GW Analysis Tools

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Chapter 1

Gravitational Waves Analysis Tools

A suite of analysis tools useful for gravitational wave science. All code is written in C++, with some of the interface classes wrapped in Cython to allow for python-access.

1.1 Compatibility

Known to work with gcc/g++-7

Known to work with gcc/g++-9

Need nvcc – known to work with v9.1 of CUDA

1.2 Required Software

Required non-standard C libraries: FFTW3 ADOL-C GSL CUDA

Required non-standard Python packages: Cython

Required non-standard packages for documentation: Doxygen

1.3 Current Development

NOTE: currently using static parameters to share data between threads for mcmc_gw.cpp. This could cause issues when running multiple samplers at the same time. Investigating further.

To do:

Change MCMC_MH to use the more general threadPool class instead of a custom threadpool, incorporate job class and comparator

1.4 Installation

For proper compilation, update or create the enviornment variables CPATH, LIBRARY_PATH,and LD_LIBRARY↩
_PATH, which should point to header files and lib files, respectively. Specifically, these variables should point to the above libraries.

Also, the PYTHONPATH environment variables must point to /gw_analysis_tools_py/src because I can't figure how to get this shit to work.

In the root directory of the project, run 'make' to compile source files, create the library file and create the cython modules, and create the documentation.

To just create C++/C files, run 'make c'.

Run 'make test' to build a test program that will create an executable.

1.5 Supported Functionality

1.5.1 Waveform Generation

IMRPhenomD, IMRPhenomPv2

1.5.2 Modified Gravity

ppE_IMRPhenomD_Inspiral ppE_IMRPhenomD_IMR ppE_IMRPhenomPv2_Inspiral ppE_IMRPhenomPv2_IMR

1.5.3 Fisher Analysis

utilizes the above waveform templates

1.5.4 MCMC Routines

Has a generic MCMC sampler, MCMC_MH, that utilizes gaussian steps, differential evolution steps, and Fisher informed steps. Includes wrapping MCMC_MH_GW for GW specific sampling, currently only for one detector.

Includes log likelihood caclulation for implementation in other samplers.

1.6 Usage

1.6.1 Environment variables

The environment variable PYTHONPATH should include the directory $(PROJECT_DIR)

1.6.2 Include

To include header files, use -I$(PROJECT_DIRECTORY)/include

1.6.3 Link

To link object files, use -L$(PROJECT_DIRECTORY)/lib -lgwat (the -L command is un-needed if you add /lib to the environment variable CPATH)

For dynamic linking, the following environment variables for Linux (MacOs) should be updated to include /lib – LD_LIBRARY_PATH (DYLD_LIBRARY_PATH)

For Cuda code: use -lcuda -lcudart

For Cuda, may need to link to /usr/local/cuda/lib64/ (or wherever this library is on your machine)

1.6.4 Python Importable Code

Two modules currently available:

1.6.4.1 gw_analysis_tools_py.mcmc_routines_ext

mcmc_routines_ext.pyx wraps the log_likelihood functions in mcmc_routines.cpp

1.6.4.2 gw_analysis_tools_py.waveform_generator_ext

waveform_generator_ext.pyx wraps the fourier_waveform function in waveform_generator.cpp

Also contains the SNR calculation function

1.6.4.3 Custom Waveforms

If adding waveforms and to have full accesibility:

Create class, using other waveforms as template – need interface to create full waveform (plus,cross polarization), and amplitude/phase

Add the option as a waveform to waveform_generation.cpp, including the header file at the top of the waveform_↩
generation.cpp file

For autodiff Fishers – write the class as a template with double and adouble types for all variables. Then write the necessary fisher subroutines (see fisher file to determine whats necessary)

For numerical Fishers – write finite difference method, following the template of the previous waveforms

For MCMC sampling – write mcmc_fisher_wrapper and mcmc_likelihood_wrapper options and write any necessary initialization in MCMC_MH_GW

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Chapter 2

gw_analysis_tools

A suite of tools useful for doing statistical studies on gravitational wave science, including routines useful in MC↩
MC studies, wave template generation, Fisher analysis, etc. Written in C++ and wrapped in Cython for access in Python.

Chapter 3

Namespace Index

3.1 Namespace List

Here is a list of all documented namespaces with brief descriptions:

Chapter 4

Hierarchical Index

4.1 Class Hierarchy

This inheritance list is sorted roughly, but not completely, alphabetically:

Chapter 5

Class Index

5.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 6

File Index

6.1 File List

Here is a list of all documented files with brief descriptions:

Chapter 7

Namespace Documentation

7.1 waveform_generator_ext Namespace Reference

Python wrapper for the waveform generation in waveform_generator.cpp.

Classes

- class gen_params_py

  Python wrapper for the generation parameters structure, as defined in util.cpp.

Functions

- def **double** (self, double, mass1, double, mass2, double, DL, spin1, spin2, double, phic, double, tc, :1] bppe, double[::1] betappe, int Nmod, double theta, double phi, double incl_angle, double f_ref, double phiRef, bool NSflag):self.params.mass1=mass1 self.params.mass2=mass2 self.params.Luminosity←_Distance=DL self.params.spin1=spin1 self.params.spin2=spin2 self.params.phic=phic self.params.tc=tc self.params.bppe=&bppe[0] self.params.betappe=&betappe[0] self.params.Nmod=Nmod self.params.incl←_angle=incl_angle self.params.theta=theta self.params.phi=phi self.params.f_ref=f_ref self.params.phi←Ref=phiRef self.params.NSflag=NSflag ##Computes the waveform in Fourier space # @param frequencies The array of frequencies to use # @param generation_method Method to use for the waveform generation # @param gen_params_py Parameters of the binary def fourier_waveform_py(double[::1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] waveform_real=np.←ascontiguousarray(np.zeros((frequencies.size) int, dtype=np.float64)
- def **double** (:1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] amplitude=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64, frequencies, frequencies, size, amplitude, generation_method, parameters, params, :1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] phase=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64, frequencies, frequencies, size, phase, generation_method, parameters, params, :1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] waveform_plus_←real=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64)

Variables

- **complex128_t**
- **ndim**
- **waveform**
- **dtype**
- **i** = i +1

7.1.1 Detailed Description

Python wrapper for the waveform generation in waveform_generator.cpp.

Chapter 8

Class Documentation

8.1 alpha_coeffs< T > Struct Template Reference

Public Attributes

- T **coeff1**
- T **coeff2**
- T **coeff3**
- T **coeff4**
- T **coeff5**

The documentation for this struct was generated from the following file:

- include/IMRPhenomP.h

8.2 Comparator Class Reference

Class to facilitate the comparing of chains for priority.

Public Member Functions

- bool **operator()** (int i, int j)

8.2.1 Detailed Description

Class to facilitate the comparing of chains for priority.

3 levels of priority: 0 (high) 1 (default) 2 (low)

The documentation for this class was generated from the following file:

- src/mcmc_sampler.cpp

8.3 comparator_ac_fft Class Reference

comparator to sort ac-jobs

```
#include <autocorrelation.h>
```

Public Member Functions

- bool **operator()** (threaded_ac_jobs_fft t, threaded_ac_jobs_fft k)

8.3.1 Detailed Description

comparator to sort ac-jobs

Starts with the longest jobs, then works down the list

The documentation for this class was generated from the following file:

- include/autocorrelation.h

8.4 comparator_ac_serial Class Reference

comparator to sort ac-jobs

```
#include <autocorrelation.h>
```

Public Member Functions

- bool **operator()** (threaded_ac_jobs_serial t, threaded_ac_jobs_serial k)

8.4.1 Detailed Description

comparator to sort ac-jobs

Starts with the longest jobs, then works down the list

The documentation for this class was generated from the following file:

- include/autocorrelation.h

8.5 Comparatorswap Class Reference

Public Member Functions

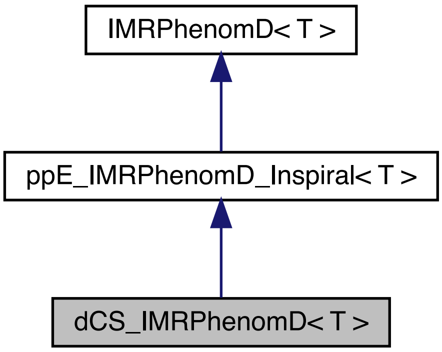
- bool **operator()** (int i, int j)

The documentation for this class was generated from the following file:

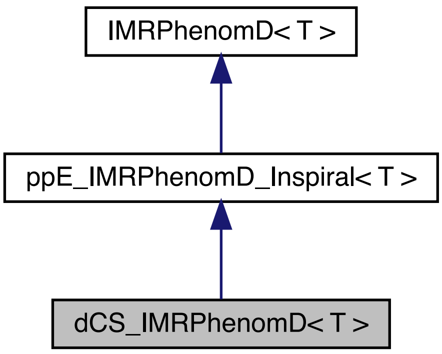
- src/mcmc_sampler.cpp

8.6 dCS_IMRPhenomD< T > Class Template Reference

Inheritance diagram for dCS_IMRPhenomD< T >:



Collaboration diagram for dCS_IMRPhenomD< T >:



Public Member Functions

- virtual int construct_waveform (T ∗frequencies, int length, std::complex< T > ∗waveform, source_parameters< T > ∗params)

  Constructs the waveform as outlined by.
- virtual T **dCS_phase_mod** (source_parameters< T > ∗param)
- virtual T **dCS_phase_factor** (source_parameters< T > ∗param)
- virtual int construct_amplitude (T ∗frequencies, int length, T ∗amplitude, source_parameters< T > ∗params)

  Constructs the Amplitude as outlined by IMRPhenomD.
- virtual int construct_phase (T ∗frequencies, int length, T ∗phase, source_parameters< T > ∗params)

  Constructs the Phase as outlined by IMRPhenomD.

8.6.1 Member Function Documentation

8.6.1.1 construct_amplitude()

```
template<class T >
int dCS_IMRPhenomD< T >::construct_amplitude (
            T * frequencies,
            int length,
            T * amplitude,
            source_parameters< T > * params ) [virtual]
```

Constructs the Amplitude as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output amplitude, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.6.1.2 construct_phase()

```
template<class T >
int dCS_IMRPhenomD< T >::construct_phase (
            T * frequencies,
            int length,
            T * phase,
            source_parameters< T > * params ) [virtual]
```

Constructs the Phase as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output phase, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.6.1.3 construct_waveform()

```
template<class T >
int dCS_IMRPhenomD< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform,
            source_parameters< T > * params ) [virtual]
```

Constructs the waveform as outlined by.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

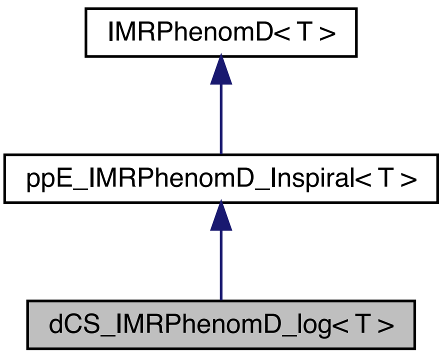
Reimplemented from IMRPhenomD< T >.

The documentation for this class was generated from the following files:

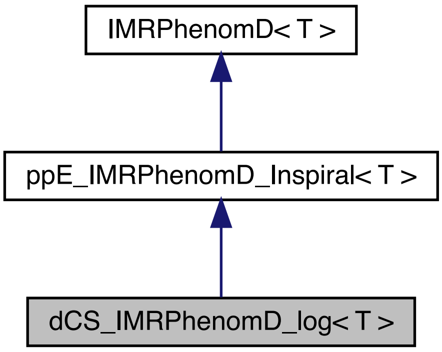
- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

8.7 dCS_IMRPhenomD_log< T > Class Template Reference

Inheritance diagram for dCS_IMRPhenomD_log< T >:



Collaboration diagram for dCS_IMRPhenomD_log< T >:



Public Member Functions

- virtual int construct_waveform (T ∗frequencies, int length, std::complex< T > ∗waveform, source_parameters< T > ∗params)

  Constructs the waveform as outlined by.
- virtual T **dCS_phase_mod** (source_parameters< T > ∗param)
- virtual T **dCS_phase_factor** (source_parameters< T > ∗param)
- virtual int construct_amplitude (T ∗frequencies, int length, T ∗amplitude, source_parameters< T > ∗params)

  Constructs the Amplitude as outlined by IMRPhenomD.
- virtual int construct_phase (T ∗frequencies, int length, T ∗phase, source_parameters< T > ∗params)

  Constructs the Phase as outlined by IMRPhenomD.

8.7.1 Member Function Documentation

8.7.1.1 construct_amplitude()

```
template<class T >
int dCS_IMRPhenomD_log< T >::construct_amplitude (
            T * frequencies,
            int length,
            T * amplitude,
            source_parameters< T > * params )  [virtual]
```

Constructs the Amplitude as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output amplitude, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.7.1.2 construct_phase()

```
template<class T >
int dCS_IMRPhenomD_log< T >::construct_phase (
            T * frequencies,
            int length,
            T * phase,
            source_parameters< T > * params ) [virtual]
```

Constructs the Phase as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output phase, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.7.1.3 construct_waveform()

```
template<class T >
int dCS_IMRPhenomD_log< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform,
            source_parameters< T > * params ) [virtual]
```

Constructs the waveform as outlined by.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

The documentation for this class was generated from the following files:

- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

8.8 default_comp< jobtype > Class Template Reference

Default comparator for priority_queue in threadPool – no comparison.

```
#include <threadPool.h>
```

Public Member Functions

- bool **operator()** (jobtype j, jobtype k)

8.8.1 Detailed Description

template<class jobtype>
class default_comp< jobtype >

Default comparator for priority_queue in threadPool – no comparison.

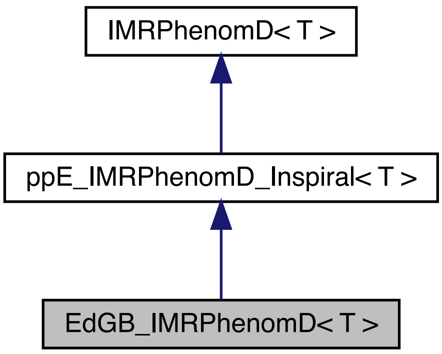
First in first out, not sorting

The documentation for this class was generated from the following file:

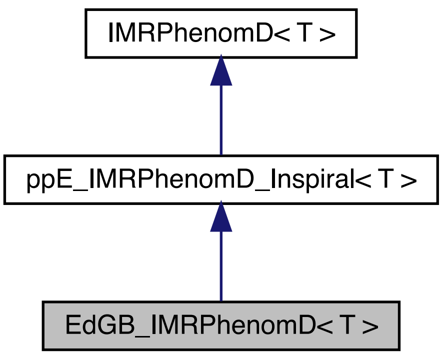
- include/threadPool.h

8.9 EdGB_IMRPhenomD< T > Class Template Reference

Inheritance diagram for EdGB_IMRPhenomD< T >:



Collaboration diagram for EdGB_IMRPhenomD< T >:



Public Member Functions

- virtual int construct_waveform (T ∗frequencies, int length, std::complex< T > ∗waveform, source_parameters< T > ∗params)

  Constructs the waveform as outlined by.
- virtual T **EdGB_phase_mod** (source_parameters< T > ∗param)
- virtual T **EdGB_phase_factor** (source_parameters< T > ∗param)
- virtual int construct_amplitude (T ∗frequencies, int length, T ∗amplitude, source_parameters< T > ∗params)

  Constructs the Amplitude as outlined by IMRPhenomD.
- virtual int construct_phase (T ∗frequencies, int length, T ∗phase, source_parameters< T > ∗params)

  Constructs the Phase as outlined by IMRPhenomD.

8.9.1 Member Function Documentation

8.9.1.1 construct_amplitude()

```
template<class T >
int EdGB_IMRPhenomD< T >::construct_amplitude (
            T * frequencies,
            int length,
            T * amplitude,
            source_parameters< T > * params ) [virtual]
```

Constructs the Amplitude as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output amplitude, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.9.1.2 construct_phase()

```
template<class T >
int EdGB_IMRPhenomD< T >::construct_phase (
            T * frequencies,
            int length,
            T * phase,
            source_parameters< T > * params ) [virtual]
```

Constructs the Phase as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output phase, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.9.1.3 construct_waveform()

```
template<class T >
int EdGB_IMRPhenomD< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform,
            source_parameters< T > * params ) [virtual]
```

Constructs the waveform as outlined by.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

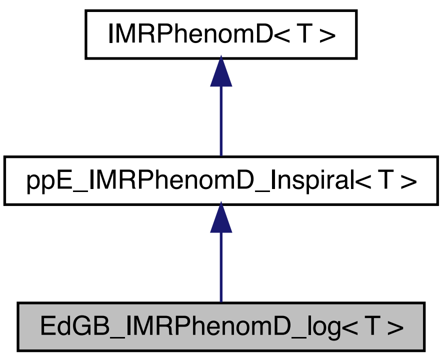
Reimplemented from IMRPhenomD< T >.

The documentation for this class was generated from the following files:

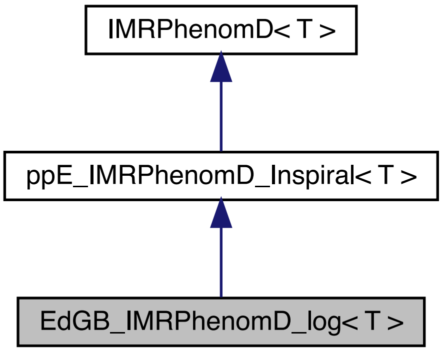
- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

8.10 EdGB_IMRPhenomD_log< T > Class Template Reference

Inheritance diagram for EdGB_IMRPhenomD_log< T >:



Collaboration diagram for EdGB_IMRPhenomD_log< T >:



Public Member Functions

- virtual int construct_waveform (T ∗frequencies, int length, std::complex< T > ∗waveform, source_parameters< T > ∗params)

    Constructs the waveform as outlined by.
- virtual T **EdGB_phase_mod** (source_parameters< T > ∗param)
- virtual T **EdGB_phase_factor** (source_parameters< T > ∗param)
- virtual int construct_amplitude (T ∗frequencies, int length, T ∗amplitude, source_parameters< T > ∗params)

    Constructs the Amplitude as outlined by IMRPhenomD.
- virtual int construct_phase (T ∗frequencies, int length, T ∗phase, source_parameters< T > ∗params)

    Constructs the Phase as outlined by IMRPhenomD.

8.10.1 Member Function Documentation

8.10.1.1 construct_amplitude()

```
template<class T >
int EdGB_IMRPhenomD_log< T >::construct_amplitude (
            T * frequencies,
            int length,
            T * amplitude,
            source_parameters< T > * params )  [virtual]
```

Constructs the Amplitude as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output amplitude, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.10.1.2 construct_phase()

```
template<class T >
int EdGB_IMRPhenomD_log< T >::construct_phase (
            T * frequencies,
            int length,
            T * phase,
            source_parameters< T > * params ) [virtual]
```

Constructs the Phase as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output phase, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

8.10.1.3 construct_waveform()

```
template<class T >
int EdGB_IMRPhenomD_log< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform,
            source_parameters< T > * params ) [virtual]
```

Constructs the waveform as outlined by.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

Reimplemented from IMRPhenomD< T >.

