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GWFish

A Fisher Matrix Analysis Software

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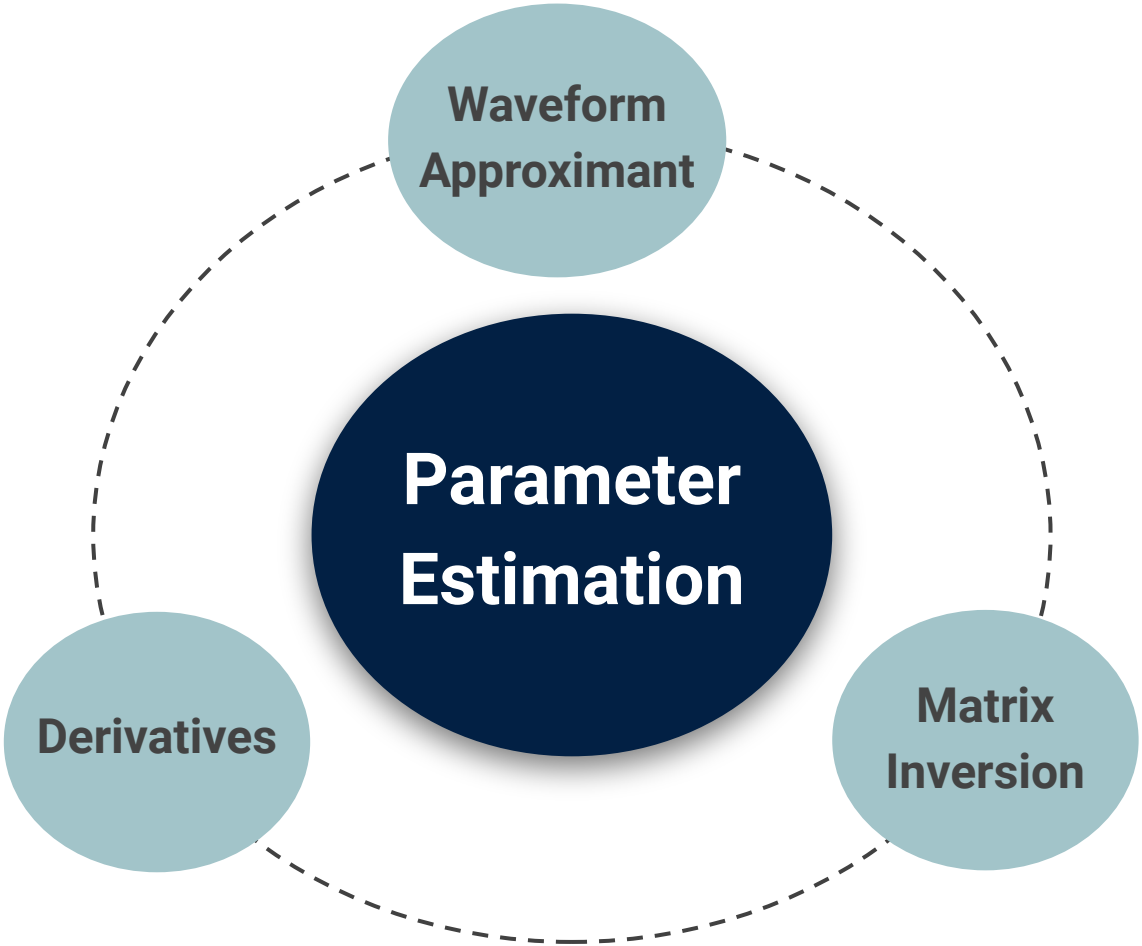
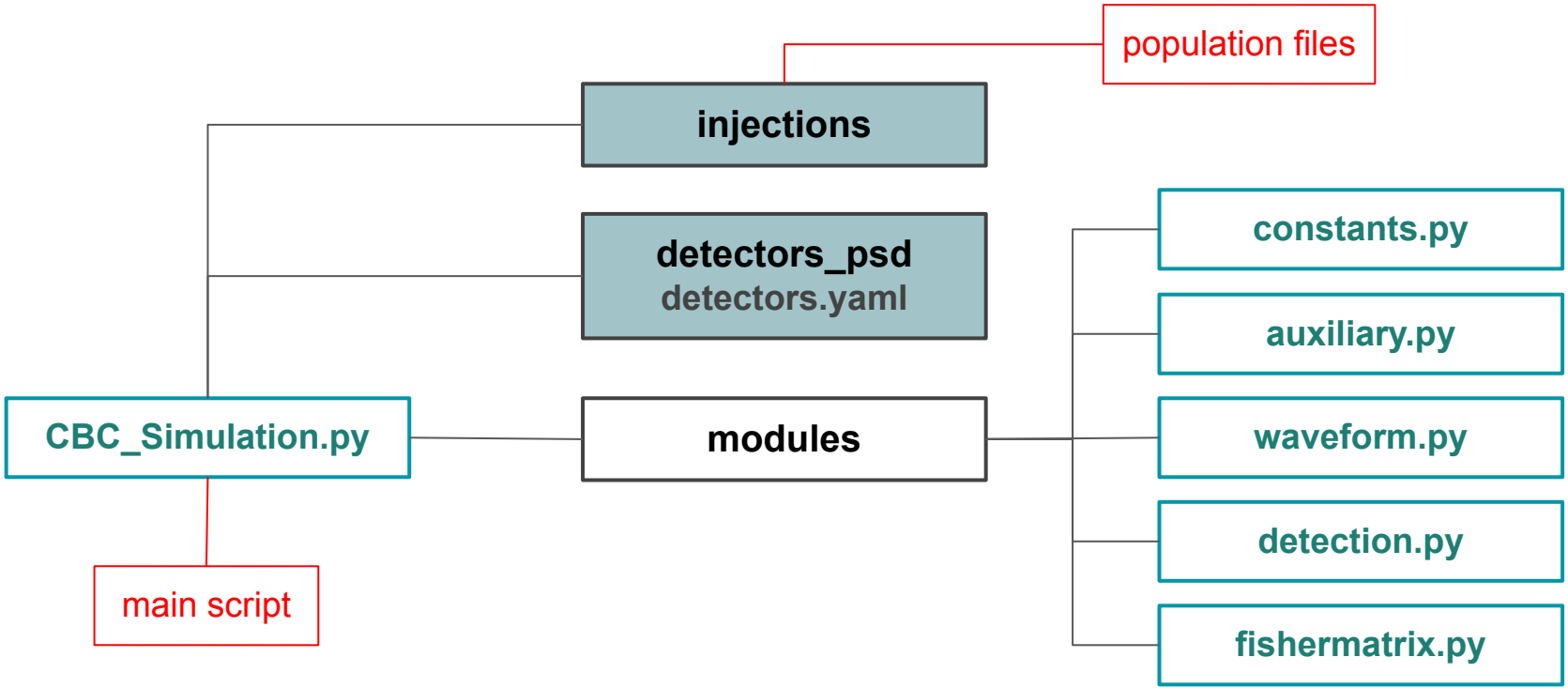
GWFISH

