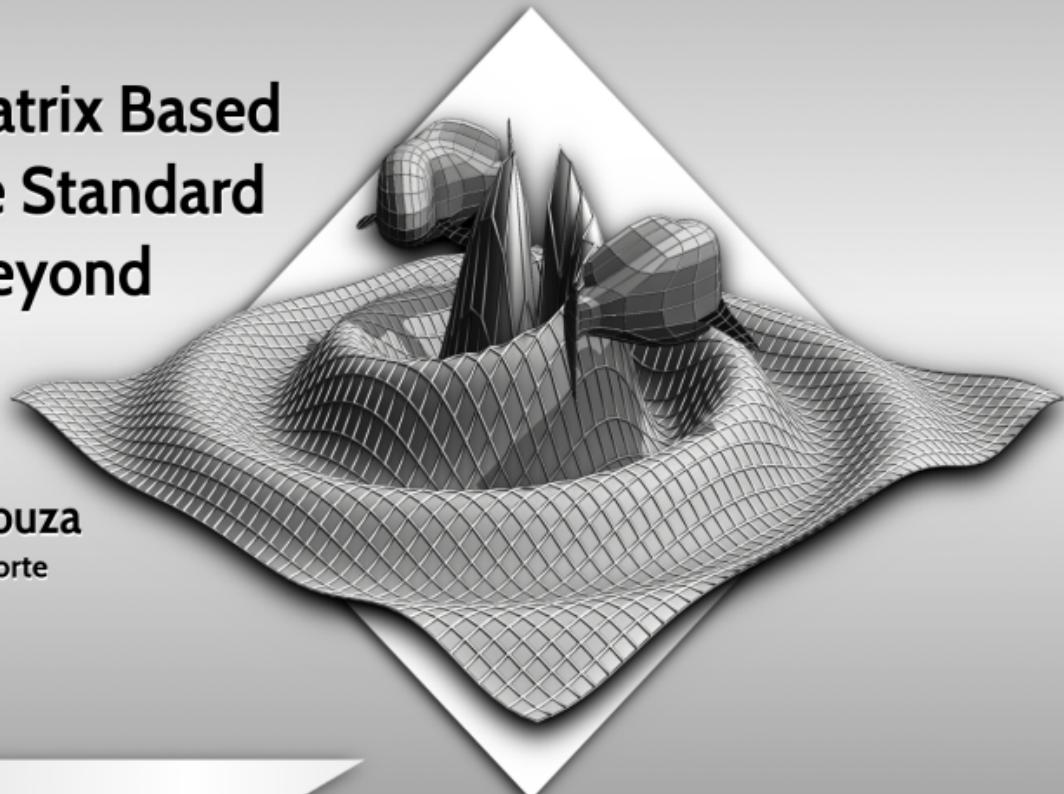


GWDALI: A Fisher Matrix Based Software to Estimate Standard Sirens Parameters Beyond Gaussianity-Level

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Installation and Documentation

```
$ pip install gwdali
```

<https://gwdali.readthedocs.io/>

The screenshot shows the documentation for the GWDALI Software. At the top, there's a navigation bar with links for "GWDALI", "Latest", "Search docs", "GWDALI Software", "API", "References", "About the Author", and "License". Below the navigation, there's a prominent "GET YOUR REVIEW" button with a "REVIEW" button underneath it. A note says "Stop the endless feedback loops. Get actionable feedback in context. See how Add by GitHub". The main content area has a heading "GWDALI Software" and a detailed description of the software's purpose and functionality. It includes sections for "Installation" (with the command `pip install gwdali`) and "Usage [example]" (with the command `import numpy as np`). At the bottom, there are "Read the Docs" and "Edit on GitHub" buttons.