The documentation for this class was generated from the following files:

- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

8.11 epsilon_coeffs< T > Struct Template Reference

Public Attributes

- T **coeff1**
- T **coeff2**
- T **coeff3**
- T **coeff4**
- T **coeff5**

The documentation for this struct was generated from the following file:

- include/IMRPhenomP.h

8.12 fftw_outline Struct Reference

Public Attributes

- fftw_complex ∗ **in**
- fftw_complex ∗ **out**
- fftw_plan **p**

The documentation for this struct was generated from the following file:

- include/util.h

8.13 mcmc_routines_ext.fftw_outline_py Class Reference

Public Member Functions

- def **__init__** (self, N)
- def **__reduce__** (self)

Public Attributes

- **N**

The documentation for this class was generated from the following file:

- gw_analysis_tools_py/src/mcmc_routines_ext.pyx

8.14 gen_params Struct Reference

Public Attributes

- double mass1
- double mass2
- double Luminosity_Distance
- double spin1 [3]
- double spin2 [3]
- double phic =0
- double tc =0
- int ∗ bppe
- double ∗ betappe
- int Nmod
- double incl_angle
- double theta
- double **phi**
- double RA
- double **DEC**
- double **gmst**

- double **psi** =0
- bool NSflag
- double f_ref =0
- double **phiRef** =0
- double **thetaJN** = -1
- double **alpha0** = 0
- double **zeta_polariz** = 0
- double **phi_aligned** = 0
- double **chil** = 0
- double **chip** = 0
- bool **sky_average**
- gsl_spline * **Z_DL_spline_ptr** =NULL
- gsl_interp_accel * **Z_DL_accel_ptr** =NULL
- std::string **cosmology** ="PLANCK15"

8.14.1 Member Data Documentation

8.14.1.1 betappe

`double* gen_params::betappe`

ppE coefficient for the phase modification - vector for multiple modifications

8.14.1.2 bppe

`int* gen_params::bppe`

ppE b parameter (power of the frequency) - vector for multiple modifications

8.14.1.3 f_ref

`double gen_params::f_ref =0`

Reference frequency for PhenomPv2

8.14.1.4 incl_angle

`double gen_params::incl_angle`

*angle between angular momentum and the total momentum

8.14.1.5 Luminosity_Distance

`double gen_params::Luminosity_Distance`

Luminosity distance to the source

8.14.1.6 mass1

`double gen_params::mass1`

mass of the larger body in Solar Masses

8.14.1.7 mass2

`double gen_params::mass2`

mass of the smaller body in Solar Masses

8.14.1.8 Nmod

`int gen_params::Nmod`

Number of phase modificatinos

8.14.1.9 NSflag

`bool gen_params::NSflag`

BOOL flag for early termination of NS binaries

8.14.1.10 phic

`double gen_params::phic =0`

coalescence phase of the binary

8.14.1.11 RA

`double gen_params::RA`

Equatorial coordinates of source

8.14.1.12 spin1

`double gen_params::spin1[3]`

Spin vector of the larger mass [Sx,Sy,Sz]

8.14.1.13 spin2

`double gen_params::spin2[3]`

Spin vector of the smaller mass [Sx,Sy,Sz]

8.14.1.14 tc

```
double gen_params::tc =0
```

coalescence time of the binary

8.14.1.15 theta

```
double gen_params::theta
```

spherical angles for the source location relative to the detector

The documentation for this struct was generated from the following file:

- include/util.h

8.15 waveform_generator_ext.gen_params_py Class Reference

Python wrapper for the generation parameters structure, as defined in util.cpp.

8.15.1 Detailed Description

Python wrapper for the generation parameters structure, as defined in util.cpp.

The documentation for this class was generated from the following file:

- gw_analysis_tools_py/src/waveform_generator_ext.pyx

8.16 GPUplan Struct Reference

Public Attributes

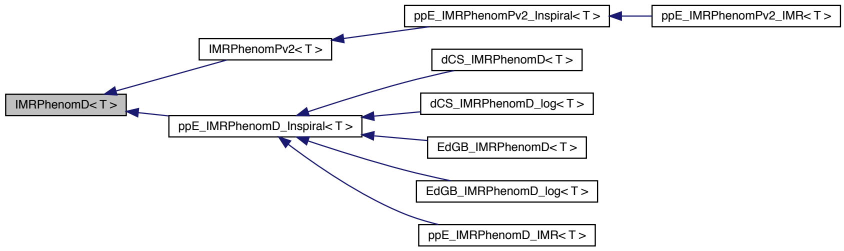
- int **device_id**
- double ∗ **device_data**
- double ∗ **host_data**
- int ∗ **host_lag**
- int ∗ **device_lag**
- int ∗ **device_lags**
- int ∗ **initial_lag**
- cudaStream_t **stream**

The documentation for this struct was generated from the following file:

- include/autocorrelation_cuda.hu

8.17 IMRPhenomD< T > Class Template Reference

Inheritance diagram for IMRPhenomD< T >:



Public Member Functions

- virtual void **fisher_calculation** (double ∗frequency, int length, gen_params ∗parameters, double ∗∗amplitude_deriv, double ∗∗phase_deriv, double ∗amplitude, int ∗amp_tapes, int ∗phase_tapes)
- virtual void change_parameter_basis (T ∗old_param, T ∗new_param, bool sky_average)

  Convience method to change parameter basis between common Fisher parameters and the intrinsic parameters of IMRPhenomD.
- virtual void construct_amplitude_derivative (double ∗frequencies, int length, int dimension, double ∗∗amplitude_derivative, source_parameters< double > ∗input_params, int ∗tapes=NULL)

  Construct the derivative of the amplitude for a given source evaluated by the given frequency.
- virtual void construct_phase_derivative (double ∗frequencies, int length, int dimension, double ∗∗phase_↩ derivative, source_parameters< double > ∗input_params, int ∗tapes=NULL)

  Construct the derivative of the phase for a given source evaluated by the given frequency.
- virtual void amplitude_tape (source_parameters< double > ∗input_params, int ∗tape)

  Creates the tapes for derivatives of the amplitude.
- virtual void phase_tape (source_parameters< double > ∗input_params, int ∗tape)

  Creates the tapes for derivatives of phase.
- virtual int construct_waveform (T ∗frequencies, int length, std::complex< T > ∗waveform, source_parameters< T > ∗params)

  Constructs the waveform as outlined by.
- virtual std::complex< T > construct_waveform (T frequency, source_parameters< T > ∗params)

  overloaded method to evaluate the waveform for one frequency instead of an array
- virtual int construct_amplitude (T ∗frequencies, int length, T ∗amplitude, source_parameters< T > ∗params)

  Constructs the Amplitude as outlined by IMRPhenomD.
- virtual int construct_phase (T ∗frequencies, int length, T ∗phase, source_parameters< T > ∗params)

  Constructs the Phase as outlined by IMRPhenomD.
- virtual T build_amp (T f, lambda_parameters< T > ∗lambda, source_parameters< T > ∗params, useful_powers< T > ∗pows, T ∗amp_coeff, T ∗deltas)

  constructs the IMRPhenomD amplitude for frequency f
- virtual T build_phase (T f, lambda_parameters< T > ∗lambda, source_parameters< T > ∗params, useful_powers< T > ∗pows, T ∗phase_coeff)

  constructs the IMRPhenomD phase for frequency f
- virtual T assign_lambda_param_element (source_parameters< T > ∗source_param, int i)

  Calculate the lambda parameters from Khan et al for element i.
- virtual void assign_lambda_param (source_parameters< T > ∗source_param, lambda_parameters< T > ∗lambda)

Wrapper for the Lambda parameter assignment that handles the looping.
- virtual void precalc_powers_ins (T f, T M, useful_powers< T > *Mf_pows)

  Pre-calculate powers of Mf, to speed up calculations for the inspiral waveform (both amplitude and phase.
- virtual void precalc_powers_PI (useful_powers< T > *PI_pows)

  Pre-calculate powers of pi, to speed up calculations for the inspiral phase.
- virtual void precalc_powers_ins_phase (T f, T M, useful_powers< T > *Mf_pows)

  Pre-calculate powers of Mf, to speed up calculations for the inspiral phase.
- virtual void precalc_powers_ins_amp (T f, T M, useful_powers< T > *Mf_pows)

  Pre-calculate powers of Mf, to speed up calculations for the inspiral amplitude.
- virtual void assign_pn_amplitude_coeff (source_parameters< T > *source_param, T *coeff)

  Calculates the static PN coeffecients for the amplitude.
- virtual void assign_static_pn_phase_coeff (source_parameters< T > *source_param, T *coeff)

  Calculates the static PN coeffecients for the phase - coeffecients 0,1,2,3,4,7.
- virtual void assign_nonstatic_pn_phase_coeff (source_parameters< T > *source_param, T *coeff, T f)

  Calculates the dynamic PN phase coefficients 5,6.
- virtual void assign_nonstatic_pn_phase_coeff_deriv (source_parameters< T > *source_param, T *Dcoeff, T f)

  Calculates the derivative of the dynamic PN phase coefficients 5,6.
- virtual void post_merger_variables (source_parameters< T > *source_param)

  Calculates the post-merger ringdown frequency and dampening frequency.
- virtual T fpeak (source_parameters< T > *params, lambda_parameters< T > *lambda)

  Solves for the peak frequency, where the waveform transitions from intermediate to merger-ringdown.
- virtual T amp_ins (T f, source_parameters< T > *param, T *pn_coeff, lambda_parameters< T > *lambda, useful_powers< T > *pow)

  Calculates the scaled inspiral amplitude A/A0 for frequency f with precomputed powers of MF and PI.
- virtual T Damp_ins (T f, source_parameters< T > *param, T *pn_coeff, lambda_parameters< T > *lambda)

  Calculates the derivative wrt frequency for the scaled inspiral amplitude A/A0 for frequency f.
- virtual T phase_ins (T f, source_parameters< T > *param, T *pn_coeff, lambda_parameters< T > *lambda, useful_powers< T > *pow)

  Calculates the inspiral phase for frequency f with precomputed powers of MF and PI for speed.
- virtual T Dphase_ins (T f, source_parameters< T > *param, T *pn_coeff, lambda_parameters< T > *lambda)

  Calculates the derivative of the inspiral phase for frequency f.
- virtual T amp_mr (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the scaled merger-ringdown amplitude A/A0 for frequency f.
- virtual T phase_mr (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the merger-ringdown phase for frequency f.
- virtual T Damp_mr (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the derivative wrt frequency for the scaled merger-ringdown amplitude A/A0 for frequency f.
- virtual T Dphase_mr (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the derivative of the merger-ringdown phase for frequency f.
- virtual T amp_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda, T *deltas)

  Calculates the scaled intermediate range amplitude A/A0 for frequency f.
- virtual T phase_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the intermediate phase for frequency f.
- virtual T Dphase_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the derivative of the intermediate phase for frequency f.
- virtual void phase_connection_coefficients (source_parameters< T > *param, lambda_parameters< T > *lambda, T *pn_coeffs)

  Calculates the phase connection coefficients alpha{0,1} and beta{0,1}.

- virtual T **calculate_beta1** (source_parameters< T > ∗param, lambda_parameters< T > ∗lambda, T ∗pn←_coeffs)
- virtual T **calculate_beta0** (source_parameters< T > ∗param, lambda_parameters< T > ∗lambda, T ∗pn←_coeffs)
- virtual T **calculate_alpha1** (source_parameters< T > ∗param, lambda_parameters< T > ∗lambda)
- virtual T **calculate_alpha0** (source_parameters< T > ∗param, lambda_parameters< T > ∗lambda)
- virtual void amp_connection_coeffs (source_parameters< T > ∗param, lambda_parameters< T > ∗lambda, T ∗pn_coeffs, T ∗coeffs)

  Solves for the connection coefficients to ensure the transition from inspiral to merger ringdown is continuous and smooth.
- virtual T calculate_delta_parameter_0 (T f1, T f2, T f3, T v1, T v2, T v3, T dd1, T dd3, T M)

  Calculates the delta_0 component.
- virtual T calculate_delta_parameter_1 (T f1, T f2, T f3, T v1, T v2, T v3, T dd1, T dd3, T M)

  Calculates the delta_1 component.
- virtual T calculate_delta_parameter_2 (T f1, T f2, T f3, T v1, T v2, T v3, T dd1, T dd3, T M)

  Calculates the delta_2 component.
- virtual T calculate_delta_parameter_3 (T f1, T f2, T f3, T v1, T v2, T v3, T dd1, T dd3, T M)

  Calculates the delta_3 component.
- virtual T calculate_delta_parameter_4 (T f1, T f2, T f3, T v1, T v2, T v3, T dd1, T dd3, T M)

  Calculates the delta_4 component.

8.17.1 Member Function Documentation

8.17.1.1 amp_ins()

```
template<class T >
T IMRPhenomD< T >::amp_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda,
            useful_powers< T > * pow ) [virtual]
```

Calculates the scaled inspiral amplitude A/A0 for frequency f with precomputed powers of MF and PI.

return a T

additional argument contains useful powers of MF and PI in structure userful_powers

8.17.1.2 amp_int()

```
template<class T >
T IMRPhenomD< T >::amp_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda,
            T * deltas ) [virtual]
```

Calculates the scaled intermediate range amplitude A/A0 for frequency f.

return a T

8.17.1.3 amp_mr()

```
template<class T >
T IMRPhenomD< T >::amp_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the scaled merger-ringdown amplitude A/A0 for frequency f.

return a T

8.17.1.4 amplitude_tape()

```
template<class T >
void IMRPhenomD< T >::amplitude_tape (
            source_parameters< double > * input_params,
            int * tape ) [virtual]
```

Creates the tapes for derivatives of the amplitude.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomD_Inspiral< T >.

8.17.1.5 assign_nonstatic_pn_phase_coeff()

```
template<class T >
void IMRPhenomD< T >::assign_nonstatic_pn_phase_coeff (
            source_parameters< T > * source_param,
            T * coeff,
            T f ) [virtual]
```

Calculates the dynamic PN phase coefficients 5,6.

f is in Hz

8.17.1.6 assign_nonstatic_pn_phase_coeff_deriv()

```
template<class T >
void IMRPhenomD< T >::assign_nonstatic_pn_phase_coeff_deriv (
            source_parameters< T > * source_param,
            T * Dcoeff,
            T f ) [virtual]
```

Calculates the derivative of the dynamic PN phase coefficients 5,6.

f is in Hz

8.17.1.7 build_amp()

```
template<class T >
T IMRPhenomD< T >::build_amp (
            T f,
            lambda_parameters< T > * lambda,
            source_parameters< T > * params,
            useful_powers< T > * pows,
            T * amp_coeff,
            T * deltas ) [virtual]
```

constructs the IMRPhenomD amplitude for frequency f

arguments: numerical parameters from Khan et al lambda_parameters structure, source_parameters structure, useful_powers<T> structure, PN parameters for the inspiral portions of the waveform, and the delta parameters for the intermediate region, numerically solved for using the amp_connection_coeffs function

8.17.1.8 build_phase()

```
template<class T >
T IMRPhenomD< T >::build_phase (
            T f,
            lambda_parameters< T > * lambda,
            source_parameters< T > * params,
            useful_powers< T > * pows,
            T * phase_coeff ) [virtual]
```

constructs the IMRPhenomD phase for frequency f

arguments: numerical parameters from Khan et al lambda_parameters structure, source_parameters structure, useful_powers structure, PN parameters for the inspiral portions of the waveform

8.17.1.9 calculate_delta_parameter_0()

```
template<class T >
T IMRPhenomD< T >::calculate_delta_parameter_0 (
            T f1,
            T f2,
            T f3,
            T v1,
            T v2,
            T v3,
            T dd1,
            T dd3,
            T M ) [virtual]
```

Calculates the delta_0 component.

Solved in Mathematica and imported to C

8.17.1.10 calculate_delta_parameter_1()

```
template<class T >
T IMRPhenomD< T >::calculate_delta_parameter_1 (
            T f1,
            T f2,
            T f3,
            T v1,
            T v2,
            T v3,
            T dd1,
            T dd3,
            T M ) [virtual]
```

Calculates the delta_1 component.

Solved in Mathematica and imported to C

8.17.1.11 calculate_delta_parameter_2()

```
template<class T >
T IMRPhenomD< T >::calculate_delta_parameter_2 (
            T f1,
            T f2,
            T f3,
            T v1,
            T v2,
            T v3,
            T dd1,
            T dd3,
            T M ) [virtual]
```

Calculates the delta_2 component.

Solved in Mathematica and imported to C

8.17.1.12 calculate_delta_parameter_3()

```
template<class T >
T IMRPhenomD< T >::calculate_delta_parameter_3 (
            T f1,
            T f2,
            T f3,
            T v1,
            T v2,
            T v3,
            T dd1,
            T dd3,
            T M ) [virtual]
```

Calculates the delta_3 component.

Solved in Mathematica and imported to C

8.17.1.13 calculate_delta_parameter_4()

```
template<class T >
T IMRPhenomD< T >::calculate_delta_parameter_4 (
            T f1,
            T f2,
            T f3,
            T v1,
            T v2,
            T v3,
            T dd1,
            T dd3,
            T M )  [virtual]
```

Calculates the delta_4 component.

Solved in Mathematica and imported to C

8.17.1.14 change_parameter_basis()

```
template<class T >
void IMRPhenomD< T >::change_parameter_basis (
            T * old_param,
            T * new_param,
            bool sky_average )  [virtual]
```

Convience method to change parameter basis between common Fisher parameters and the intrinsic parameters of IMRPhenomD.

Takes input array of old parameters and ouputs array of transformed parameters

Parameters

old_param	array of old params, order {A0, tc, phic, chirpmass, eta, spin1, spin2}
new_param	output new array: order {m1,m2,DL, spin1,spin2,phic,tc}

8.17.1.15 construct_amplitude()

```
template<class T >
int IMRPhenomD< T >::construct_amplitude (
            T * frequencies,
            int length,
            T * amplitude,
            source_parameters< T > * params )  [virtual]
```

Constructs the Amplitude as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output amplitude, and a source_parameters structure

Parameters

frequencies	T array of frequencies the waveform is to be evaulated at
length	integer length of the input array of frequencies and the output array
amplitude	output T array for the amplitude
params	Structure of source parameters to be initilized before computation

Reimplemented in EdGB_IMRPhenomD< T >, EdGB_IMRPhenomD_log< T >, dCS_IMRPhenomD< T >, and dCS_IMRPhenomD_log< T >.

8.17.1.16 construct_amplitude_derivative()

```
template<class T >
void IMRPhenomD< T >::construct_amplitude_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** amplitude_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL ) [virtual]
```

Construct the derivative of the amplitude for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
amplitude_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomD_Inspiral< T >.

8.17.1.17 construct_phase()

```
template<class T >
int IMRPhenomD< T >::construct_phase (
            T * frequencies,
            int length,
            T * phase,
            source_parameters< T > * params ) [virtual]
```

Constructs the Phase as outlined by IMRPhenomD.

arguments: array of frequencies, length of that array, T array for the output phase, and a source_parameters structure

Parameters

frequencies	T array of frequencies the waveform is to be evaluated at
length	integer length of the input and output arrays
phase	output T array for the phasee
params	structure of source parameters to be calculated before computation

Reimplemented in EdGB_IMRPhenomD< T >, EdGB_IMRPhenomD_log< T >, dCS_IMRPhenomD< T >, and dCS_IMRPhenomD_log< T >.

8.17.1.18 construct_phase_derivative()

```
template<class T >
void IMRPhenomD< T >::construct_phase_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** phase_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL ) [virtual]
```

Construct the derivative of the phase for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
phase_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomD_Inspiral< T >.

8.17.1.19 construct_waveform() [1/2]

```
template<class T >
int IMRPhenomD< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform,
            source_parameters< T > * params ) [virtual]
```

Constructs the waveform as outlined by.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

Parameters

frequencies	T array of frequencies the waveform is to be evaluated at
length	integer length of the array of frequencies and the waveform
waveform	complex T array for the waveform to be output

Reimplemented in EdGB_IMRPhenomD< T >, EdGB_IMRPhenomD_log< T >, dCS_IMRPhenomD< T >, and dCS_IMRPhenomD_log< T >.

8.17.1.20 construct_waveform() [2/2]

```
template<class T >
std::complex< T > IMRPhenomD< T >::construct_waveform (
            T frequency,
            source_parameters< T > * params ) [virtual]
```

overloaded method to evaluate the waveform for one frequency instead of an array

Parameters

frequency	T array of frequencies the waveform is to be evaluated at

8.17.1.21 Damp_ins()

```
template<class T >
T IMRPhenomD< T >::Damp_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative wrt frequency for the scaled inspiral amplitude A/A0 for frequency f.

This is an analytic derivative for the smoothness condition on the amplitude connection

return a T

8.17.1.22 Damp_mr()

```
template<class T >
T IMRPhenomD< T >::Damp_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative wrt frequency for the scaled merger-ringdown amplitude A/A0 for frequency f.

This is an analytic derivative for the smoothness condition on the amplitude connection

The analytic expression was obtained from Mathematica - See the mathematica folder for code

return a T

8.17.1.23 Dphase_ins()

```
template<class T >
T IMRPhenomD< T >::Dphase_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the inspiral phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented in ppE_IMRPhenomD_Inspiral< T >, and ppE_IMRPhenomPv2_Inspiral< T >.

8.17.1.24 Dphase_int()

```
template<class T >
T IMRPhenomD< T >::Dphase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the intermediate phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomPv2_IMR< T >.

8.17.1.25 Dphase_mr()

```
template<class T >
T IMRPhenomD< T >::Dphase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the merger-ringdown phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomPv2_IMR< T >.

8.17.1.26 fpeak()

```
template<class T >
T IMRPhenomD< T >::fpeak (
            source_parameters< T > * params,
            lambda_parameters< T > * lambda ) [virtual]
```

Solves for the peak frequency, where the waveform transitions from intermediate to merger-ringdown.

returns Hz

8.17.1.27 phase_connection_coefficients()

```
template<class T >
void IMRPhenomD< T >::phase_connection_coefficients (
            source_parameters< T > * param,
            lambda_parameters< T > * lambda,
            T * pn_coeffs ) [virtual]
```

Calculates the phase connection coefficients alpha{0,1} and beta{0,1}.

Note: these coefficients are stored in the lambda parameter structure, not a separate array

8.17.1.28 phase_ins()

```
template<class T >
T IMRPhenomD< T >::phase_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda,
            useful_powers< T > * pow ) [virtual]
```

Calculates the inspiral phase for frequency f with precomputed powers of MF and PI for speed.

return a T

extra argument of precomputed powers of MF and pi, contained in the structure useful_powers<T>

Reimplemented in ppE_IMRPhenomD_Inspiral< T >, and ppE_IMRPhenomPv2_Inspiral< T >.