- Written in Python
- Implementation relies on three main ingredients:

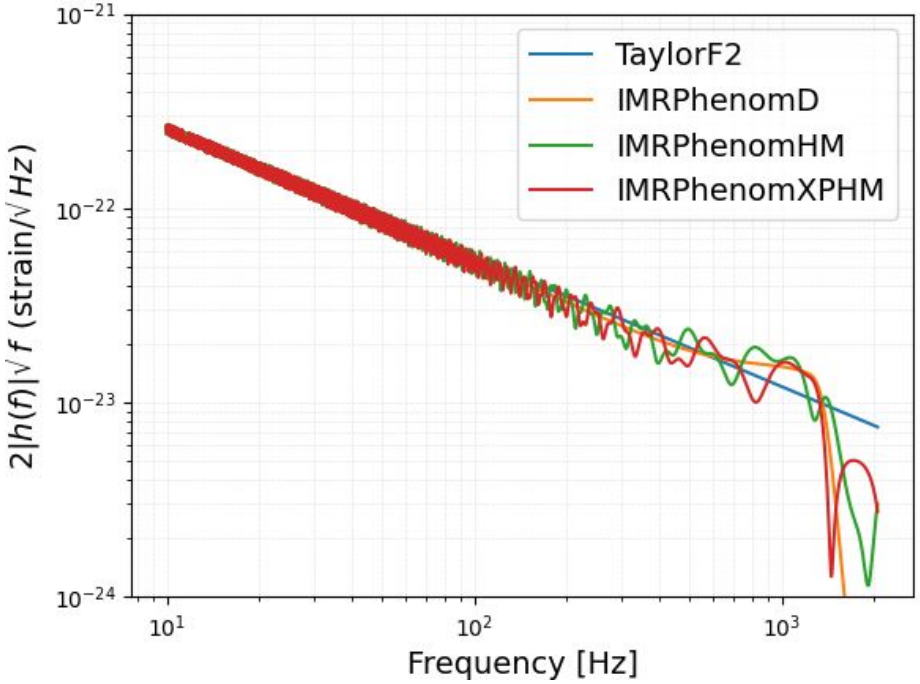


Basic Structure



GWFish Waveforms: link to LALSimulation

- All waveforms approximants from **LALSimulation**:
  - TaylorF2
  - IMRPhenomD
  - IMRPhenomXPHM
  - IMRPhenomNR_Tidalv2
  - …
- Independent implementation of TaylorF2 and IMRPhenomD waveform approximants



Derivative Implementation in GWFish

- Numerical differentiation suffers from limitations of numerical precision
- Analytic derivatives with respect to:
  - Waveform phase at merger
  - Merger time
  - Luminosity distance
- Derivatives with respect to all the other parameters are calculated numerically:

```
pv_set1[p] = pv - dp / 2.
pv_set2[p] = pv + dp / 2.

signal1 = det.projection(pv_set1, detector, wave, t_of_f)
signal2 = det.projection(pv_set2, detector, wave, t_of_f)

derivative = (signal2 - signal1) / dp
```

Matrix Inversion in GWFish: SVD

```
dm = np.sqrt(np.diag(matrix))
normalizer = np.outer(dm, dm)
matrix_norm = matrix / normalizer

[U, S, Vh] = np.linalg.svd(matrix_norm)

kVal = sum(S > thresh)
matrix_inverse_norm = U[:, 0:kVal] @ np.diag(1. / S[0:kVal]) @ Vh[0:kVal, :]

return matrix_inverse_norm / normalizer
```

Normalize matrix before inversion

Discard singular eigenvalues smaller than 1e-10

Undo the normalization

Setting up a Run with GWFish

```
parser.add_argument(
        '--pop_file', type=str, default='./injections/CBC_pop.hdf5')
parser.add_argument(
        '--detectors', type=str, default=['ET', 'CE'], nargs='+')
parser.add_argument(
        '--networks', default='[[0,1]]'))
parser.add_argument(
        '--config', type=str, default='GWFish/detectors.yaml')
```