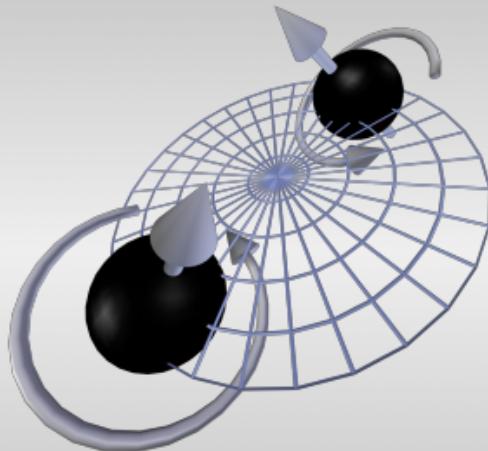
<https://pypi.org/project/gwdali/>

The screenshot shows the PyPI project page for "gwdali 0.0.2". The header includes a search bar, a "Search projects" button, and links for "Help", "Sponsor", "Log In", and "Register". There's a green "Last release" button with a checkmark. The main title is "gwdali 0.0.2" with a "pip install gwdali" button below it. A note says "Released: 1 minute ago". The description is "A Fisher-Based Software for Parameter Estimation from Gravitational Waves". On the left, there's a "Navigation" sidebar with "Project description", "Release history", "Download files", and "Statistics". The "Project description" section contains the same detailed software description as the documentation page. The "Download files" section shows a single file: "gwdali-0.0.2-py3-none-any.whl" (1.2 MB). The "Statistics" section shows 1 total download and 0 forks.

Choose Source Parameters (15)

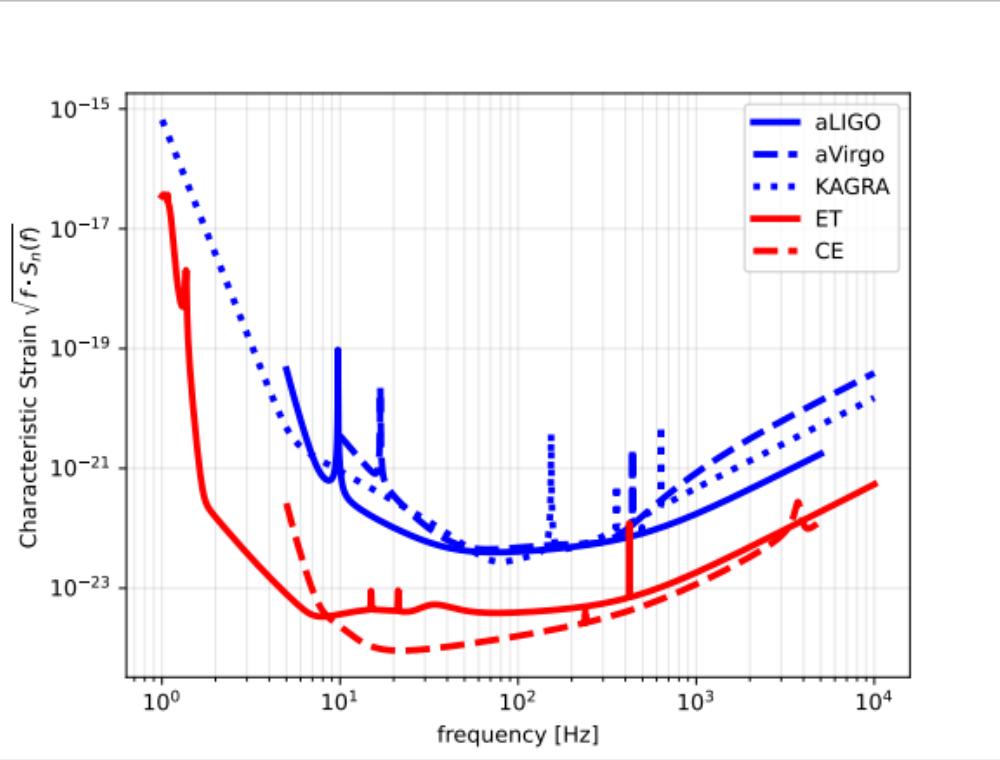
Parameters:

- ▶ "m1" ▶ "RA"
- ▶ "m2" ▶ "Dec"
- ▶ "sx1" ▶ "DL"
- ▶ "sy1" ▶ "iota"
- ▶ "sz1" ▶ "psi"
- ▶ "sx2" ▶ "t_coal"
- ▶ "sy2" ▶ "phi_coal"
- ▶ "sz2"

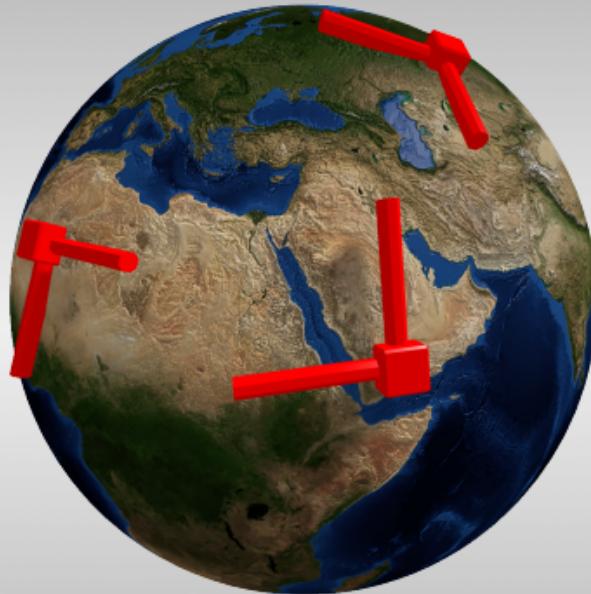
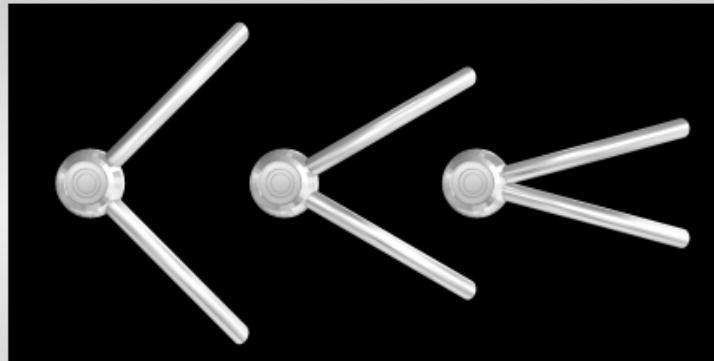


```
gw_params = { "m1":1.5 , "m2":1.5, "DL": 100 , ...}
```

Choose The Detector Sensitivity



Choose Any Detector Coordinates/Shape



```
det = {"name": "CE", "lon": -119, "lat": 46, "rot": 45, "shape": 90}
```

Parameter Estimation (Standard/Fisher/DALI)

Standard:

$$\log \mathcal{L} = -\frac{1}{2} \sum_{a=1}^{N_{det}} \langle H_a - h_a(\{\theta\}) | H_a - h_a(\{\theta\}) \rangle$$

where,

- ▶ H_a : Output of the a-th detector (the data)
- ▶ $h_a(\{\theta\})$: The GW template in the a-th detector (the model)
- ▶ $\{\theta\}$: Set of GW parameters

Scalar Product:

$$\langle X_a | Y_a \rangle \equiv 4\text{Real} \left\{ \int_0^{\infty} df \frac{\tilde{X}_a^*(f) \tilde{Y}_a(f)}{S_{n,a}(f)} \right\}$$

N_{det} : Number of detectors.