8.17.1.29 phase_int()

```
template<class T >
T IMRPhenomD< T >::phase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the intermediate phase for frequency f.

return a T

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomPv2_IMR< T >.

8.17.1.30 phase_mr()

```
template<class T >
T IMRPhenomD< T >::phase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the merger-ringdown phase for frequency f.

return a T

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomPv2_IMR< T >.

8.17.1.31 phase_tape()

```
template<class T >
void IMRPhenomD< T >::phase_tape (
            source_parameters< double > * input_params,
            int * tape ) [virtual]
```

Creates the tapes for derivatives of phase.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented in ppE_IMRPhenomD_IMR< T >, and ppE_IMRPhenomD_Inspiral< T >.

8.17.1.32 post_merger_variables()

```
template<class T >
void IMRPhenomD< T >::post_merger_variables (
            source_parameters< T > * source_param ) [virtual]
```

Calculates the post-merger ringdown frequency and dampening frequency.

Returns in Hz - assigns fRD to var[0] and fdamp to var[1]

8.17.1.33 precalc_powers_ins()

```
template<class T >
void IMRPhenomD< T >::precalc_powers_ins (
            T f,
            T M,
            useful_powers< T > * Mf_pows )  [virtual]
```

Pre-calculate powers of Mf, to speed up calculations for the inspiral waveform (both amplitude and phase.

It seems the pow() function is very slow, so to speed things up, powers of Mf will be precomputed and passed to the functions within the frequency loops

8.17.1.34 precalc_powers_ins_amp()

```
template<class T >
void IMRPhenomD< T >::precalc_powers_ins_amp (
            T f,
            T M,
            useful_powers< T > * Mf_pows )  [virtual]
```

Pre-calculate powers of Mf, to speed up calculations for the inspiral amplitude.

It seems the pow() function is very slow, so to speed things up, powers of Mf will be precomputed and passed to the functions within the frequency loops

8.17.1.35 precalc_powers_ins_phase()

```
template<class T >
void IMRPhenomD< T >::precalc_powers_ins_phase (
            T f,
            T M,
            useful_powers< T > * Mf_pows )  [virtual]
```

Pre-calculate powers of Mf, to speed up calculations for the inspiral phase.

It seems the pow() function is very slow, so to speed things up, powers of Mf will be precomputed and passed to the functions within the frequency loops

8.17.1.36 precalc_powers_PI()

```
template<class T >
void IMRPhenomD< T >::precalc_powers_PI (
            useful_powers< T > * PI_pows )  [virtual]
```

Pre-calculate powers of pi, to speed up calculations for the inspiral phase.

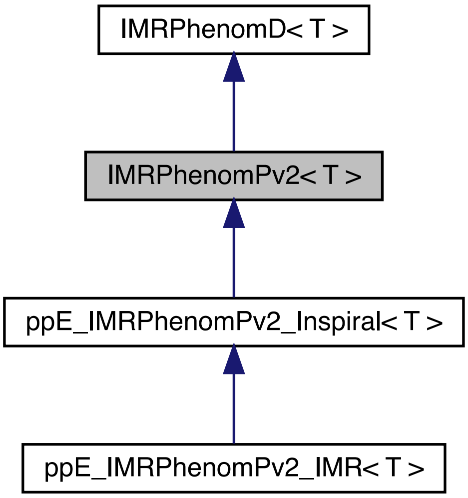
It seems the pow() function is very slow, so to speed things up, powers of PI will be precomputed and passed to the functions within the frequency loops

The documentation for this class was generated from the following files:

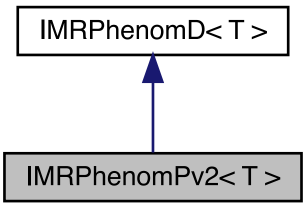
- include/IMRPhenomD.h
- src/IMRPhenomD.cpp

8.18 IMRPhenomPv2< T > Class Template Reference

Inheritance diagram for IMRPhenomPv2< T >:



Collaboration diagram for IMRPhenomPv2< T >:



Public Member Functions

- virtual T **alpha** (T omega, T q, T chi2l, T chi2)
- virtual T **epsilon** (T omega, T q, T chi2l, T chi2)
- virtual void calculate_euler_coeffs (alpha_coeffs< T > *acoeffs, epsilon_coeffs< T > *ecoeffs, source_parameters< T > *params)

  Pre calculate euler angle coefficients.
- virtual T **d** (int l, int mp, int m, T s)
- virtual int construct_waveform (T *frequencies, int length, std::complex< T > *waveform_plus, std::complex< T > *waveform_cross, source_parameters< T > *params)

Constructs the waveform for IMRPhenomPv2 - uses IMRPhenomD, then twists up.

- virtual void **WignerD** (T d2[5], T dm2[5], useful_powers< T > *pows, source_parameters< T > *params)
- virtual void **calculate_twistup** (T alpha, std::complex< T > *hp_factor, std::complex< T > *hc_factor, T d2[5], T dm2[5], sph_harm< T > *sph_harm)
- virtual void **calculate_euler_angles** (T *alpha, T *epsilon, useful_powers< T > *pows, alpha_coeffs< T > *acoeffs, epsilon_coeffs< T > *ecoeffs)
- virtual void PhenomPv2_Param_Transform (source_parameters< T > *params)
- virtual void PhenomPv2_Param_Transform_J (source_parameters< T > *params)
- virtual T **L2PN** (T eta, useful_powers< T > *pow)

8.18.1 Member Function Documentation

8.18.1.1 calculate_euler_coeffs()

```
template<class T >
void IMRPhenomPv2< T >::calculate_euler_coeffs (
            alpha_coeffs< T > * acoeffs,
            epsilon_coeffs< T > * ecoeffs,
            source_parameters< T > * params )  [virtual]
```

Pre calculate euler angle coefficients.

Straight up stolen from LALsuite

8.18.1.2 construct_waveform()

```
template<class T >
int IMRPhenomPv2< T >::construct_waveform (
            T * frequencies,
            int length,
            std::complex< T > * waveform_plus,
            std::complex< T > * waveform_cross,
            source_parameters< T > * params )  [virtual]
```

Constructs the waveform for IMRPhenomPv2 - uses IMRPhenomD, then twists up.

arguments: array of frequencies, length of that array, a complex array for the output waveform, and a source_parameters structure

Parameters

frequencies	T array of frequencies the waveform is to be evaluated at
length	integer length of the array of frequencies and the waveform
waveform_plus	complex T array for the plus polariaztion waveform to be output
waveform_cross	complex T array for the cross polarization waveform to be output

8.18.1.3 PhenomPv2_Param_Transform()

```
template<class T >
void IMRPhenomPv2< T >::PhenomPv2_Param_Transform (
            source_parameters< T > * params ) [virtual]
```

/Brief Parameter transformtion to precalculate needed parameters for PhenomP from source parameters

Pretty much stolen verbatim from lalsuite

Reimplemented in ppE_IMRPhenomPv2_IMR< T >, and ppE_IMRPhenomPv2_Inspiral< T >.

8.18.1.4 PhenomPv2_Param_Transform_J()

```
template<class T >
void IMRPhenomPv2< T >::PhenomPv2_Param_Transform_J (
            source_parameters< T > * params ) [virtual]
```

/Brief Parameter transformtion to precalculate needed parameters for PhenomP from source parameters – assumed inclination of total angular momentum J is given, not orbital angular momentum (in source frame (Lhat == zhat)

Pretty much stolen verbatim from lalsuite

The documentation for this class was generated from the following files:

- include/IMRPhenomP.h
- src/IMRPhenomP.cpp

8.19 lambda_parameters< T > Struct Template Reference

Public Attributes

- T **rho** [4]
- T **v2**
- T **gamma** [4]
- T **sigma** [5]
- T **beta** [5]
- T **alpha** [7]

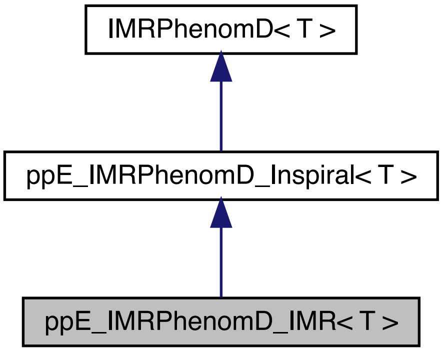
The documentation for this struct was generated from the following file:

- include/IMRPhenomD.h

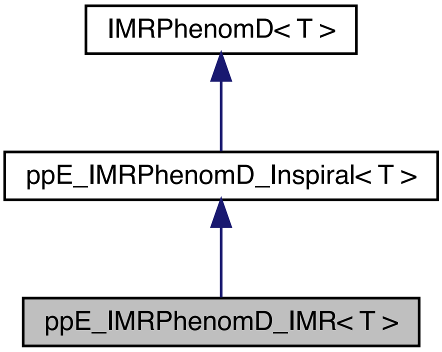
8.20 ppE_IMRPhenomD_IMR$<$ T $>$ Class Template Reference

```
#include <ppE_IMRPhenomD.h>
```

Inheritance diagram for ppE_IMRPhenomD_IMR$<$ T $>$:



Collaboration diagram for ppE_IMRPhenomD_IMR$<$ T $>$:



Public Member Functions

- virtual T Dphase_mr (T f, source_parameters$<$ T $>$ $*$param, lambda_parameters$<$ T $>$ $*$lambda)

    Calculates the derivative of the merger-ringdown phase for frequency f.
- virtual T phase_mr (T f, source_parameters$<$ T $>$ $*$param, lambda_parameters$<$ T $>$ $*$lambda)

    Calculates the merger-ringdown phase for frequency f.
- virtual T phase_int (T f, source_parameters$<$ T $>$ $*$param, lambda_parameters$<$ T $>$ $*$lambda)

Calculates the intermediate phase for frequency f.

- virtual T Dphase_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

    Calculates the derivative of the intermediate phase for frequency f.
- virtual void **fisher_calculation** (double *frequency, int length, gen_params *parameters, double **amplitude_deriv, double **phase_deriv, double *amplitude, int *amp_tapes, int *phase_tapes)
- virtual void amplitude_tape (source_parameters< double > *input_params, int *tape)

    Creates the tapes for derivatives of the amplitude.
- virtual void phase_tape (source_parameters< double > *input_params, int *tape)

    Creates the tapes for derivatives of phase.
- virtual void construct_amplitude_derivative (double *frequencies, int length, int dimension, double **amplitude_derivative, source_parameters< double > *input_params, int *tapes=NULL)

    Construct the derivative of the amplitude for a given source evaluated by the given frequency.
- virtual void construct_phase_derivative (double *frequencies, int length, int dimension, double **phase_↩ derivative, source_parameters< double > *input_params, int *tapes=NULL)

    Construct the derivative of the phase for a given source evaluated by the given frequency.

8.20.1 Detailed Description

template<class T>
class ppE_IMRPhenomD_IMR< T >

Class that extends the IMRPhenomD waveform to include non-GR terms in the full phase. This is an appropriate waveform choice for propagation effects

8.20.2 Member Function Documentation

8.20.2.1 amplitude_tape()

```
template<class T >
void ppE_IMRPhenomD_IMR< T >::amplitude_tape (
            source_parameters< double > * input_params,
            int * tape )  [virtual]
```

Creates the tapes for derivatives of the amplitude.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented from ppE_IMRPhenomD_Inspiral< T >.

8.20.2.2 construct_amplitude_derivative()

```
template<class T >
void ppE_IMRPhenomD_IMR< T >::construct_amplitude_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** amplitude_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL )  [virtual]
```

Construct the derivative of the amplitude for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
amplitude_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented from ppE_IMRPhenomD_Inspiral< T >.

8.20.2.3 construct_phase_derivative()

```
template<class T >
void ppE_IMRPhenomD_IMR< T >::construct_phase_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** phase_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL )  [virtual]
```

Construct the derivative of the phase for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
phase_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented from ppE_IMRPhenomD_Inspiral< T >.

8.20.2.4 Dphase_int()

```
template<class T >
T ppE_IMRPhenomD_IMR< T >::Dphase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the intermediate phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.20.2.5 Dphase_mr()

```
template<class T >
T ppE_IMRPhenomD_IMR< T >::Dphase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the merger-ringdown phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.20.2.6 phase_int()

```
template<class T >
T ppE_IMRPhenomD_IMR< T >::phase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the intermediate phase for frequency f.

return a T

Reimplemented from IMRPhenomD< T >.

8.20.2.7 phase_mr()

```
template<class T >
T ppE_IMRPhenomD_IMR< T >::phase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the merger-ringdown phase for frequency f.

return a T

Reimplemented from IMRPhenomD< T >.

8.20.2.8 phase_tape()

```
template<class T >
void ppE_IMRPhenomD_IMR< T >::phase_tape (
            source_parameters< double > * input_params,
            int * tape ) [virtual]
```

Creates the tapes for derivatives of phase.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented from ppE_IMRPhenomD_Inspiral< T >.

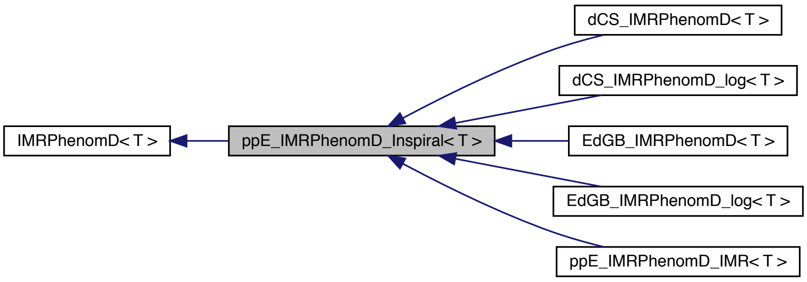
The documentation for this class was generated from the following files:

- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

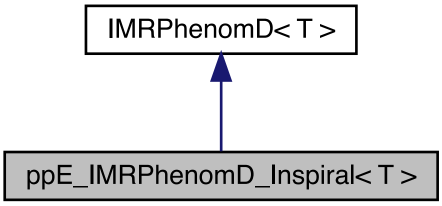
8.21 ppE_IMRPhenomD_Inspiral< T > Class Template Reference

```
#include <ppE_IMRPhenomD.h>
```

Inheritance diagram for ppE_IMRPhenomD_Inspiral< T >:



Collaboration diagram for ppE_IMRPhenomD_Inspiral< T >:



Public Member Functions

- virtual T phase_ins (T f, source_parameters< T > ∗param, T ∗pn_coeff, lambda_parameters< T > ∗lambda, useful_powers< T > ∗pow)

    Overloaded method for the inspiral portion of the phase.
- virtual T Dphase_ins (T f, source_parameters< T > ∗param, T ∗pn_coeff, lambda_parameters< T > ∗lambda)

    Calculates the derivative of the inspiral phase for frequency f.
- virtual void **fisher_calculation** (double ∗frequency, int length, gen_params ∗parameters, double ∗∗amplitude_deriv, double ∗∗phase_deriv, double ∗amplitude, int ∗amp_tapes, int ∗phase_tapes)
- virtual void amplitude_tape (source_parameters< double > ∗input_params, int ∗tape)

    Creates the tapes for derivatives of the amplitude.
- virtual void phase_tape (source_parameters< double > ∗input_params, int ∗tape)

    Creates the tapes for derivatives of phase.
- virtual void construct_amplitude_derivative (double ∗frequencies, int length, int dimension, double ∗∗amplitude_derivative, source_parameters< double > ∗input_params, int ∗tapes=NULL)

    Construct the derivative of the amplitude for a given source evaluated by the given frequency.
- virtual void construct_phase_derivative (double ∗frequencies, int length, int dimension, double ∗∗phase_←derivative, source_parameters< double > ∗input_params, int ∗tapes=NULL)

    Construct the derivative of the phase for a given source evaluated by the given frequency.

8.21.1 Detailed Description

template<class T>
class ppE_IMRPhenomD_Inspiral< T >

Class that extends the IMRPhenomD waveform to include non-GR terms in the inspiral portion of the phase. This is an appropriate waveform choice for generation effects, but not necessarily for propagation effects

8.21.2 Member Function Documentation

8.21.2.1 amplitude_tape()

```
template<class T >
void ppE_IMRPhenomD_Inspiral< T >::amplitude_tape (
            source_parameters< double > * input_params,
            int * tape )  [virtual]
```

Creates the tapes for derivatives of the amplitude.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented from IMRPhenomD< T >.

Reimplemented in ppE_IMRPhenomD_IMR< T >.

8.21.2.2 construct_amplitude_derivative()

```
template<class T >
void ppE_IMRPhenomD_Inspiral< T >::construct_amplitude_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** amplitude_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL )  [virtual]
```

Construct the derivative of the amplitude for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
amplitude_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented from IMRPhenomD< T >.

Reimplemented in ppE_IMRPhenomD_IMR< T >.

8.21.2.3 construct_phase_derivative()

```
template<class T >
void ppE_IMRPhenomD_Inspiral< T >::construct_phase_derivative (
            double * frequencies,
            int length,
            int dimension,
            double ** phase_derivative,
            source_parameters< double > * input_params,
            int * tapes = NULL ) [virtual]
```

Construct the derivative of the phase for a given source evaluated by the given frequency.

Order of output: dh/d \theta : \theta \el {A0,tc, phic, chirp mass, eta, symmetric spin, antisymmetric spin}

Parameters

frequencies	input array of frequency
length	length of the frequency array
phase_derivative	< dimension of the fisher output array for all the derivatives double[dimension][length]
input_params	Source parameters structure for the source
tapes	int array of tape ids, if NULL, these will be calculated

Reimplemented from IMRPhenomD< T >.

Reimplemented in ppE_IMRPhenomD_IMR< T >.

8.21.2.4 Dphase_ins()

```
template<class T >
T ppE_IMRPhenomD_Inspiral< T >::Dphase_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the inspiral phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.21.2.5 phase_tape()

```
template<class T >
void ppE_IMRPhenomD_Inspiral< T >::phase_tape (
            source_parameters< double > * input_params,
            int * tape ) [virtual]
```

Creates the tapes for derivatives of phase.

For efficiency in long runs of large sets of fishers, the tapes can be precomputed and reused

Parameters

input_params	source parameters structure of the desired source
tape	tape ids

Reimplemented from IMRPhenomD< T >.

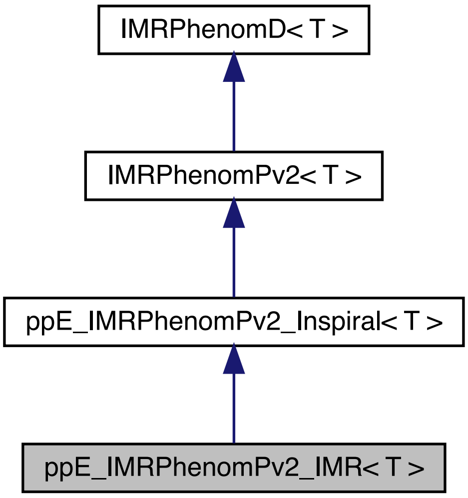
Reimplemented in ppE_IMRPhenomD_IMR< T >.

The documentation for this class was generated from the following files:

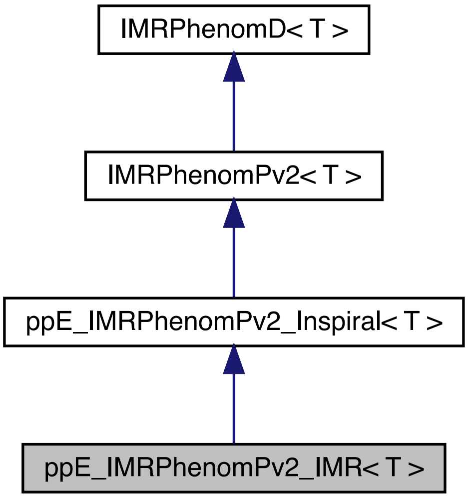
- include/ppE_IMRPhenomD.h
- src/ppE_IMRPhenomD.cpp

8.22 ppE_IMRPhenomPv2_IMR< T > Class Template Reference

Inheritance diagram for ppE_IMRPhenomPv2_IMR< T >:



Collaboration diagram for ppE_IMRPhenomPv2_IMR< T >:



Public Member Functions

- virtual T phase_mr (T f, source_parameters< T > ∗param, lambda_parameters< T > ∗lambda)

Calculates the merger-ringdown phase for frequency f.

- virtual T Dphase_mr (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the derivative of the merger-ringdown phase for frequency f.
- virtual T phase_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the intermediate phase for frequency f.
- virtual T Dphase_int (T f, source_parameters< T > *param, lambda_parameters< T > *lambda)

  Calculates the derivative of the intermediate phase for frequency f.
- virtual void PhenomPv2_Param_Transform (source_parameters< T > *params)

8.22.1 Member Function Documentation

8.22.1.1 Dphase_int()

```
template<class T >
T ppE_IMRPhenomPv2_IMR< T >::Dphase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the intermediate phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.22.1.2 Dphase_mr()

```
template<class T >
T ppE_IMRPhenomPv2_IMR< T >::Dphase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda ) [virtual]
```

Calculates the derivative of the merger-ringdown phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.22.1.3 phase_int()

```
template<class T >
T ppE_IMRPhenomPv2_IMR< T >::phase_int (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda )  [virtual]
```

Calculates the intermediate phase for frequency f.

return a T

Reimplemented from IMRPhenomD< T >.