population file

detectors

detector networks

detector config file

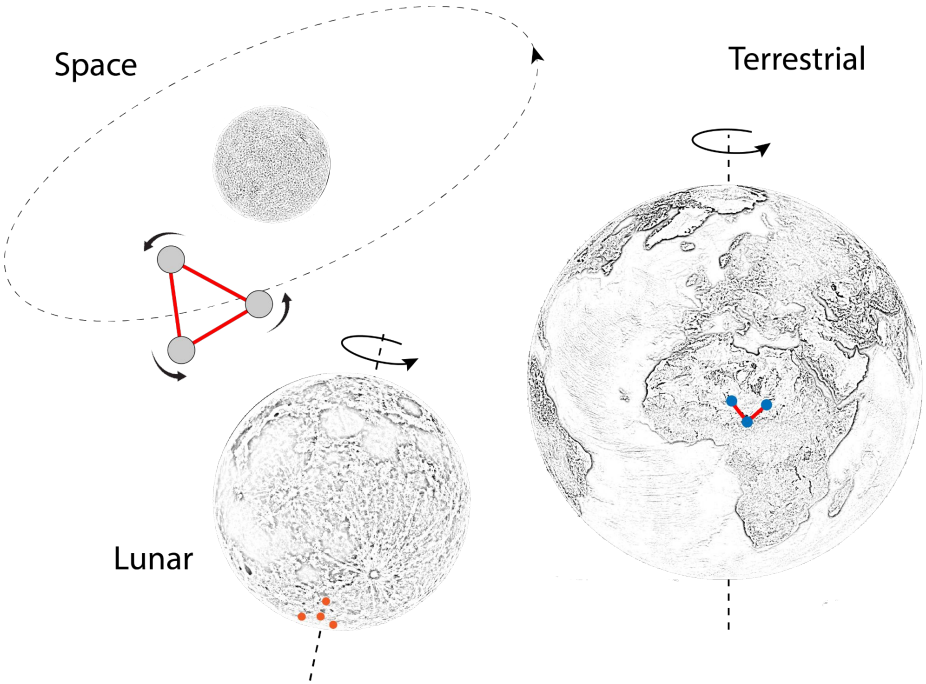
```
threshold_SNR = np.array([0., 8.])
calculate_errors = True
duty_cycle = False

fisher_parameters = ['theta_jn', 'luminosity_distance', 'mass_1', 'mass_2']

waveform_model = 'lalsim_IMRPhenomXPHM'
```

Detector Networks available in GWFish

- Potential upgrades of the current infrastructures: **Virgo**, **LIGO** (Hanford and Livingston), **LIGO India** and **KAGRA**
- The proposed **Einstein Telescope** and **Cosmic Explorer** (both second half of 2030s)
- The approved space-borne detector **LISA**, expected to begin observations in the second half of 2030s
- New detector concept on the lunar surface: **LGWA**



Detector Settings

```
ET:
   lat:              (40 + 31. / 60) * np.pi / 180.
   lon:              (9 + 25. / 60) * np.pi / 180.
   opening_angle:    np.pi / 3.
   azimuth:          70.5674 * np.pi / 180.
   psd_data:         ET_psd.txt
   duty_factor:      0.85
   detector_class:   earthDelta
   plotrange:        3, 1000, 1e-25, 1e-20
   fmin:             1.
   fmax:             2048.
   spacing:          geometric
   df:               1./16.
   npoints:          5000
```

All the detectors' settings are listed in the **detectors.yaml** file

Example of variables needed to set up a detector

These define the **frequency vector** (from fmin to fmax) and one can choose either a **linear** or a **geometric spacing**

GWFish Output Files

1. **Signals.txt**: injection parameters + SNR of all the chosen detector networks
2. **Errors.txt**: parameters **1 sigma** errors + 1 sigma **sky localization** (if RA and DEC are among the chosen Fisher parameters)

$$\Delta\Omega = \pi |\cos(DEC)| \sqrt{\sigma^2_{RA}\sigma^2_{DEC} - \sigma^2_{RA,DEC}}$$

3. Fishers.npy: list of Fisher matrices for the events above the SNR threshold
4. Inv_Fishers.npy: list of covariance matrices for the events above the SNR threshold
5. Sing_Values.npy: list of singular eigenvalues for each of the Fisher matrix in Fishers.npy file

Thanks!