Parameter Estimation (Standard/Fisher/DALI)

GW Fisher Approach [arXiv:gr-qc/9301003]

$$\log \mathcal{L} \approx -\frac{1}{2} \sum_{a=1}^{N_{det}} \sum_{i,j}^{N_p} \left\langle \frac{\partial h_a(\{\theta\})}{\partial \theta_i} \middle| \frac{\partial h_a(\{\theta\})}{\partial \theta_j} \right\rangle_0 (\theta_i - \hat{\theta}_i)(\theta_j - \hat{\theta}_j)$$

$\{\hat{\theta}\}$: GW parameters of the injection (best-fit parameters).

Fisher Matrix: $\Gamma_{ij} \equiv \sum_{a=1}^{N_{det}} \left\langle \frac{\partial h_a(\{\theta\})}{\partial \theta_i} \middle| \frac{\partial h_a(\{\theta\})}{\partial \theta_j} \right\rangle_0$

Covariance Matrix: $C_{ij} = (\Gamma^{-1})_{ij}$

N_p : Number of free parameters.

Parameter Estimation (Standard/Fisher/DALI)

DALI (Doublet) [arXiv:1401.6892 & arXiv:2203.02670]

$$\log \mathcal{L} \approx - \left[\frac{1}{2} \sum_{i,j} \langle \partial_i h | \partial_j h \rangle_0 \Delta\theta_i \Delta\theta_j \right] \\ - \left[\frac{1}{2} \sum_{i,j,k} \langle \partial_i h | \partial_j \partial_k h \rangle_0 \Delta\theta_{ijk} + \frac{1}{8} \sum_{i,j,k,l} \langle \partial_i \partial_j h | \partial_k \partial_l h \rangle_0 \Delta\theta_{ijkl} \right]$$

where,

$$\Delta\theta_i \equiv \theta_i - \hat{\theta}_i$$

$$\Delta\theta_{ij} \equiv \Delta\theta_i \Delta\theta_j$$

$$\Delta\theta_{ij\dots n} \equiv \Delta\theta_i \Delta\theta_j \dots \Delta\theta_n$$

Parameter Estimation (Standard/Fisher/DALI)

DALI (Triplet) [arXiv:1401.6892 & arXiv:2203.02670]

$$\begin{aligned} \log \mathcal{L} \approx & - \left[\frac{1}{2} \sum_{i,j} \langle \partial_i h | \partial_j h \rangle_0 \Delta \theta_i \Delta \theta_j \right] \\ & - \left[\frac{1}{2} \sum_{i,j,k} \langle \partial_i h | \partial_j \partial_k h \rangle_0 \Delta \theta^{ijk} + \frac{1}{8} \sum_{i,j,k,l} \langle \partial_i \partial_j h | \partial_k \partial_l h \rangle_0 \Delta \theta_{ijkl} \right] \\ & - \left[\frac{1}{6} \sum_{i,\dots,l} \langle \partial_i h | \partial_j \partial_k \partial_l h \rangle \Delta \theta_{ijkl} + \frac{1}{12} \sum_{i,\dots,m} \langle \partial_i \partial_j h | \partial_k \partial_l \partial_m h \rangle \Delta \theta_{ijklm} \right. \\ & \left. + \frac{1}{72} \sum_{i,\dots,n} \langle \partial_i \partial_j \partial_k h | \partial_l \partial_m \partial_n h \rangle \Delta \theta_{ijklmn} \right] \end{aligned}$$

Main Module

GWDALI function

```
GWDALI.GWDALI(Detection_Dict, FreeParams, detectors, approximant='TaylorF2',
dali_method='Fisher_Sampling', sampler_method='nestle', save_fisher=True,
save_cov=True, plot_corner=True, save_samples=True, hide_info=False, index=1,
rcond=1.e-4, npoints=300)
```

method: standard, fisher, fisher_sampling , doublet , triplet.

sampler_method: Any method of *Bilby Package* (e.g. 'nestle', 'dynest', 'emcee')

GWDALI Output: Fisher Matrix, Covariance Matrix, SNR, MCMC samples, Recovered Parameters, Uncertainties (CL=60%)

Thank You