8.22.1.4 phase_mr()

```
template<class T >
T ppE_IMRPhenomPv2_IMR< T >::phase_mr (
            T f,
            source_parameters< T > * param,
            lambda_parameters< T > * lambda )  [virtual]
```

Calculates the merger-ringdown phase for frequency f.

return a T

Reimplemented from IMRPhenomD< T >.

8.22.1.5 PhenomPv2_Param_Transform()

```
template<class T >
void ppE_IMRPhenomPv2_IMR< T >::PhenomPv2_Param_Transform (
            source_parameters< T > * params )  [virtual]
```

/Brief Parameter transformtion to precalculate needed parameters for PhenomP from source parameters

Pretty much stolen verbatim from lalsuite

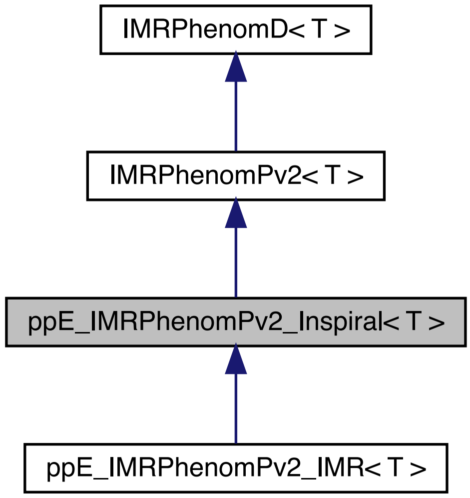
Reimplemented from ppE_IMRPhenomPv2_Inspiral< T >.

The documentation for this class was generated from the following files:

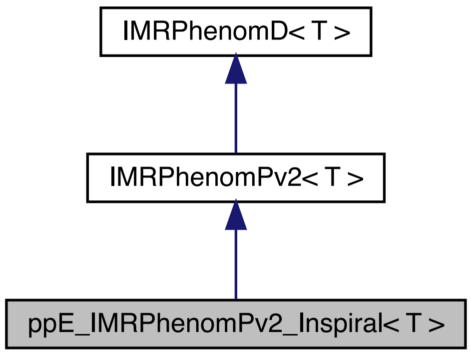
- include/ppE_IMRPhenomP.h
- src/ppE_IMRPhenomP.cpp

8.23 ppE_IMRPhenomPv2_Inspiral< T > Class Template Reference

Inheritance diagram for ppE_IMRPhenomPv2_Inspiral< T >:



Collaboration diagram for ppE_IMRPhenomPv2_Inspiral< T >:



Public Member Functions

- virtual T phase_ins (T f, source_parameters< T > ∗param, T ∗pn_coeff, lambda_parameters< T > ∗lambda, useful_powers< T > ∗pow)

    Calculates the inspiral phase for frequency f with precomputed powers of MF and PI for speed.

- virtual T Dphase_ins (T f, source_parameters< T > *param, T *pn_coeff, lambda_parameters< T > *lambda)

    Calculates the derivative of the inspiral phase for frequency f.
- virtual void PhenomPv2_Param_Transform (source_parameters< T > *params)

8.23.1 Member Function Documentation

8.23.1.1 Dphase_ins()

```
template<class T >
T ppE_IMRPhenomPv2_Inspiral< T >::Dphase_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda )  [virtual]
```

Calculates the derivative of the inspiral phase for frequency f.

For phase continuity and smoothness return a T

Reimplemented from IMRPhenomD< T >.

8.23.1.2 phase_ins()

```
template<class T >
T ppE_IMRPhenomPv2_Inspiral< T >::phase_ins (
            T f,
            source_parameters< T > * param,
            T * pn_coeff,
            lambda_parameters< T > * lambda,
            useful_powers< T > * pow )  [virtual]
```

Calculates the inspiral phase for frequency f with precomputed powers of MF and PI for speed.

return a T

extra argument of precomputed powers of MF and pi, contained in the structure useful_powers<T>

Reimplemented from IMRPhenomD< T >.

8.23.1.3 PhenomPv2_Param_Transform()

```
template<class T >
void ppE_IMRPhenomPv2_Inspiral< T >::PhenomPv2_Param_Transform (
            source_parameters< T > * params )  [virtual]
```

/Brief Parameter transformtion to precalculate needed parameters for PhenomP from source parameters

Pretty much stolen verbatim from lalsuite

Reimplemented from IMRPhenomPv2< T >.

Reimplemented in ppE_IMRPhenomPv2_IMR< T >.

The documentation for this class was generated from the following files:

- include/ppE_IMRPhenomP.h
- src/ppE_IMRPhenomP.cpp

8.24 sampler Class Reference

```
#include <mcmc_sampler_internals.h>
```

Public Attributes

- int **types_of_steps** = 5
- double ** **step_prob**
- double ** **prob_boundaries**
- double * **chain_temps**
- bool * **waiting**
- int * **chain_pos**
- double **swp_freq**
- int **chain_N**
- int **numThreads**
- int **N_steps**
- int **dimension**
- int **min_dim**
- int **max_dim**
- bool **fisher_exist**
- bool * **de_primed**
- int * **priority**
- bool * **ref_chain_status**
- bool **prioritize_cold_chains** = true
- double *** **output**
- bool **pool**
- int **progress** =0
- bool **show_progress**
- int **num_threads**
- int **history_length** =500
- int **history_update** =5
- int * **current_hist_pos**

- double ∗∗∗ **history**
- int ∗∗∗ **history_status**
- double ∗ **current_likelihoods**
- int ∗ **check_stepsize_freq**
- double ∗ **max_target_accept_ratio**
- double ∗ **min_target_accept_ratio**
- int ∗ **gauss_last_accept_ct**
- int ∗ **gauss_last_reject_ct**
- int ∗ **de_last_accept_ct**
- int ∗ **de_last_reject_ct**
- int ∗ **fish_last_accept_ct**
- int ∗ **fish_last_reject_ct**
- double ∗∗ **randgauss_width**
- double ∗∗∗ **fisher_vecs**
- double ∗∗ **fisher_vals**
- int ∗ **fisher_update_ct**
- int **fisher_update_number** =200
- std::function< double(double ∗, int ∗, int, int)> **lp**
- std::function< double(double ∗, int ∗, int, int)> **ll**
- std::function< void(double ∗, int ∗, int, double ∗∗, int)> **fish**
- gsl_rng ∗∗ **rvec**
- int ∗ **nan_counter**
- int ∗ **num_gauss**
- int ∗ **num_fish**
- int ∗ **num_de**
- int ∗ **num_mmala**
- int ∗ **num_RJstep**
- double **time_elapsed_cpu**
- double **time_elapsed_wall**
- double **time_elapsed_cpu_ac**
- double **time_elapsed_wall_ac**
- int ∗ **fish_accept_ct**
- int ∗ **fish_reject_ct**
- int ∗ **de_accept_ct**
- int ∗ **de_reject_ct**
- int ∗ **gauss_accept_ct**
- int ∗ **gauss_reject_ct**
- int ∗ **mmala_accept_ct**
- int ∗ **mmala_reject_ct**
- int ∗ **RJstep_accept_ct**
- int ∗ **RJstep_reject_ct**
- int ∗ **swap_accept_ct**
- int ∗ **swap_reject_ct**
- int ∗ **step_accept_ct**
- int ∗ **step_reject_ct**
- double ∗∗∗ **ll_lp_output**
- bool **log_ll** =false
- bool **log_lp** =false
- int ∗ **A**
- bool **PT_alloc** =false
- int ∗∗∗ **param_status**
- bool **RJMCMC** =false
- std::function< void(double ∗, double ∗, int ∗, int ∗, int, int)> **rj**

8.24.1 Detailed Description

Class storing everything that defines an instance of the sampler

The documentation for this class was generated from the following file:

- include/mcmc_sampler_internals.h

8.25 source_parameters< T > Struct Template Reference

Static Public Member Functions

- static source_parameters< T > populate_source_parameters (gen_params *param_in)

  Builds the structure that shuttles source parameters between functions -updated version to incorporate structure argument.
- static source_parameters< T > populate_source_parameters_old (T mass1, T mass2, T Luminosity_←
Distance, T *spin1, T *spin2, T phi_c, T t_c, bool sky_average)

  Builds the structure that shuttles source parameters between functions- outdated in favor of structure argument.

Public Attributes

- T mass1
- T mass2
- T M
- T **q**
- T spin1z
- T spin2z
- T spin1x
- T spin2x
- T spin1y
- T spin2y
- T chirpmass
- T eta
- T chi_s
- T chi_a
- T chi_eff
- T chi_pn
- T DL
- T delta_mass
- T fRD
- T fdamp
- T f1
- T f3
- T f1_phase
- T f2_phase
- T phic
- T tc
- T **A0**
- T **s**
- T **chil**
- T **chip**

- T **f_ref**
- T **phi_aligned**
- T **incl_angle**
- T **phiRef**
- T **alpha0**
- T **thetaJN**
- T **zeta_polariz**
- T ∗ **betappe**
- int ∗ **bppe**
- int Nmod
- T **phi**
- T **theta**
- T **SP**
- T **SL**
- bool **sky_average**
- gsl_spline ∗ **Z_DL_spline_ptr** =NULL
- gsl_interp_accel ∗ **Z_DL_accel_ptr** =NULL
- std::string **cosmology**

8.25.1 Member Function Documentation

8.25.1.1 populate_source_parameters()

```
template<class T >
source_parameters< T > source_parameters< T >::populate_source_parameters (
            gen_params * param_in )  [static]
```

Builds the structure that shuttles source parameters between functions -updated version to incorporate structure argument.

Populates the structure that is passed to all generation methods - contains all relavent source parameters

8.25.1.2 populate_source_parameters_old()

```
template<class T >
source_parameters< T > source_parameters< T >::populate_source_parameters_old (
            T mass1,
            T mass2,
            T Luminosity_Distance,
            T * spin1,
            T * spin2,
            T phi_c,
            T t_c,
            bool sky_average )  [static]
```

Builds the structure that shuttles source parameters between functions- outdated in favor of structure argument.

Populates the structure that is passed to all generation methods - contains all relavent source parameters

Parameters

mass1	mass of the larger body - in Solar Masses
mass2	mass of the smaller body - in Solar Masses
Luminosity_Distance	Luminosity Distance in Mpc
spin2	spin vector of the larger body {sx,sy,sz}
phi_c	spin vector of the smaller body {sx,sy,sz}
t_c	coalescence phase
sky_average	coalescence time

8.25.2 Member Data Documentation

8.25.2.1 chi_a

```
template<class T>
T source_parameters< T >::chi_a
```

Antisymmetric spin combination

8.25.2.2 chi_eff

```
template<class T>
T source_parameters< T >::chi_eff
```

Effective spin

8.25.2.3 chi_pn

```
template<class T>
T source_parameters< T >::chi_pn
```

PN spin

8.25.2.4 chi_s

```
template<class T>
T source_parameters< T >::chi_s
```

Symmetric spin combination

8.25.2.5 chirpmass

```
template<class T>
T source_parameters< T >::chirpmass
```

Chirp mass of the binary

8.25.2.6 delta_mass

```
template<class T>
T source_parameters< T >::delta_mass
```

Delta mass comibination

8.25.2.7 DL

```
template<class T>
T source_parameters< T >::DL
```

Luminoisity Distance

8.25.2.8 eta

```
template<class T>
T source_parameters< T >::eta
```

Symmetric mass ratio

8.25.2.9 f1

```
template<class T>
T source_parameters< T >::f1
```

Transition Frequency 1 for the amplitude

8.25.2.10 f1_phase

```
template<class T>
T source_parameters< T >::f1_phase
```

Transition frequency 1 for the phase

8.25.2.11 f2_phase

```
template<class T>
T source_parameters< T >::f2_phase
```

Transition frequency 2 for the phase

8.25.2.12 f3

```
template<class T>
T source_parameters< T >::f3
```

Transition Frequency 2 for the amplitude

8.25.2.13 fdamp

```
template<class T>
T source_parameters< T >::fdamp
```

Dampening frequency after merger

8.25.2.14 fRD

```
template<class T>
T source_parameters< T >::fRD
```

Ringdown frequency after merger

8.25.2.15 M

```
template<class T>
T source_parameters< T >::M
```

Total mass

8.25.2.16 mass1

```
template<class T>
T source_parameters< T >::mass1
```

mass of the larger component

8.25.2.17 mass2

```
template<class T>
T source_parameters< T >::mass2
```

mass of the smaller component

8.25.2.18 Nmod

```
template<class T>
int source_parameters< T >::Nmod
```

Number of modifications to phase

8.25.2.19 phic

```
template<class T>
T source_parameters< T >::phic
```

Coalescence phase

8.25.2.20 spin1x

```
template<class T>
T source_parameters< T >::spin1x
```

x-Spin component of the larger body

8.25.2.21 spin1y

```
template<class T>
T source_parameters< T >::spin1y
```

y-Spin component of the larger body

8.25.2.22 spin1z

```
template<class T>
T source_parameters< T >::spin1z
```

z-Spin component of the larger body

8.25.2.23 spin2x

```
template<class T>
T source_parameters< T >::spin2x
```

x-Spin component of the smaller body

8.25.2.24 spin2y

```
template<class T>
T source_parameters< T >::spin2y
```

y-Spin component of the smaller body

8.25.2.25 spin2z

```
template<class T>
T source_parameters< T >::spin2z
```

z-Spin component of the smaller body

8.25.2.26 tc

```
template<class T>
T source_parameters< T >::tc
```

Coalescence time

The documentation for this struct was generated from the following files:

- include/util.h
- src/util.cpp

8.26 sph_harm< T > Struct Template Reference

Public Attributes

- std::complex< T > **Y22**
- std::complex< T > **Y21**
- std::complex< T > **Y20**
- std::complex< T > **Y2m1**
- std::complex< T > **Y2m2**

The documentation for this struct was generated from the following file:

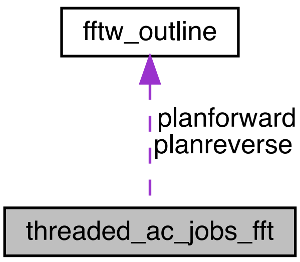
- include/util.h

8.27 threaded_ac_jobs_fft Class Reference

Class to contain spectral method jobs.

```
#include <autocorrelation.h>
```

Collaboration diagram for threaded_ac_jobs_fft:



Public Attributes

- double ** **data**
- int * length
- int * start
- int * end
- int dimension
- fftw_outline * planforward
- fftw_outline * planreverse
- int * lag
- double * target

8.27.1 Detailed Description

Class to contain spectral method jobs.

8.27.2 Member Data Documentation

8.27.2.1 dimension

`int threaded_ac_jobs_fft::dimension`

Read only – end index

8.27.2.2 end

`int* threaded_ac_jobs_fft::end`

Read only – start index

8.27.2.3 lag

`int* threaded_ac_jobs_fft::lag`

fftw plan to use for spectral method

8.27.2.4 length

`int* threaded_ac_jobs_fft::length`

Read only – Data to use – full chain

8.27.2.5 planforward

```
fftw_outline* threaded_ac_jobs_fft::planforward
```

Read only – dimension being analyzed

8.27.2.6 planreverse

```
fftw_outline* threaded_ac_jobs_fft::planreverse
```

fftw plan to use for spectral method

8.27.2.7 start

```
int* threaded_ac_jobs_fft::start
```

Read only – length of total data

8.27.2.8 target

```
double* threaded_ac_jobs_fft::target
```

READ AND WRITE – final lag

The documentation for this class was generated from the following file:

- include/autocorrelation.h

8.28 threaded_ac_jobs_serial Class Reference

Class to contain serial method jobs.

```
#include <autocorrelation.h>
```

Public Attributes

- double ** **data**
- int * length
- int * start
- int * end
- int dimension
- int * lag
- double * target

8.28.1 Detailed Description

Class to contain serial method jobs.

8.28.2 Member Data Documentation

8.28.2.1 dimension

`int threaded_ac_jobs_serial::dimension`

Read only – end index

8.28.2.2 end

`int* threaded_ac_jobs_serial::end`

Read only – start index

8.28.2.3 lag

`int* threaded_ac_jobs_serial::lag`

Read only – dimension being analyzed

8.28.2.4 length

`int* threaded_ac_jobs_serial::length`

Read only – Data to use – full chain

8.28.2.5 start

`int* threaded_ac_jobs_serial::start`

Read only – length of total data

8.28.2.6 target

`double* threaded_ac_jobs_serial::target`

READ AND WRITE – final lag

The documentation for this class was generated from the following file:

- include/autocorrelation.h

8.29 threadPool< jobtype, comparator > Class Template Reference

Class for creating a pool of threads to asynchronously distribute work.

```
#include <threadPool.h>
```

Public Member Functions

- threadPool (std::size_t numThreads, std::function< void(int, jobtype)> work_fn)

    Constructor – starts thread pool running.
- ∼threadPool ()

    Destructor – stops threads.
- void enqueue (jobtype job_id)

    Places jobs in queue to wait for scheduling.
- int get_num_threads ()

    Get the number of threads being used by the thread pool.
- int get_queue_length ()

    Get the current length of the job queue.

8.29.1 Detailed Description

template<class jobtype = int, class comparator = default_comp<jobtype>>
class threadPool< jobtype, comparator >

Class for creating a pool of threads to asynchronously distribute work.

Template parameters:

jobtype defines a structure or class that represents a job or task

comparator defines how to compare jobs for sorting the list

Default options correspond to jobs being defined by an integer job_id, and no sorting of the list (first in first out)

8.29.2 Member Function Documentation

8.29.2.1 enqueue()

```
template<class jobtype = int, class comparator = default_comp<jobtype>>
void threadPool< jobtype, comparator >::enqueue (
            jobtype job_id )  [inline]
```

Places jobs in queue to wait for scheduling.

job_id is sorted if a comparator is provided

The documentation for this class was generated from the following file:

- include/threadPool.h

8.30 threadPool< jobtype, comparator > Class Template Reference

Class for creating a pool of threads to asynchronously distribute work.

`#include <threadPool.h>`

Public Member Functions

- threadPool (std::size_t numThreads, std::function< void(int, jobtype)> work_fn)
  Constructor – starts thread pool running.
- ~threadPool ()
  Destructor – stops threads.
- void enqueue (jobtype job_id)
  Places jobs in queue to wait for scheduling.
- int get_num_threads ()
  Get the number of threads being used by the thread pool.
- int get_queue_length ()
  Get the current length of the job queue.

8.30.1 Detailed Description

template<class jobtype = int, class comparator = default_comp<jobtype>>
class threadPool< jobtype, comparator >

Class for creating a pool of threads to asynchronously distribute work.

Template parameters:

jobtype defines a structure or class that represents a job or task

comparator defines how to compare jobs for sorting the list

Default options correspond to jobs being defined by an integer job_id, and no sorting of the list (first in first out)

8.30.2 Member Function Documentation

8.30.2.1 enqueue()

```
template<class jobtype = int, class comparator = default_comp<jobtype>>
void threadPool< jobtype, comparator >::enqueue (
            jobtype job_id ) [inline]
```

Places jobs in queue to wait for scheduling.

job_id is sorted if a comparator is provided

The documentation for this class was generated from the following file:

- include/threadPool.h

8.31 useful_powers< T > Struct Template Reference

To speed up calculations within the for loops, we pre-calculate reoccuring powers of M∗F and Pi, since the pow() function is prohibatively slow.

```
#include <util.h>
```

Public Attributes

- T **MFthird**
- T **MFsixth**
- T **MF7sixth**
- T **MF2third**
- T **MF4third**
- T **MF5third**
- T **MFsquare**
- T **MF7third**
- T **MF8third**
- T **MFcube**
- T **MFminus_5third**
- T **MF3fourth**
- double **PIsquare**
- double **PIcube**
- double **PIthird**
- double **PI2third**
- double **PI4third**
- double **PI5third**
- double **PI7third**
- double **PIminus_5third**

8.31.1 Detailed Description

template<class T>
struct useful_powers< T >

To speed up calculations within the for loops, we pre-calculate reoccuring powers of M∗F and Pi, since the pow() function is prohibatively slow.

Powers of PI are initialized once, and powers of MF need to be calculated once per for loop (if in the inspiral portion).

use the functions precalc_powers_ins_amp, precalc_powers_ins_phase, precalc_powers_pi to initialize

The documentation for this struct was generated from the following file:

- include/util.h

Chapter 9

File Documentation

9.1 gw_analysis_tools_py/src/mcmc_routines_ext.pyx File Reference

File that wraps the code in mcmc_gw.cpp, mcmc_sampler.cpp, mcmc_sampler_internals.cpp, autocorrelation.cpp.

Classes

- class mcmc_routines_ext.fftw_outline_py

Functions

- def **mcmc_routines_ext.write_auto_corr_file_from_data_file_py** (string, autocorr_filename, string, datafile, int, length, int, dimension, int, num_segments, double, target_corr, int, num_threads)
- def **mcmc_routines_ext.arange** (string, autocorr_filename, :1] data, int length, int dimension, int num_segments, double target_corr, int num_threads):#Not ideal -- have to wrap the memview in a real c++array cdef double **temparr=< double ** >malloc(sizeof(double *double, length)
- def **mcmc_routines_ext.allocate_FFTW_mem_forward_py** (fftw_outline_py, plan, int, length)
- def **mcmc_routines_ext.deallocate_FFTW_mem_py** (fftw_outline_py, plan)

9.1.1 Detailed Description

File that wraps the code in mcmc_gw.cpp, mcmc_sampler.cpp, mcmc_sampler_internals.cpp, autocorrelation.cpp.

9.2 gw_analysis_tools_py/src/waveform_generator_ext.pyx File Reference

File that contains cython code to wrap the c++ library.

Classes

- class waveform_generator_ext.gen_params_py

  Python wrapper for the generation parameters structure, as defined in util.cpp.

Namespaces

- waveform_generator_ext

    Python wrapper for the waveform generation in waveform_generator.cpp.

Functions

- def **waveform_generator_ext.double** (self, double, mass1, double, mass2, double, DL, spin1, spin2, double, phic, double, tc, :1] bppe, double[::1] betappe, int Nmod, double theta, double phi, double incl_angle, double f_ref, double phiRef, bool NSflag):self.params.mass1=mass1 self.params.mass2=mass2 self.params.Luminosity_Distance=DL self.params.spin1=spin1 self.params.spin2=spin2 self.params.phic=phic self.params.tc=tc self.params.bppe=&bppe[0] self.params.betappe=&betappe[0] self.params.Nmod=Nmod self.params.incl_angle=incl_angle self.params.theta=theta self.params.phi=phi self.params.f_ref=f_ref self.params.phiRef=phiRef self.params.NSflag=NSflag ##Computes the waveform in Fourier space # @param frequencies The array of frequencies to use # @param generation_method Method to use for the waveform generation # @param gen_params_py Parameters of the binary def fourier_waveform_py(double[::1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] waveform_real=np.ascontiguousarray(np.zeros((frequencies.size) int, dtype=np.float64)
- def **waveform_generator_ext.double** (:1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] amplitude=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64, frequencies, frequencies, size, amplitude, generation_method, parameters, params, :1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] phase=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64, frequencies, frequencies, size, phase, generation_method, parameters, params, :1] frequencies, string generation_method, gen_params_py parameters):cdef double[::1] waveform_plus_real=np.ascontiguousarray(np.zeros((frequencies.size) double, dtype=np.float64)

Variables

- **waveform_generator_ext.complex128_t**
- **waveform_generator_ext.ndim**
- **waveform_generator_ext.waveform**
- **waveform_generator_ext.dtype**
- **waveform_generator_ext.i** = i +1

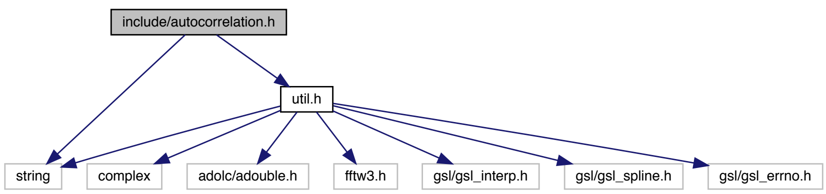
9.2.1 Detailed Description

File that contains cython code to wrap the c++ library.

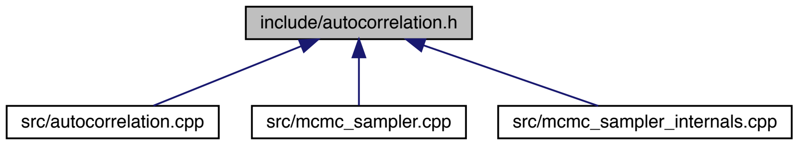
9.3 include/autocorrelation.h File Reference

```
#include <string>
#include "util.h"
```

Include dependency graph for autocorrelation.h:



This graph shows which files directly or indirectly include this file:



Classes

- class threaded_ac_jobs_fft

  Class to contain spectral method jobs.
- class threaded_ac_jobs_serial

  Class to contain serial method jobs.
- class comparator_ac_fft

  comparator to sort ac-jobs
- class comparator_ac_serial

  comparator to sort ac-jobs

Functions

- void write_auto_corr_file_from_data_file (std::string autocorr_filename, std::string datafile, int length, int dimension, int num_segments, double target_corr, int num_threads)
- void write_auto_corr_file_from_data (std::string autocorr_filename, double ∗∗data, int length, int dimension, int num_segments, double target_corr, int num_threads)

  Writes the autocorrelation file from a data array.
- void auto_corr_from_data (double ∗∗data, int length, int dimension, int ∗∗output, int num_segments, double target_corr, int num_threads)

  Calculates the autocorrelation length for a set of data for a number of segments for each dimension – completely host code, utilitizes FFTW3 for longer chuncks of the chains.
- void threaded_ac_spectral (int thread, threaded_ac_jobs_fft job)

  Internal routine to calculate an spectral autocorrelation job.
- void threaded_ac_serial (int thread, threaded_ac_jobs_serial job)

  Internal routine to calculate an serial autocorrelation job.
- double auto_correlation_serial (double ∗arr, int length, int start, double target)

  Calculates the autocorrelation of a chain with the brute force method.
- void auto_correlation_spectral (double ∗chain, int length, double ∗autocorr, fftw_outline ∗plan_forw, fftw_outline ∗plan_rev)

  Wrapper function for convience – assumes the data array starts at 0.
- void auto_correlation_spectral (double ∗chain, int length, int start, double ∗autocorr, fftw_outline ∗plan_forw, fftw_outline ∗plan_rev)

  Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT – accepts FFTW plan as argument for plan reuse and multi-threaded applications.
- void auto_correlation_spectral (double ∗chain, int length, double ∗autocorr)

  Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT.
- double auto_correlation (double ∗arr, int length, double tolerance)

  OUTDATED – numerically finds autocorrelation length – not reliable.

- double auto_correlation_serial_old (double ∗arr, int length)

  OUTDATED Calculates the autocorrelation – less general version.
- double auto_correlation_grid_search (double ∗arr, int length, int box_num=10, int final_length=50, double target_length=.01)

  OUTDATED – Grid search method of computing the autocorrelation – unreliable.
- double auto_correlation_internal (double ∗arr, int length, int lag, double ave)

  Internal function to compute the auto correlation for a given lag.
- void auto_corr_intervals_outdated (double ∗data, int length, double ∗output, int num_segments, double accuracy)

  Function that computes the autocorrelation length on an array of data at set intervals to help determine convergence.
- void write_auto_corr_file_from_data (std::string autocorr_filename, double ∗∗output, int intervals, int dimension, int N_steps)

  OUTDATED – writes autocorrelation lengths for a data array, but only with the serial method and only for a target correlation of .01.
- void write_auto_corr_file_from_data_file (std::string autocorr_filename, std::string output_file, int intervals, int dimension, int N_steps)

  OUTDATED – writes autocorrelation lengths for a data file, but only with the serial method and only for a target correlation of .01.

9.3.1 Detailed Description

Autocorrelation header file

9.3.2 Function Documentation

9.3.2.1 auto_corr_from_data()

```
void auto_corr_from_data (
            double ** data,
            int length,
            int dimension,
            int ** output,
            int num_segments,
            double target_corr,
            int num_threads )
```

Calculates the autocorrelation length for a set of data for a number of segments for each dimension – completely host code, utilitizes FFTW3 for longer chuncks of the chains.

Takes in the data from a sampler, shape data[N_steps][dimension]

Outputs lags that correspond to the target_corr – shape output[dimension][num_segments]

Parameters

	data	Input data
	length	length of input data
	dimension	dimension of data
out	*output*	array that stores the auto-corr lengths – array[num_segments]
	num_segments	number of segements to compute the auto-corr length
	target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
	num_threads	Total number of threads to use

9.3.2.2 auto_corr_intervals_outdated()

```
void auto_corr_intervals_outdated (
            double * data,
            int length,
            double * output,
            int num_segments,
            double accuracy )
```

Function that computes the autocorrelation length on an array of data at set intervals to help determine convergence.

outdated version – new version uses FFTs

Parameters

	data	Input data
	length	length of input data
out	*output*	array that stores the auto-corr lengths – array[num_segments]
	num_segments	number of segements to compute the auto-corr length
	accuracy	longer chains are computed numerically, this specifies the tolerance

9.3.2.3 auto_correlation_grid_search()

```
double auto_correlation_grid_search (
            double * arr,
            int length,
            int box_num,
            int final_length,
            double target_length )
```

OUTDATED – Grid search method of computing the autocorrelation – unreliable.

Hopefully more reliable than the box-search method, which can sometimes get caught in a recursive loop when the stepsize isn't tuned, but also faster than the basic linear, serial search

Parameters

arr	Input array to use for autocorrelation
length	Length of input array
box_num	number of boxes to use for each iteration, default is 10
final_length	number of elements per box at which the grid search ends and the serial calculation begins
target_length	target correlation that corresponds to the returned lag

9.3.2.4 auto_correlation_internal()

```
double auto_correlation_internal (
            double * arr,
            int length,
            int lag,
            double ave )
```

Internal function to compute the auto correlation for a given lag.

9.3.2.5 auto_correlation_serial()

```
double auto_correlation_serial (
            double * arr,
            int length,
            int start,
            double target )
```

Calculates the autocorrelation of a chain with the brute force method.

Parameters

arr	input array
length	Length of input array
start	starting index (probably 0)
target	Target autocorrelation for which ``length'' is defined

9.3.2.6 auto_correlation_spectral() [1/2]

```
void auto_correlation_spectral (
            double * chain,
            int length,
            int start,
            double * autocorr,
            fftw_outline * plan_forw,
            fftw_outline * plan_rev )
```

Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT – accepts FFTW plan as argument for plan reuse and multi-threaded applications.

Based on the Wiener-Khinchin Theorem.

Algorithm used from `https://lingpipe-blog.com/2012/06/08/autocorrelation-fft-kiss-eigen/`

NOTE the length used in initializing the fftw plans should be L = pow(2, std::ceil(std::log2(length))) – the plans are padded so the total length is a power of two

Option to provide starting index for multi-dimension arrays in collapsed to one dimension

length is the length of the segment to be analyzed, not necessarily the dimension of the chain

9.3.2.7 auto_correlation_spectral() [2/2]

```
void auto_correlation_spectral (
            double * chain,
            int length,
            double * autocorr )
```

Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT.

Based on the Wiener-Khinchin Theorem.

Algorithm used from https://lingpipe-blog.com/2012/06/08/autocorrelation-fft-kiss-eigen/

9.3.2.8 threaded_ac_serial()

```
void threaded_ac_serial (
            int thread,
            threaded_ac_jobs_serial job )
```

Internal routine to calculate an serial autocorrelation job.

Allows for a more efficient use of the threadPool class

9.3.2.9 threaded_ac_spectral()

```
void threaded_ac_spectral (
            int thread,
            threaded_ac_jobs_fft job )
```

Internal routine to calculate an spectral autocorrelation job.

Allows for a more efficient use of the threadPool class

9.3.2.10 write_auto_corr_file_from_data()

```
void write_auto_corr_file_from_data (
            std::string autocorr_filename,
            double ** data,
            int length,
            int dimension,
            int num_segments,
            double target_corr,
            int num_threads )
```

Writes the autocorrelation file from a data array.

Parameters

autocorr_filename	Name of the file to write the autocorrelation to
data	Input chains
length	length of input data
dimension	dimension of data
num_segments	number of segements to compute the auto-corr length
target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
num_threads	Total number of threads to use

9.3.2.11 write_auto_corr_file_from_data_file()

```
void write_auto_corr_file_from_data_file (
            std::string autocorr_filename,
            std::string datafile,
            int length,
            int dimension,
            int num_segments,
            double target_corr,
            int num_threads )
```

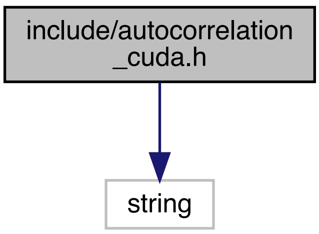
Parameters

length	length of input data
dimension	dimension of data
num_segments	number of segements to compute the auto-corr length
target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
num_threads	Total number of threads to use

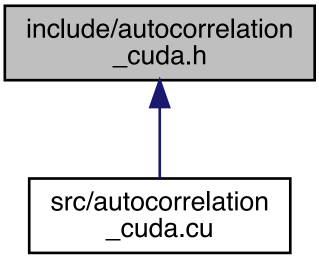
9.4 include/autocorrelation_cuda.h File Reference

```
#include <string>
```

Include dependency graph for autocorrelation_cuda.h:



This graph shows which files directly or indirectly include this file:



Macros

- #define **THREADS_PER_BLOCK** 512

Functions

- void write_file_auto_corr_from_data_file_accel (std::string acfile, std::string chains_file, int dimension, int N_steps, int num_segments, double target_corr)

    Write data file for autocorrelation lengths of the data given a data file name, as written by the mcmc_sampler.
- void write_file_auto_corr_from_data_accel (std::string acfile, double **output, int dimension, int N_steps, int num_segments, double target_corr)

    Write data file given output chains, as formatted by the mcmc_sampler.
- void auto_corr_from_data_accel (double **output, int dimension, int N_steps, int num_segments, double target_corr, double **autocorr)

    Find autocorrelation of data at different points in the chain length and output to autocorr.
- void launch_ac_gpu (int device, int element, double **data, int length, int dimension, double target_corr, int num_segments)

    Launch the GPU kernel, formatted for the thread pool.
- void ac_gpu_wrapper (int thread, int job_id)

    Wrapper function for the thread pool.
- void **auto_correlation_spectral_accel** (double *chains, int length, double *autocorr)

9.4.1 Detailed Description

Header file for CUDA accelerated algorithms

Currently, no algorithms are used in any other parts of the project, so if CUDA or CUDA-enabled devices are not available, this file can be skipped in compilation by commenting out the OBJECTSCUDA line in the makefile

9.4.2 Function Documentation

9.4.2.1 ac_gpu_wrapper()

```
void ac_gpu_wrapper (
            int thread,
            int job_id )
```

Wrapper function for the thread pool.

Parameters

thread	Host thread
job_id	Job ID

9.4.2.2 auto_corr_from_data_accel()

```
void auto_corr_from_data_accel (
            double ** output,
            int dimension,
            int N_steps,
            int num_segments,
            double target_corr,
            double ** autocorr )
```

Find autocorrelation of data at different points in the chain length and output to autocorr.

Parameters

	output	Chain data input
	dimension	Dimension of the data
	N_steps	Number of steps in the data
	num_segments	number of segments to calculate the autocorrelation length
	target_corr	Target correlation ratio
out	*autocorr*	Autocorrelation lengths for the different segments

9.4.2.3 write_file_auto_corr_from_data_accel()

```
void write_file_auto_corr_from_data_accel (
            std::string acfile,
            double ** output,
            int dimension,
            int N_steps,
            int num_segments,
            double target_corr )
```

Write data file given output chains, as formatted by the mcmc_sampler.

Parameters

acfile	Output autocorrelation filename
output	Chain data from MCMC_sampler
dimension	Dimension of the data
N_steps	Number of steps in the chain
num_segments	Number of segments to check the autocorrelation length for each dimension
target_corr	Target correlation ratio to use for the correlation length calculation

9.4.2.4 write_file_auto_corr_from_data_file_accel()

```
void write_file_auto_corr_from_data_file_accel (
            std::string acfile,
            std::string chains_file,
            int dimension,
            int N_steps,
            int num_segments,
            double target_corr )
```

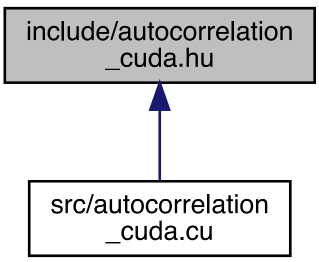
Write data file for autocorrelation lengths of the data given a data file name, as written by the mcmc_sampler.

Parameters

acfile	Filename of the autocorrelation data
chains_file	Filename of the data file for the chains
dimension	Dimension of the data
N_steps	Number of steps in the chain
num_segments	Number of segments to check the autocorrelation length for each dimension
target_corr	Target correlation ratio to use for the correlation length calculation

9.5 include/autocorrelation_cuda.hu File Reference

This graph shows which files directly or indirectly include this file:



Classes

- struct GPUplan

Functions

- __device__ __host__ void auto_corr_internal (double ∗arr, int length, int lag, double average, double ∗corr, int start_id)

  Internal function to calculate the autocorrelation for a given lag Customized for the thread pool architecture, with extra arguments because of the way the memory is allocated.
- __global__ void auto_corr_internal_kernal (double ∗arr, int length, double average, int ∗rho_index, double target_corr, double var, int start_id)

  Internal function to launch the CUDA kernel for a range of autocorrelations.
- void allocate_gpu_plan (GPUplan ∗plan, int data_length, int dimension, int num_segments)

  Allocates memory for autocorrelation–GPU structure.
- void deallocate_gpu_plan (GPUplan ∗plan, int data_length, int dimension, int num_segments)

  Deallocates memory for the autocorrelation–GPU structure.
- void copy_data_to_device (GPUplan ∗plan, double ∗∗input_data, int data_length, int dimension, int num_↩ segments)

  Copy data to device before starting kernels.

9.5.1 Function Documentation

9.5.1.1 allocate_gpu_plan()

```
void allocate_gpu_plan (
            GPUplan * plan,
            int data_length,
            int dimension,
            int num_segments )
```

Allocates memory for autocorrelation–GPU structure.

Parameters

plan	Structure for GPU plan
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

9.5.1.2 auto_corr_internal()

```
__device__ __host__ void auto_corr_internal (
            double * arr,
```

```
            int length,
            int lag,
            double average,
            double * corr,
            int start_id )
```

Internal function to calculate the autocorrelation for a given lag Customized for the thread pool architecture, with extra arguments because of the way the memory is allocated.

Parameters

	arr	Input array of data
	length	Length of input array
	lag	Lag to be used to calculate the correlation
	average	Average of the array arr
out	*corr*	output correlation
	start_id	ID of location to start calculation – input arrary arr is assumed to be contiguous for multiple dimensions

9.5.1.3 auto_corr_internal_kernal()

```
__global__ void auto_corr_internal_kernal (
            double * arr,
            int length,
            double average,
            int * rho_index,
            double target_corr,
            double var,
            int start_id )
```

Internal function to launch the CUDA kernel for a range of autocorrelations.

Correlation function used:

rho(lag) = 1 / (length - lag) \sum (arr[i+lag]-average) (arr[i]- average)

target_corr = rho(rho_index)/rho(0) = rho(rho_index)/var

Parameters

	arr	Input array of data
	length	Length of data array
	average	Average of input data
out	*rho_index*	Index of the lag that results ina correlation ratio target_corr
	target_corr	Target correlation ratio rho(lag)/rho(0) = target_corr
	var	Variance rho(0)
	start_id	Starting index to use for the data array arr

9.5.1.4 copy_data_to_device()

```
void copy_data_to_device (
            GPUplan * plan,
            double ** input_data,
            int data_length,
            int dimension,
            int num_segments )
```

Copy data to device before starting kernels.

Parameters

plan	GPU plan
input_data	Input chain data
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

9.5.1.5 deallocate_gpu_plan()

```
void deallocate_gpu_plan (
            GPUplan * plan,
            int data_length,
            int dimension,
            int num_segments )
```

Deallocates memory for the autocorrelation–GPU structure.

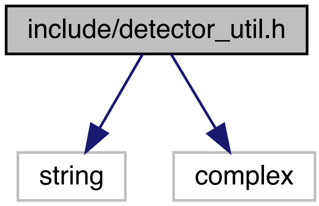
Parameters

plan	Structure for the GPU plan
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

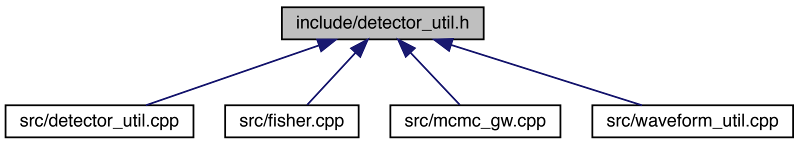
9.6 include/detector_util.h File Reference

```
#include <string>
#include <complex>
```

Include dependency graph for detector_util.h:



This graph shows which files directly or indirectly include this file:



Functions

- void populate_noise (double ∗frequencies, std::string detector, double ∗noise_root, int length=0)

    Function to populate the squareroot of the noise curve for various detectors.
- double aLIGO_analytic (double f)

    Analytic function approximating the PSD for aLIGO.
- std::complex< double > Q (double theta, double phi, double iota)

    Utility for the overall amplitude and phase shift for spin-aligned systems.
- double right_interferometer_cross (double theta, double phi)

    Response function of a 90 deg interferometer for cross polarization.
- double right_interferometer_plus (double theta, double phi)

    Response function of a 90 deg interferometer for plus polarization.
- double Hanford_O1_fitted (double f)

    Numerically fit PSD to the Hanford Detector's O1.
- void celestial_horizon_transform (double RA, double DEC, double gps_time, std::string detector, double ∗phi, double ∗theta)

    Transform from celestial coordinates to local horizontal coords.
- void derivative_celestial_horizon_transform (double RA, double DEC, double gps_time, std::string detector, double ∗dphi_dRA, double ∗dtheta_dRA, double ∗dphi_dDEC, double ∗dtheta_dDEC)

    Numerical derivative of the transformation.
- double DTOA (double theta1, double theta2, std::string detector1, std::string detector2)

    calculate difference in time of arrival (DTOA) for a given source location and 2 different detectors
- double radius_at_lat (double latitude, double elevation)

- void detector_response_functions_equatorial (double D[3][3], double ra, double dec, double psi, double gmst, double ∗Fplus, double ∗Fcross)

  Calculates the response coefficients for a detector with response tensor D for a source at RA, Dec, and psi.
- void detector_response_functions_equatorial (std::string detector, double ra, double dec, double psi, double gmst, double ∗Fplus, double ∗Fcross)

  Same as the other function, but for active detectors.

Variables

- const double **H_LAT** =0.81079526383
- const double **H_LONG** =-2.08405676917
- const double **H_azimuth_offset** = 2.199
- const double **H_radius** = 6367299.93401105
- const double **H_elevation** = 142.554
- const double **L_LAT** =0.53342313506
- const double **L_LONG** =-1.58430937078
- const double **L_azimuth_offset** = 3.4557
- const double **L_radius** = 6372795.50144497
- const double **L_elevation** = -6.574
- const double **V_LAT** =0.76151183984
- const double **V_LONG** =0.18333805213
- const double **V_azimuth_offset** = 1.239
- const double **V_radius** = 6368051.92301
- const double **V_elevation** = 51.884
- const double **RE_polar** =6357e3
- const double **RE_equatorial** = 6378e3
- const double **Hanford_D** [3][3]
- const double **Livingston_D** [3][3]
- const double **Virgo_D** [3][3]

9.6.1 Detailed Description

Header file for all detector-specific utilities

9.6.2 Function Documentation

9.6.2.1 aLIGO_analytic()

```
double aLIGO_analytic (
            double f )
```

Analytic function approximating the PSD for aLIGO.

CITE (Will?)

9.6.2.2 celestial_horizon_transform()

```
void celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            std::string detector,
            double * phi,
            double * theta )
```

Transform from celestial coordinates to local horizontal coords.

(RA,DEC) -> (altitude, azimuth)

Need gps_time of transformation, as the horizontal coords change in time

detector is used to specify the lat and long of the local frame

Parameters

RA	in RAD
DEC	in RAD
phi	in RAD
theta	in RAD

9.6.2.3 derivative_celestial_horizon_transform()

```
void derivative_celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            std::string detector,
            double * dphi_dRA,
            double * dtheta_dRA,
            double * dphi_dDEC,
            double * dtheta_dDEC )
```

Numerical derivative of the transformation.

Planned for use in Fisher calculations, but not currently implemented anywhere

Parameters

RA	in RAD
DEC	in RAD

9.6.2.4 detector_response_functions_equatorial() [1/2]

```
void detector_response_functions_equatorial (
```

```
double D[3][3],
double ra,
double dec,
double psi,
double gmst,
double * Fplus,
double * Fcross )
```

Calculates the response coefficients for a detector with response tensor D for a source at RA, Dec, and psi.

Taken from LALSuite

The response tensor for each of the operational detectors is precomputed in detector_util.h, but to create a new tensor, follow the outline in Anderson et al 36 PRD 63 042003 (2001) Appendix B

Parameters

	D	Detector Response tensor (3x3)
	ra	Right ascension in rad
	dec	Declination in rad
	psi	polarization angle in rad
	gmst	Greenwich mean sidereal time (rad)
out	*Fplus*	Fplus response coefficient
out	*Fcross*	Fcross response coefficient

9.6.2.5 detector_response_functions_equatorial() [2/2]

```
void detector_response_functions_equatorial (
            std::string detector,
            double ra,
            double dec,
            double psi,
            double gmst,
            double * Fplus,
            double * Fcross )
```

Same as the other function, but for active detectors.

Parameters

	detector	Detector
	ra	Right ascension in rad
	dec	Declination in rad
	psi	polarization angle in rad
	gmst	Greenwich mean sidereal time (rad)
out	*Fplus*	Fplus response coefficient
out	*Fcross*	Fcross response coefficient

9.6.2.6 DTOA()

```
double DTOA (
            double theta1,
            double theta2,
            std::string detector1,
            std::string detector2 )
```

calculate difference in time of arrival (DTOA) for a given source location and 2 different detectors

Parameters

theta1	spherical polar angle for detector 1 in RAD
theta2	spherical polar angle for detector 2 in RAD
detector1	name of detector one
detector2	name of detector two

9.6.2.7 Hanford_O1_fitted()

```
double Hanford_O1_fitted (
            double f )
```

Numerically fit PSD to the Hanford Detector's O1.

CITE (Yunes?)

9.6.2.8 populate_noise()

```
void populate_noise (
            double * frequencies,
            std::string detector,
            double * noise_root,
            int length )
```

Function to populate the squareroot of the noise curve for various detectors.

If frequencies are left as NULL, standard frequency spacing is applied and the frequencies are returned, in which case the frequencies argument becomes an output array

Detector names must be spelled exactly

Detectors include: aLIGO_analytic, Hanford_O1_fitted

Parameters

frequencies	double array of frquencies (NULL)
detector	String to designate the detector noise curve to be used
noise_root	ouptput double array for the square root of the PSD of the noise of the specified detector
length	integer length of the output and input arrays

9.6.2.9 Q()

```
std::complex<double> Q (
            double theta,
            double phi,
            double iota )
```

Utility for the overall amplitude and phase shift for spin-aligned systems.

For spin aligned, all the extrinsic parameters have the effect of an overall amplitude modulation and phase shift

9.6.2.10 radius_at_lat()

```
double radius_at_lat (
            double latitude,
            double elevation )
```

/brief Analytic approximation of the radius from the center of earth to a given location

Just the raidus as a function of angles, modelling an oblate spheroid

Parameters

latitude	latitude in degrees
elevation	elevation in meters

9.6.2.11 right_interferometer_cross()

```
double right_interferometer_cross (
            double theta,
            double phi )
```

Response function of a 90 deg interferometer for cross polarization.

Theta and phi are local, horizontal coordinates relative to the detector

9.6.2.12 right_interferometer_plus()

```
double right_interferometer_plus (
            double theta,
            double phi )
```

Response function of a 90 deg interferometer for plus polarization.

Theta and phi are local, horizontal coordinates relative to the detector

9.6.3 Variable Documentation

9.6.3.1 Hanford_D

```
const double Hanford_D[3][3]
```

Initial value:
```
= {{-0.392632, -0.0776099, -0.247384}, {-0.0776099, 0.319499,
  0.227988}, {-0.247384, 0.227988, 0.0730968}}
```

9.6.3.2 Livingston_D

```
const double Livingston_D[3][3]
```

Initial value:
```
= {{0.411318, 0.14021,
  0.247279}, {0.14021, -0.108998, -0.181597}, {0.247279, -0.181597,
-0.302236}}
```

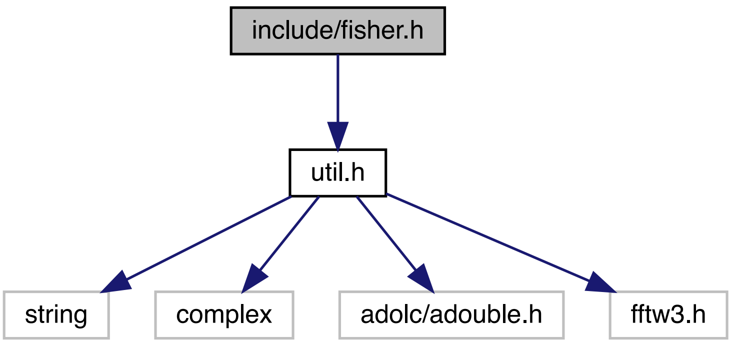
9.6.3.3 Virgo_D

```
const double Virgo_D[3][3]
```

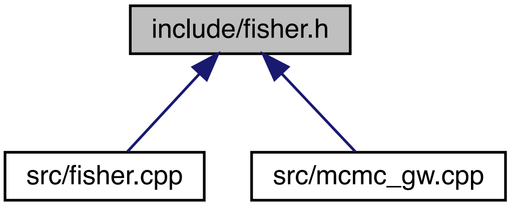
Initial value:
```
= {{0.243903, -0.0990959, -0.232603}, {-0.0990959, -0.447841,
  0.187841}, {-0.232603, 0.187841, 0.203979}}
```

9.7 include/fisher.h File Reference

```
#include "util.h"
```
Include dependency graph for fisher.h:



This graph shows which files directly or indirectly include this file:



Functions

- void fisher (double ∗frequency, int length, string generation_method, string detector, double ∗∗output, int dimension, gen_params ∗parameters, int ∗amp_tapes=NULL, int ∗phase_tapes=NULL, double ∗noise=N←ULL)

  Calculates the fisher matrix for the given arguments.
- void calculate_derivatives (double ∗∗amplitude_deriv, double ∗∗phase_deriv, double ∗amplitude, double ∗frequencies, int length, string detector, string gen_method, gen_params ∗parameters)

  Abstraction layer for handling the case separation for the different waveforms.
- void fisher_autodiff (double ∗frequency, int length, string generation_method, string detector, double ∗∗output, int dimension, gen_params ∗parameters, int ∗amp_tapes=NULL, int ∗phase_tapes=NULL, double ∗noise=NULL)

  Calculates the fisher matrix for the given arguments to within numerical error using automatic differention - slower than the numerical version.

9.7.1 Function Documentation

9.7.1.1 calculate_derivatives()

```
void calculate_derivatives (
            double ** amplitude_deriv,
            double ** phase_deriv,
            double * amplitude,
            double * frequencies,
            int length,
            string detector,
            string gen_method,
            gen_params * parameters )
```

Abstraction layer for handling the case separation for the different waveforms.

9.7.1.2 fisher()

```
void fisher (
        double * frequency,
        int length,
        string generation_method,
        string detector,
        double ** output,
        int dimension,
        gen_params * parameters,
        int * amp_tapes = NULL,
        int * phase_tapes = NULL,
        double * noise = NULL )
```

Calculates the fisher matrix for the given arguments.

Parameters

length	if 0, standard frequency range for the detector is used
output	double [dimension][dimension]
amp_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method
phase_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method

9.7.1.3 fisher_autodiff()

```
void fisher_autodiff (
        double * frequency,
        int length,
        string generation_method,
        string detector,
        double ** output,
        int dimension,
        gen_params * parameters,
        int * amp_tapes = NULL,
        int * phase_tapes = NULL,
        double * noise = NULL )
```

Calculates the fisher matrix for the given arguments to within numerical error using automatic differention - slower than the numerical version.

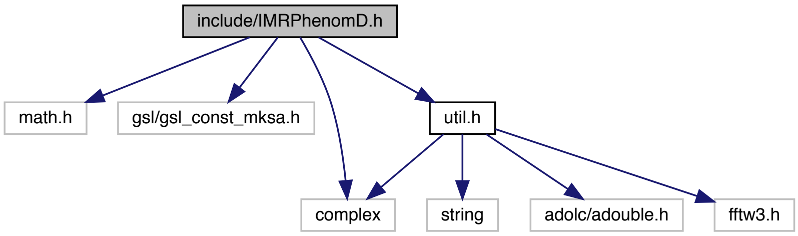
Parameters

length	if 0, standard frequency range for the detector is used
output	double [dimension][dimension]
amp_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method
phase_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method

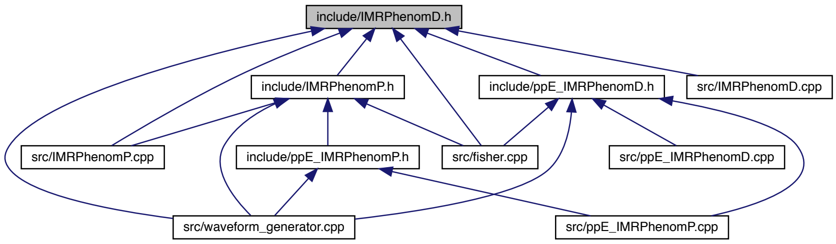
9.8 include/IMRPhenomD.h File Reference

```
#include <math.h>
#include <gsl/gsl_const_mksa.h>
#include <complex>
#include "util.h"
```

Include dependency graph for IMRPhenomD.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct lambda_parameters< T >
- class IMRPhenomD< T >

Variables

- const double lambda_num_params [19][11]

9.8.1 Detailed Description

Header file for utilities

9.8.2 Variable Documentation

9.8.2.1 lambda_num_params

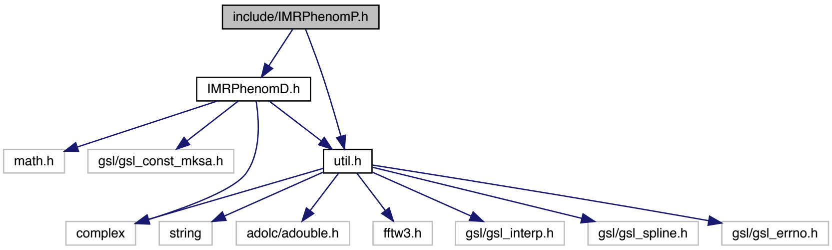
```
const double lambda_num_params[19][11]
```

Numerically calibrated parameters from arXiv:1508.07253 see the table in the data directory for labeled version

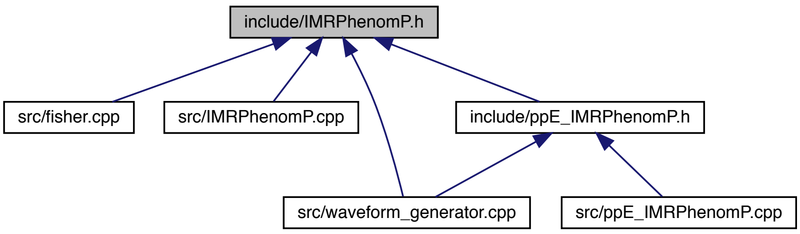
9.9 include/IMRPhenomP.h File Reference

```
#include "IMRPhenomD.h"
#include "util.h"
```

Include dependency graph for IMRPhenomP.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct alpha_coeffs< T >
- struct epsilon_coeffs< T >
- class IMRPhenomPv2< T >

9.9.1 Detailed Description

Header file for IMRPhenomP functions

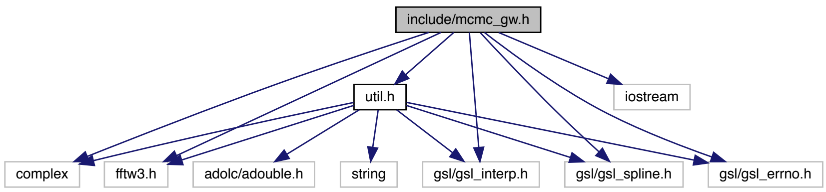
Currently, only Pv2 is supported.

Wrapped around IMRPhenomD

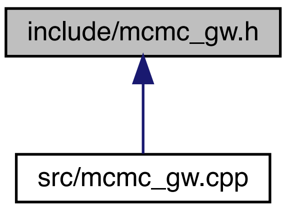
9.10 include/mcmc_gw.h File Reference

```
#include <complex>
#include <fftw3.h>
#include "util.h"
#include <iostream>
#include <gsl/gsl_interp.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_errno.h>
```

Include dependency graph for mcmc_gw.h:



This graph shows which files directly or indirectly include this file:



Functions

- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, int length, std::complex< double > ∗data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag, fftw_outline ∗plan)

  Function to calculate the log Likelihood as defined by -1/2 (d-h|d-h) maximized over the extrinsic parameters phic and tc.
- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag)
- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag, fftw_outline ∗plan)
- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, int length, std::complex< double > ∗data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag, fftw_outline ∗plan)

- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag)
- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag, fftw_outline ∗plan)
- double maximized_Log_Likelihood_aligned_spin_internal (std::complex< double > ∗data, double ∗psd, double ∗frequencies, std::complex< double > ∗detector_response, size_t length, fftw_outline ∗plan)

    Maximized match over coalescence variables - returns log likelihood NOT NORMALIZED for aligned spins.
- double Log_Likelihood (std::complex< double > ∗data, double ∗psd, double ∗frequencies, size_t length, gen_params ∗params, std::string detector, std::string generation_method, fftw_outline ∗plan)

    Unmarginalized log of the likelihood.
- double maximized_Log_Likelihood_unaligned_spin_internal (std::complex< double > ∗data, double ∗psd, double ∗frequencies, std::complex< double > ∗hplus, std::complex< double > ∗hcross, size_t length, fftw_outline ∗plan)

    log likelihood function that maximizes over extrinsic parameters tc, phic, D, and phiRef, the reference frequency - for unaligned spins
- double maximized_Log_Likelihood (std::complex< double > ∗data, double ∗psd, double ∗frequencies, size↩_t length, gen_params ∗params, std::string detector, std::string generation_method, fftw_outline ∗plan)

    routine to maximize over all extrinsic quantities and return the log likelihood
- double **maximized_Log_Likelihood** (double ∗data_real, double ∗data_imag, double ∗psd, double ∗frequencies, size_t length, gen_params ∗params, std::string detector, std::string generation_method, fftw_outline ∗plan)
- double maximized_coal_Log_Likelihood (std::complex< double > ∗data, double ∗psd, double ∗frequencies, size_t length, gen_params ∗params, std::string detector, std::string generation_method, fftw_outline ∗plan, double ∗tc, double ∗phic)

    Function to maximize only over coalescence variables tc and phic, returns the maximum values used.
- double **maximized_coal_Log_Likelihood_internal** (std::complex< double > ∗data, double ∗psd, double ∗frequencies, std::complex< double > ∗detector_response, size_t length, fftw_outline ∗plan, double ∗tc, double ∗phic)
- double Log_Likelihood_internal (std::complex< double > ∗data, double ∗psd, double ∗frequencies, std↩::complex< double > ∗detector_response, int length, fftw_outline ∗plan)

    Internal function for the unmarginalized log of the likelihood.
- void PTMCMC_MH_GW (double ∗∗∗output, int dimension, int N_steps, int chain_N, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_freq, double(∗log_prior)(double ∗param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > ∗∗data, double ∗∗noise_psd, double ∗∗frequencies, int ∗data_length, double gps_time, std::string ∗detector, int Nmod, int ∗bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_filename)

    Wrapper for the MCMC_MH function, specifically for GW analysis.
- void PTMCMC_MH_dynamic_PT_alloc_GW (double ∗∗∗output, int dimension, int N_steps, int chain_N, int max_chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp↩_freq, int t0, int nu, std::string chain_distribution_scheme, double(∗log_prior)(double ∗param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > ∗∗data, double ∗∗noise_psd, double ∗∗frequencies, int ∗data_length, double gps_time, std::string ∗detectors, int Nmod, int ∗bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_filename)

    Takes in an MCMC checkpoint file and continues the chain.
- void continue_PTMCMC_MH_GW (std::string start_checkpoint_file, double ∗∗∗output, int dimension, int N↩_steps, int swp_freq, double(∗log_prior)(double ∗param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > ∗∗data, double ∗∗noise_psd, double ∗∗frequencies, int ∗data_length, double gps_time, std::string ∗detector, int Nmod, int ∗bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string final_checkpoint_filename)

    Takes in an MCMC checkpoint file and continues the chain.

- void PTMCMC_method_specific_prep (std::string generation_method, int dimension, double *seeding_var, bool local_seeding)

    Unpacks MCMC parameters for method specific initiation.
- double **MCMC_likelihood_extrinisic** (bool save_waveform, gen_params *parameters, std::string generation_method, int *data_length, double **frequencies, std::complex< double > **data, double **psd, std::string *detectors, fftw_outline *fftw_plans, int num_detectors, double RA, double DEC, double gps_time)
- void MCMC_fisher_wrapper (double *param, int dimension, double **output, int chain_id)

    Fisher function for MCMC for GW.
- double MCMC_likelihood_wrapper (double *param, int dimension, int chain_id)

    log likelihood function for MCMC for GW

9.10.1 Detailed Description

Header file for the Graviational Wave specific MCMC routines

9.10.2 Function Documentation

9.10.2.1 continue_PTMCMC_MH_GW()

```
void continue_PTMCMC_MH_GW (
            std::string start_checkpoint_file,
            double *** output,
            int dimension,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string final_checkpoint_filename )
```

Takes in an MCMC checkpoint file and continues the chain.

Obviously, the user must be sure to correctly match the dimension, number of chains, the generation_method, the prior function, the data, psds, freqs, and the detectors (number and name), and the gps_time to the previous run, otherwise the behavior of the sampler is undefined.

numThreads and pool do not necessarily have to be the same

9.10.2.2 Log_Likelihood()

```
double Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan )
```

Unmarginalized log of the likelihood.

9.10.2.3 Log_Likelihood_internal()

```
double Log_Likelihood_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * detector_response,
            int length,
            fftw_outline * plan )
```

Internal function for the unmarginalized log of the likelihood.

$.5 * ((h | h) - 2 (D | h))$

9.10.2.4 maximized_coal_Log_Likelihood()

```
double maximized_coal_Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan,
            double * tc,
            double * phic )
```

Function to maximize only over coalescence variables tc and phic, returns the maximum values used.

9.10.2.5 maximized_coal_log_likelihood_IMRPhenomD() [1/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
            int length,
            std::complex< double > * data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag,
            fftw_outline * plan )
```

Function to calculate the log Likelihood as defined by -1/2 (d-h|d-h) maximized over the extrinsic parameters phic and tc.

frequency array must be uniform spacing - this shouldn't be a problem when working with real data as DFT return uniform spacing

Parameters

chirpmass	in solar masses

9.10.2.6 maximized_coal_log_likelihood_IMRPhenomD() [2/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag )
```

Parameters

chirpmass	in solar masses

9.10.2.7 maximized_coal_log_likelihood_IMRPhenomD() [3/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
```

```
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.10.2.8 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [1/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            int length,
            std::complex< double > * data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            double Luminosity_Distance,
            double theta,
            double phi,
            double iota,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.10.2.9 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [2/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
```

```
double spin2,
double Luminosity_Distance,
double theta,
double phi,
double iota,
bool NSflag )
```

Parameters

chirpmass	in solar masses

9.10.2.10 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [3/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            double Luminosity_Distance,
            double theta,
            double phi,
            double iota,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.10.2.11 maximized_Log_Likelihood()

```
double maximized_Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan )
```

routine to maximize over all extrinsic quantities and return the log likelihood

IMRPhenomD – maximizes over DL, phic, tc, \iota, \phi, \theta IMRPhenomP – maximizes over DL, phic,tc, \psi, \phi , \theta

9.10.2.12 maximized_Log_Likelihood_aligned_spin_internal()

```
double maximized_Log_Likelihood_aligned_spin_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * detector_response,
            size_t length,
            fftw_outline * plan )
```

Maximized match over coalescence variables - returns log likelihood NOT NORMALIZED for aligned spins.

Note: this function is not properly normalized for an absolute comparison. This is made for MCMC sampling, so to minimize time, constant terms like (Data|Data), which would cancel in the Metropolis-Hasting ratio, are left out for efficiency

9.10.2.13 maximized_Log_Likelihood_unaligned_spin_internal()

```
double maximized_Log_Likelihood_unaligned_spin_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            size_t length,
            fftw_outline * plan )
```

log likelihood function that maximizes over extrinsic parameters tc, phic, D, and phiRef, the reference frequency - for unaligned spins

Ref: arXiv 1603.02444v2

9.10.2.14 MCMC_fisher_wrapper()

```
void MCMC_fisher_wrapper (
            double * param,
            int dimension,
            double ** output,
            int chain_id )
```

Fisher function for MCMC for GW.

Wraps the fisher calculation in src/fisher.cpp and unpacks parameters correctly for common GW analysis

Supports all the method/parameter combinations found in MCMC_MH_GW

9.10.2.15 MCMC_likelihood_wrapper()

```
double MCMC_likelihood_wrapper (
            double * param,
            int dimension,
            int chain_id )
```

log likelihood function for MCMC for GW

Wraps the above likelihood functions and unpacks parameters correctly for common GW analysis

Supports all the method/parameter combinations found in MCMC_MH_GW

9.10.2.16 PTMCMC_method_specific_prep()

```
void PTMCMC_method_specific_prep (
            std::string generation_method,
            int dimension,
            double * seeding_var,
            bool local_seeding )
```

Unpacks MCMC parameters for method specific initiation.

Populates seeding vector if non supplied, populates mcmc_Nmod, populates mcmc_log_beta, populates mcmc_↩ intrinsic

9.10.2.17 PTMCMC_MH_dynamic_PT_alloc_GW()

```
void PTMCMC_MH_dynamic_PT_alloc_GW (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_filename )
```

Takes in an MCMC checkpoint file and continues the chain.

Obviously, the user must be sure to correctly match the dimension, number of chains, the generation_method, the prior function, the data, psds, freqs, and the detectors (number and name), and the gps_time to the previous run, otherwise the behavior of the sampler is undefined.

numThreads and pool do not necessarily have to be the same

9.10.2.18 PTMCMC_MH_GW()

```
void PTMCMC_MH_GW (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Wrapper for the MCMC_MH function, specifically for GW analysis.

Handles the details of setting up the MCMC sampler and wraps the fisher and log likelihood to conform to the format of the sampler

NOTE – This sampler is NOT thread safe. There is global memory declared for each call to MCMC_MH_GW, so separate samplers should not be run in the same process space

Supported parameter combinations:

IMRPhenomD - 4 dimensions – ln chirpmass, eta, chi1, chi2

IMRPhenomD - 7 dimensions – ln D_L, tc, phic, ln chirpmass, eta, chi1, chi2

IMRPhenomD - 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2

dCS_IMRPhenomD_log - 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, ln \alpha^2 (the coupling parameter)

dCS_IMRPhenomD- 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, \alpha^2 (the coupling parameter)

dCS_IMRPhenomD_root_alpha- 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, \sqrt \alpha (in km) (the coupling parameter)

IMRPhenomPv2 - 9 dimensions – cos J_N, ln chirpmass, eta, |chi1|, |chi1|, theta_1, theta_2, phi_1, phi_2

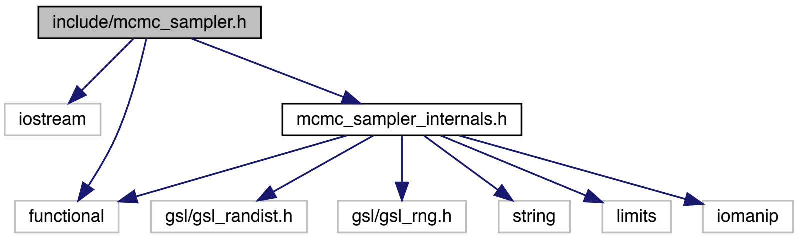
Parameters

statistics_filename	Filename to output sampling statistics, if empty string, not output
chain_filename	Filename to output data (chain 0 only), if empty string, not output
auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

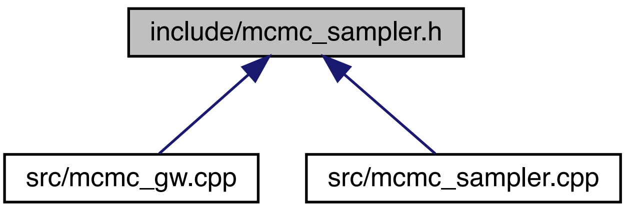
9.11 include/mcmc_sampler.h File Reference

```
#include <iostream>
#include <functional>
#include "mcmc_sampler_internals.h"
```

Include dependency graph for mcmc_sampler.h:



This graph shows which files directly or indirectly include this file:



Functions

- void **mcmc_step_threaded** (int j)
- void **mcmc_swap_threaded** (int i, int j)

- void RJPTMCMC_MH_internal (double ∗∗∗output, int ∗∗∗parameter_status, int max_dimension, int min↩ _dimension, int N_steps, int chain_N, double ∗initial_pos, int ∗initial_status, double ∗seeding_var, double ∗chain_temps, int swp_freq, std::function< double(double ∗, int ∗, int, int)> log_prior, std::function< double(double ∗, int ∗, int, int)> log_likelihood, std::function< void(double ∗, int ∗, int, double ∗∗, int)>fisher, std::function< void(double ∗, double ∗, int ∗, int ∗, int, int)> RJ_proposal, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std↩ ::string likelihood_log_filename, std::string checkpoint_file)

    Generic reversable jump sampler, where the likelihood, prior, and reversable jump proposal are parameters supplied by the user.
- void RJPTMCMC_MH (double ∗∗∗output, int ∗∗∗parameter_status, int max_dimension, int min_dimension, int N_steps, int chain_N, double ∗initial_pos, int ∗initial_status, double ∗seeding_var, double ∗chain_temps, int swp_freq, double(∗log_prior)(double ∗param, int ∗status, int max_dimension, int chain_id), double(∗log↩ _likelihood)(double ∗param, int ∗status, int max_dimension, int chain_id), void(∗fisher)(double ∗param, int ∗status, int max_dimension, double ∗∗fisher, int chain_id), void(∗RJ_proposal)(double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int max_dimension, int chain_id), int num↩ Threads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void PTMCMC_MH_dynamic_PT_alloc_internal (double ∗∗∗output, int dimension, int N_steps, int chain↩ _N, int max_chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_freq, int t0, int nu, std::string chain_distribution_scheme, std::function< double(double ∗, int ∗, int, int)> log_prior, std::function< double(double ∗, int ∗, int, int)> log_likelihood, std::function< void(double ∗, int ∗, int, double ∗∗, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_file)

    Dyanmically tunes an MCMC for optimal spacing. step width, and chain number.
- void PTMCMC_MH_dynamic_PT_alloc (double ∗∗∗output, int dimension, int N_steps, int chain_N, int max↩ _chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp↩ _freq, int t0, int nu, std::string chain_distribution_scheme, double(∗log_prior)(double ∗param, int dimension, int chain_id), double(∗log_likelihood)(double ∗param, int dimension, int chain_id), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void PTMCMC_MH_dynamic_PT_alloc (double ∗∗∗output, int dimension, int N_steps, int chain_N, int max↩ _chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_↩ freq, int t0, int nu, std::string chain_distribution_scheme, double(∗log_prior)(double ∗param, int dimension), double(∗log_likelihood)(double ∗param, int dimension), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_↩ filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void continue_PTMCMC_MH (std::string start_checkpoint_file, double ∗∗∗output, int N_steps, int swp_↩ freq, double(∗log_prior)(double ∗param, int dimension, int chain_id), double(∗log_likelihood)(double ∗param, int dimension, int chain_id), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string end_checkpoint_file)
- void continue_PTMCMC_MH (std::string start_checkpoint_file, double ∗∗∗output, int N_steps, int swp_↩ freq, double(∗log_prior)(double ∗param, int dimension), double(∗log_likelihood)(double ∗param, int dimension), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher), int numThreads, bool pool, bool show↩ _prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string end_checkpoint_file)
- void PTMCMC_MH_loop (sampler ∗sampler)

    Internal function that runs the actual loop for the sampler.
- void PTMCMC_MH_step_incremental (sampler ∗sampler, int increment)

    Internal function that runs the actual loop for the sampler – increment version.
- void PTMCMC_MH (double ∗∗∗output, int dimension, int N_steps, int chain_N, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_freq, double(∗log_prior)(double ∗param, int dimension), double(∗log_likelihood)(double ∗param, int dimension), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_↩ filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_filename)
- void PTMCMC_MH (double ∗∗∗output, int dimension, int N_steps, int chain_N, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_freq, double(∗log_prior)(double ∗param, int dimension, int

chain_id), double(*log_likelihood)(double *param, int dimension, int chain_id), void(*fisher)(double *param, int dimension, double **fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_↩ filename, std::string checkpoint_filename)

- void PTMCMC_MH_internal (double ***output, int dimension, int N_steps, int chain_N, double *initial_↩ pos, double *seeding_var, double *chain_temps, int swp_freq, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_↩ filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std↩ ::string checkpoint_filename)

    Generic sampler, where the likelihood, prior are parameters supplied by the user.
- void continue_PTMCMC_MH_internal (std::string start_checkpoint_file, double ***output, int N_steps, int swp_freq, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_↩ filename, std::string likelihood_log_filename, std::string end_checkpoint_file)

    Routine to take a checkpoint file and begin a new chain at said checkpoint.

9.11.1 Detailed Description

Header file for mcmc_sampler

9.11.2 Function Documentation

9.11.2.1 continue_PTMCMC_MH() [1/2]

```
void continue_PTMCMC_MH (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string end_checkpoint_file )
```

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	Funcion pointer for the log_prior

Parameters

	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use
	pool	Boolean for whether to use `deterministic'' vs`stochastic" sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.11.2.2 continue_PTMCMC_MH() [2/2]

```
void continue_PTMCMC_MH (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string end_checkpoint_file )
```

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use
	pool	Boolean for whether to use `deterministic'' vs`stochastic" sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output

Parameters

	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.11.2.3 continue_PTMCMC_MH_internal()

```
void continue_PTMCMC_MH_internal (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string end_checkpoint_file )
```

Routine to take a checkpoint file and begin a new chain at said checkpoint.

See MCMC_MH_internal for more details of parameters (pretty much all the same)

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id
	numThreads	Number of threads to use
	pool	Boolean for whether to use `deterministic'' vs`stochastic'' sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.11.2.4 PTMCMC_MH() [1/2]

```
void PTMCMC_MH (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_filename )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to `'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_filename	Filename to output data for checkpoint, if empty string, not saved

9.11.2.5 PTMCMC_MH() [2/2]

```
void PTMCMC_MH (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_filename )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_filename	Filename to output data for checkpoint, if empty string, not saved

9.11.2.6 PTMCMC_MH_dynamic_PT_alloc() [1/2]

```
void PTMCMC_MH_dynamic_PT_alloc (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics ($\sim$1000)
	nu	Initial amplitude of the dynamics ($\sim$100)
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output

Parameters

	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.11.2.7 PTMCMC_MH_dynamic_PT_alloc() [2/2]

```
void PTMCMC_MH_dynamic_PT_alloc (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics (∼1000)
	nu	Initial amplitude of the dynamics (∼100)
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood

Parameters

	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.11.2.8 PTMCMC_MH_dynamic_PT_alloc_internal()

```
void PTMCMC_MH_dynamic_PT_alloc_internal (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Dyanmically tunes an MCMC for optimal spacing. step width, and chain number.

NOTE: nu, and t0 parameters determine the dynamics, so these are important quantities. nu is related to how many swap attempts it takes to substantially change the temperature ladder, why t0 determines the length of the total dyanimcally period. Moderate initial choices would be 10 and 1000, respectively.

Based on arXiv:1501.05823v3

Currently, Chain number is fixed

max_chain_N_thermo_ensemble sets the maximium number of chains to use to in successively hotter chains to cover the likelihood surface while targeting an optimal swap acceptance target_swp_acc.

max_chain_N determines the total number of chains to run once thermodynamic equilibrium has been reached. This results in chains being added after the initial PT dynamics have finished according to chain_distribution_↩
scheme.

If no preference, set max_chain_N_thermo_ensemble = max_chain_N = numThreads = (number of cores (number of threads if hyperthreaded))– this will most likely be the most optimal configuration. If the number of cores on the system is low, you may want to use n∗numThreads for some integer n instead, depending on the system.

chain_distribution_scheme:

"cold": All chains are added at T=1 (untempered)

"refine": Chains are added between the optimal temps geometrically – this may be a good option as it will be a good approximation of the ideal distribution of chains, while keeping the initial dynamical time low

"double": Chains are added in order of rising temperature that mimic the distribution achieved by the earier PT dynamics

"half_ensemble": For every cold chain added, half of the ensemble is added again. Effectively, two cold chains for every ensemble

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
out	*chain_temps*	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics (∼1000)
	nu	Initial amplitude of the dynamics (∼100)
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.11.2.9 PTMCMC_MH_internal()

```
void PTMCMC_MH_internal (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Generic sampler, where the likelihood, prior are parameters supplied by the user.

Base of the sampler, generic, with user supplied quantities for most of the samplers properties

Uses the Metropolis-Hastings method, with the option for Fisher/MALA steps if the Fisher routine is supplied.

3 modes to use -

single threaded (numThreads = 1) runs single threaded

multi-threaded `‘deterministic’' (numThreads>1 ; pool = false) progresses each chain in parallel for swp_freq steps, then waits for all threads to complete before swapping temperatures in sequenctial order (j, j+1) then (j+1, j+2) etc (sequenctially)

multi-threaded `‘stochastic’' (numThreads>2 ; pool = true) progresses each chain in parallel by queueing each temperature and evaluating them in the order they were submitted. Once finished, the threads are queued to swap, where they swapped in the order they are submitted. This means the chains are swapped randomly, and the chains do NOT finish at the same time. The sampler runs until the the 0th chain reaches the step number

Note on limits: In the prior function, if a set of parameters should be disallowed, return -std::numeric_↩ limits<double>::infinity() – (this is in the <limits> file in std)

Format for the auto_corr file (compatable with csv, dat, txt extensions): each row is a dimension of the cold chain, with the first row being the lengths used for the auto-corr calculation:

lengths: length1 , length2 ...

dim1: length1 , length2 ...

Format for the chain file (compatable with csv, dat, txt extensions): each row is a step, each column a dimension:

Step1: dim1 , dim2 , ...

Step2: dim1 , dim2 , ...

Statistics_filename : should be txt extension

checkpoint_file : This file saves the final position of all the chains, as well as other metadata, and can be loaded by the function <FUNCTION> to continue the chain from the point it left off. Not meant to be read by humans, the data order is custom to this software library. An empty string ("") means no checkpoint will be saved. For developers, the contents are:

dimension, # of chains

temps of chains

Stepping widths of all chains

Final position of all chains

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.11.2.10 PTMCMC_MH_loop()

```
void PTMCMC_MH_loop (
            sampler * sampler )
```

Internal function that runs the actual loop for the sampler.

9.11.2.11 PTMCMC_MH_step_incremental()

```
void PTMCMC_MH_step_incremental (
            sampler * sampler,
            int increment )
```

Internal function that runs the actual loop for the sampler – increment version.

The regular loop function runs for the entire range, this increment version will only step \`'increment'' steps – asynchronous: steps are measured by the cold chains NEEDS TO CHANGE

9.11.2.12 RJPTMCMC_MH()

```
void RJPTMCMC_MH (
            double *** output,
            int *** parameter_status,
            int max_dimension,
            int min_dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            int * initial_status,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int *status, int max_dimension, int chain_id) log_prior,
            double(*)(double *param, int *status, int max_dimension, int chain_id) log_↩
likelihood,
            void(*)(double *param, int *status, int max_dimension, double **fisher, int chain↩
_id) fisher,
            void(*)(double *current_param, double *proposed_param, int *current_status, int
*proposed_status, int max_dimension, int chain_id) RJ_proposal,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
out	*parameter_status*	Parameter status for each step corresponding to the output chains, shape is double[chain_N, N_steps,dimension]
	max_dimension	maximum dimension of the parameter space being explored – only consideration is memory, as memory scales with dimension. Keep this reasonable, unless memory is REALLY not an issue
	min_dimension	minimum dimension of the parameter space being explored >=1
	N_steps	Number of total steps to be taken, per chain

Parameters

	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	initial_status	Initial status of the parameters in the initial position in parameter space - shape int[max_dim]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[max_dimension] – initial seeding of zero corresponds to the dimension turned off initially
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	RJ_proposal	std::function for the log_likelihood function – takes double ∗position, int ∗param_status,int dimension, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to `'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.11.2.13 RJPTMCMC_MH_internal()

```
void RJPTMCMC_MH_internal (
            double *** output,
            int *** parameter_status,
            int max_dimension,
            int min_dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            int * initial_status,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            std::function< void(double *, double *, int *, int *, int, int)> RJ_proposal,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Generic reversable jump sampler, where the likelihood, prior, and reversable jump proposal are parameters supplied by the user.

Note: Using a min_dimension tells the sampler that there is a `base model'', and that the dimensions from min_dim to max_dim are`small'' corrections to that model. This helps inform some of the proposal algorithms and speeds up computation. If using discrete models with no overlap of variables (ie model A or model B), set min_dim to 0. Even if reusing certain parameters, if the extra dimensions don't describe `‘small'' deviations, it's probably best to set min_dim to 0.

Currently, no dynamic PT option, as it would be too many free parameters for the sampler to converge to a reasonable temperature distribution in a reasonable amount of time. Best use case, use the PTMCMC_MH_dyanmic_PT for the `‘base'' dimension space, and use that temperature ladder.

Base of the sampler, generic, with user supplied quantities for most of the samplers properties

Uses the Metropolis-Hastings method, with the option for Fisher/MALA steps if the Fisher routine is supplied.

3 modes to use -

single threaded (numThreads = 1) runs single threaded

multi-threaded `‘deterministic'' (numThreads>1 ; pool = false) progresses each chain in parallel for swp_freq steps, then waits for all threads to complete before swapping temperatures in sequenctial order (j, j+1) then (j+1, j+2) etc (sequenctially)

multi-threaded `‘stochastic'' (numThreads>2 ; pool = true) progresses each chain in parallel by queueing each temperature and evaluating them in the order they were submitted. Once finished, the threads are queued to swap, where they swapped in the order they are submitted. This means the chains are swapped randomly, and the chains do NOT finish at the same time. The sampler runs until the the 0th chain reaches the step number

Note on limits: In the prior function, if a set of parameters should be disallowed, return -std::numeric_↩ limits<double>::infinity() – (this is in the <limits> file in std)

The parameter array uses the dimensions [0,min_dim] always, and [min_dim, max_dim] in RJPTMCMC fashion

Format for the auto_corr file (compatable with csv, dat, txt extensions): each row is a dimension of the cold chain, with the first row being the lengths used for the auto-corr calculation:

lengths: length1 , length2 ...

dim1: length1 , length2 ...

Format for the chain file (compatable with csv, dat, txt extensions): each row is a step, each column a dimension:

Step1: dim1 , dim2 , ..., max_dim, param_status1, param_status2, ...

Step2: dim1 , dim2 , ..., max_dim, param_status1, param_status2, ...

Statistics_filename : should be txt extension

checkpoint_file : This file saves the final position of all the chains, as well as other metadata, and can be loaded by the function <FUNCTION> to continue the chain from the point it left off. Not meant to be read by humans, the data order is custom to this software library. An empty string ("") means no checkpoint will be saved. For developers, the contents are:

dimension, # of chains

temps of chains

Stepping widths of all chains

Final position of all chains

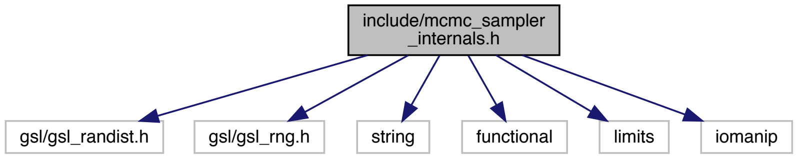
Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
out	*parameter_status*	Parameter status for each step corresponding to the output chains, shape is double[chain_N, N_steps,dimension]
	max_dimension	maximum dimension of the parameter space being explored – only consideration is memory, as memory scales with dimension. Keep this reasonable, unless memory is REALLY not an issue
	min_dimension	minimum dimension of the parameter space being explored $>=1$
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	initial_status	Initial status of the parameters in the initial position in parameter space - shape int[max_dim]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[max_dimension] – initial seeding of zero corresponds to the dimension turned off initially
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	std::function for the log_prior function – takes double ∗position, int ∗param_status, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int ∗param_status,int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int ∗param_status,int dimension, double ∗∗output_fisher, int chain_id
	RJ_proposal	std::function for the log_likelihood function – takes double ∗position, int ∗param_status,int dimension, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to `'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

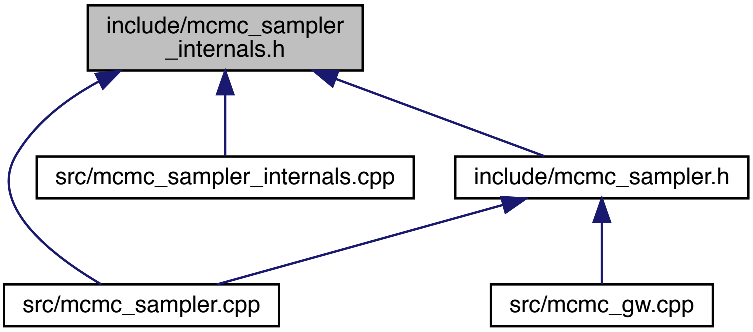
9.12 include/mcmc_sampler_internals.h File Reference

```
#include <gsl/gsl_randist.h>
#include <gsl/gsl_rng.h>
#include <string>
#include <functional>
#include <limits>
#include <iomanip>
```

Include dependency graph for mcmc_sampler_internals.h:



This graph shows which files directly or indirectly include this file:



Classes

- class sampler

Functions

- int mcmc_step (sampler ∗sampler, double ∗current_param, double ∗next_param, int ∗current_status, int ∗next_status, int chain_number)

  interface function between the sampler and the internal step functions
- void gaussian_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_id)

  Straight gaussian step.
- void fisher_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_index)

  Fisher informed gaussian step.
- void **update_fisher** (sampler ∗sampler, double ∗current_param, int ∗param_status, int chain_index)
- void mmala_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status)

  MMALA informed step – Currently not supported.

- void diff_ev_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_id)

  differential evolution informed step
- void RJ_smooth_history (sampler ∗sampler, double ∗current_param, int ∗current_param_status, int base_history_id, double ∗eff_history_coord, int ∗eff_history_status, int chain_id)
- void RJ_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_number)

  RJ-proposal step for trans-dimensional MCMCs.
- void chain_swap (sampler ∗sampler, double ∗∗∗output, int ∗∗∗param_status, int step_num, int ∗swp_accepted, int ∗swp_rejected)

  subroutine to perform chain comparison for parallel tempering
- int single_chain_swap (sampler ∗sampler, double ∗chain1, double ∗chain2, int ∗chain1_status, int ∗chain2_status, int T1_index, int T2_index)

  subroutine to actually swap two chains
- void assign_probabilities (sampler ∗sampler, int chain_index)

  update and initiate probabilities for each variety of step
- void transfer_chain (sampler ∗samplerptr_dest, sampler ∗samplerptr_source, int id_destination, int id_source, bool transfer_output)

  Copies contents of one chain to another.
- bool check_sampler_status (sampler ∗samplerptr)

  Checks the status of a sampler for the stochastic sampling.
- void update_step_widths (sampler ∗samplerptr, int chain_id)

  Updates the step widths, shooting for 20% acceptance ratios for each type of step.
- void **allocate_sampler_mem** (sampler ∗sampler)
- void **deallocate_sampler_mem** (sampler ∗sampler)
- void **update_history** (sampler ∗sampler, double ∗new_params, int ∗new_param_status, int chain_index)
- void **write_stat_file** (sampler ∗sampler, std::string filename)
- void write_checkpoint_file (sampler ∗sampler, std::string filename)

  Routine that writes metadata and final positions of a sampler to a checkpoint file.
- void load_checkpoint_file (std::string check_file, sampler ∗sampler)

  load checkpoint file into sampler struct
- void load_temps_checkpoint_file (std::string check_file, double ∗temps, int chain_N)

  load temperatures from checkpoint file
- void **assign_ct_p** (sampler ∗sampler, int step, int chain_index)
- void **assign_ct_m** (sampler ∗sampler, int step, int chain_index)
- void **assign_initial_pos** (sampler ∗samplerptr, double ∗initial_pos, int ∗initial_status, double ∗seeding_var)
- double PT_dynamical_timescale (int t0, int nu, int t)

  Timescale of the PT dynamics.
- void update_temperatures (sampler ∗samplerptr, int t0, int nu, int t)

  updates the temperatures for a sampler such that all acceptance rates are equal
- void initiate_full_sampler (sampler ∗sampler_new, sampler ∗sampler_old, int chain_N_thermo_ensemble, int chain_N, std::string chain_allocation_scheme)

  For the dynamic PT sampler, this is the function that starts the full sampler with the max number of chains.

Variables

- const double **limit_inf** = -std::numeric_limits<double>::infinity()

9.12.1 Detailed Description

Internal functions of the generic MCMC sampler (nothing specific to GW)

9.12.2 Function Documentation

9.12.2.1 assign_probabilities()

```
void assign_probabilities (
            sampler * sampler,
            int chain_index )
```

update and initiate probabilities for each variety of step

Type 0: Gaussian step

Type 1: Differential Evolution step

Type 2: MMALA step (currently not supported)

Type 3: Fisher step

9.12.2.2 chain_swap()

```
void chain_swap (
            sampler * sampler,
            double *** output,
            int *** param_status,
            int step_num,
            int * swp_accepted,
            int * swp_rejected )
```

subroutine to perform chain comparison for parallel tempering

The total output file is passed, and the chains are swapped sequentially

This is the routine for \`'Deterministic'' sampling (parallel or sequential, but not pooled)

Parameters

sampler	sampler struct
output	output vector containing chains
param_status	Parameter status
step_num	current step number

9.12.2.3 check_sampler_status()

```
bool check_sampler_status (
            sampler * samplerptr )
```

Checks the status of a sampler for the stochastic sampling.

Just loops through the ref_chain_status variables

9.12.2.4 diff_ev_step()

```
void diff_ev_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_id )
```

differential evolution informed step

Differential evolution uses the past history of the chain to inform the proposed step:

Take the difference of two random, accepted previous steps and step along that with some step size, determined by a gaussian

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.12.2.5 fisher_step()

```
void fisher_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_index )
```

Fisher informed gaussian step.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.12.2.6 gaussian_step()

```
void gaussian_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
```

```
            int * current_status,
            int * proposed_status,
            int chain_id )
```

Straight gaussian step.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.12.2.7 initiate_full_sampler()

```
void initiate_full_sampler (
            sampler * sampler_new,
            sampler * sampler_old,
            int chain_N_thermo_ensemble,
            int chain_N,
            std::string chain_allocation_scheme )
```

For the dynamic PT sampler, this is the function that starts the full sampler with the max number of chains.

The output file will be reused, but the positions are set back to zero (copying the current position to position zero)

Assumes the output, chain_temps have been allocated in memory for the final number of chains chain_N and steps N_steps

Allocates memory for the new sampler sampler_new -> it's the user's responsibility to deallocate with deallocate↩_sampler_mem

Parameters

sampler_old	Dynamic sampler
chain_N_thermo_ensemble	Number of chains used in the thermodynamic ensemble
chain_N	Number of chains to use in the static sampler
chain_allocation_scheme	Scheme to use to allocate any remaining chains

9.12.2.8 load_checkpoint_file()

```
void load_checkpoint_file (
            std::string check_file,
            sampler * sampler )
```

load checkpoint file into sampler struct

NOTE – allocate_sampler called in function – MUST deallocate manually

NOTE – sampler->chain_temps allocated internally – MUST free manually

9.12.2.9 load_temps_checkpoint_file()

```
void load_temps_checkpoint_file (
            std::string check_file,
            double * temps,
            int chain_N )
```

load temperatures from checkpoint file

Assumed the temps array is already allocated in memory for the correct number of chains

Just a utility routine to read temperatures from checkpoint file

It would be easy to read in the chain number and allocate memory in the function, but I prefer to leave allocation/deallocation up to the client

9.12.2.10 mmala_step()

```
void mmala_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status )
```

MMALA informed step – Currently not supported.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.12.2.11 PT_dynamical_timescale()

```
double PT_dynamical_timescale (
            int t0,
            int nu,
            int t )
```

Timescale of the PT dynamics.

kappa in the the language of arXiv:1501.05823v3

Parameters

t0	Timescale of the dyanmics
nu	Initial amplitude (number of steps to base dynamics on)
t	current time

9.12.2.12 RJ_smooth_history()

```
void RJ_smooth_history (
            sampler * sampler,
            double * current_param,
            int * current_param_status,
            int base_history_id,
            double * eff_history_coord,
            int * eff_history_status,
            int chain_id )
```

Parameters

	sampler	Current sampler
	current_param	Current parameters to match
	current_param_status	Current parameters to match
	base_history_id	Original history element
out	*eff_history_coord*	Modified history coord
out	*eff_history_status*	Modified History status
	chain_id	Chain ID of the current chain

9.12.2.13 RJ_step()

```
void RJ_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_number )
```

RJ-proposal step for trans-dimensional MCMCs.

This extra step may seem unnecessary, I'm just adding it in in case the extra flexibility is useful in the future for preprocessing of the chain before sending it to the user's RJ_proposal

Parameters

	sampler	sampler
	current_param	current coordinates in parameter space
out	*proposed_param*	Proposed coordinates in parameter space
	current_status	Current status of parameters
out	*proposed_status*	Proposed status of parameters
	chain_number	chain mumber

9.12.2.14 single_chain_swap()

```
int single_chain_swap (
            sampler * sampler,
            double * chain1,
            double * chain2,
            int * chain1_status,
            int * chain2_status,
            int T1_index,
            int T2_index )
```

subroutine to actually swap two chains

This is the more general subroutine, which just swaps the two chains passed to the function

Parameters

sampler	sampler structure
chain1	parameter position of chain that could be changed
chain2	chain that is not swapped, but provides parameters to be swapped by the other chain
chain1_status	Parameter status array for chain1
chain2_status	Parameter status array for chain2
T1_index	number of chain swappe in chain_temps
T2_index	number of chain swapper in chain_temps

9.12.2.15 transfer_chain()

```
void transfer_chain (
            sampler * samplerptr_dest,
            sampler * samplerptr_source,
            int id_dest,
            int id_source,
            bool transfer_output )
```

Copies contents of one chain to another.

Transfers id_source in samplerptr_source to id_dest samplerptr_dest

NOTE: This copies the VALUE, not the reference. This could be expensive, so use with caution

id_dest is ERASED

samplerptr_dest and samplerptr_source MUST have the same dimension, the same sampling details (like having or not having a fisher) etc

samplerptr_dest must be previously allocated properly

As output is the largest transfer by far, the transfer_output flag can be used to allow the user to handle that manually.

9.12.2.16 update_temperatures()

```
void update_temperatures (
            sampler * samplerptr,
            int t0,
            int nu,
            int t )
```

updates the temperatures for a sampler such that all acceptance rates are equal

Follows the algorithm outlined in arXiv:1501.05823v3

Fixed temperatures for the first and last chain

used in MCMC_MH_dynamic_PT_alloc_internal

For defined results, this should be used while the sampler is using non-pooling methods

9.12.2.17 write_checkpoint_file()

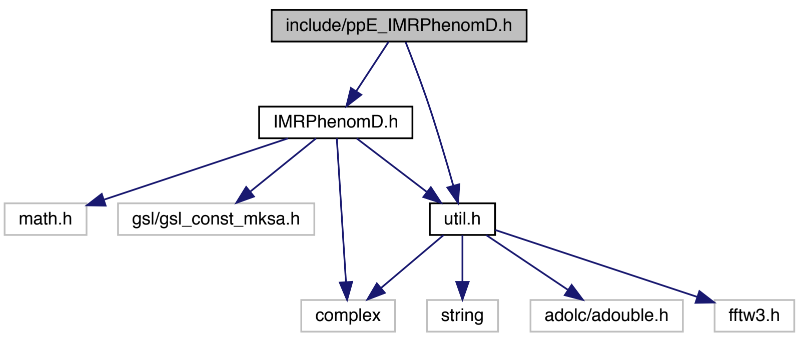
```
void write_checkpoint_file (
            sampler * sampler,
            std::string filename )
```

Routine that writes metadata and final positions of a sampler to a checkpoint file.

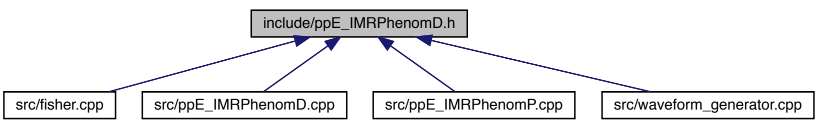
9.13 include/ppE_IMRPhenomD.h File Reference

```
#include "IMRPhenomD.h"
#include "util.h"
```

Include dependency graph for ppE_IMRPhenomD.h:



This graph shows which files directly or indirectly include this file:



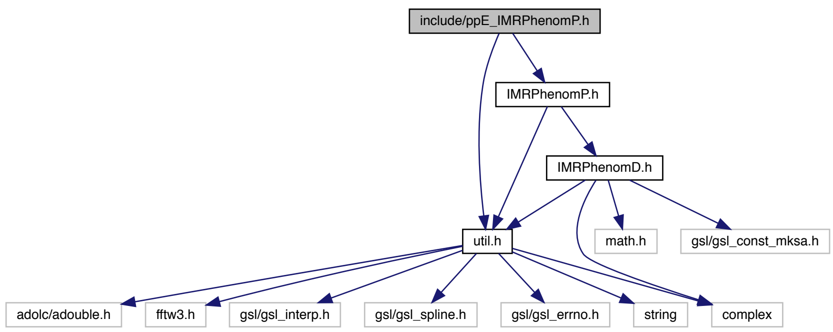
Classes

- class ppE_IMRPhenomD_Inspiral< T >
- class ppE_IMRPhenomD_IMR< T >
- class dCS_IMRPhenomD_log< T >
- class dCS_IMRPhenomD< T >
- class EdGB_IMRPhenomD_log< T >
- class EdGB_IMRPhenomD< T >

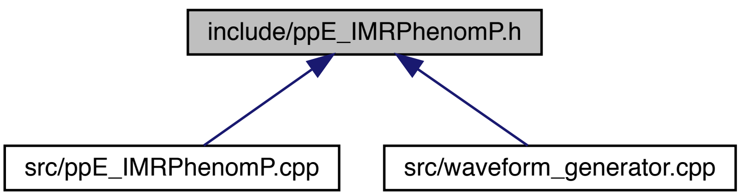
9.14 include/ppE_IMRPhenomP.h File Reference

```
#include "util.h"
#include "IMRPhenomP.h"
```

Include dependency graph for ppE_IMRPhenomP.h:



This graph shows which files directly or indirectly include this file:



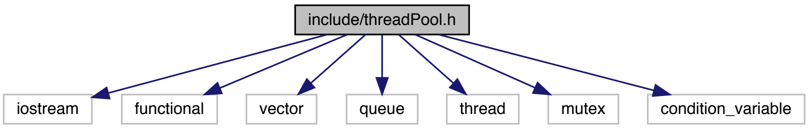
Classes

- class ppE_IMRPhenomPv2_Inspiral< T >
- class ppE_IMRPhenomPv2_IMR< T >

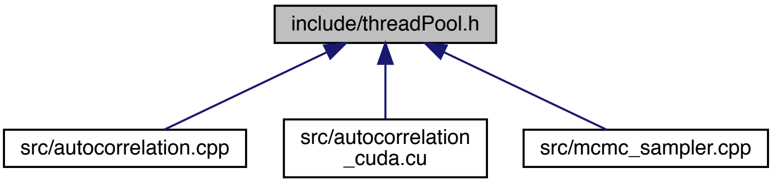
9.15 include/threadPool.h File Reference

```
#include <iostream>
#include <functional>
#include <vector>
#include <queue>
#include <thread>
#include <mutex>
#include <condition_variable>
```

Include dependency graph for threadPool.h:



This graph shows which files directly or indirectly include this file:



Classes

- class default_comp< jobtype >

    Default comparator for priority_queue in threadPool – no comparison.

- class threadPool< jobtype, comparator >

    Class for creating a pool of threads to asynchronously distribute work.

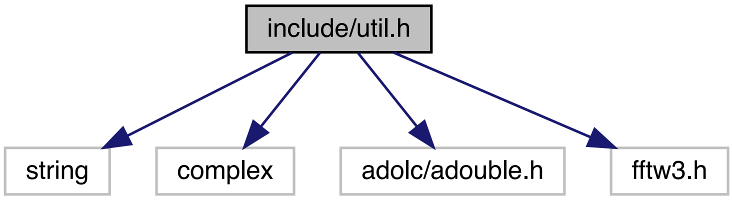
9.15.1 Detailed Description

Header file (declarations and definitions because of template functions) for the implementation of a generic thread pool

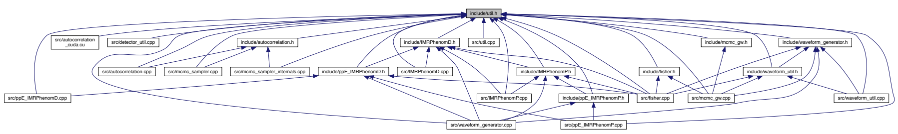
9.16 include/util.h File Reference

```
#include <string>
#include <complex>
#include "adolc/adouble.h"
#include <fftw3.h>
#include <gsl/gsl_interp.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_errno.h>
```

Include dependency graph for util.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct fftw_outline
- struct sph_harm< T >
- struct gen_params
- struct useful_powers< T >

  To speed up calculations within the for loops, we pre-calculate reoccuring powers of M∗F and Pi, since the pow() function is prohibatively slow.
- struct source_parameters< T >

Macros

- #define **PBSTR** "||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||"
- #define **PBWIDTH** 60

Functions

- void initiate_LumD_Z_interp (gsl_interp_accel **Z_DL_accel_ptr, gsl_spline **Z_DL_spline_ptr)

  Function that uses the GSL libraries to interpolate pre-calculated Z-D_L data.
- void free_LumD_Z_interp (gsl_interp_accel **Z_DL_accel_ptr, gsl_spline **Z_DL_spline_ptr)

  Frees the allocated interpolation function.
- adouble Z_from_DL_interp (adouble DL, gsl_interp_accel *Z_DL_accel_ptr, gsl_spline *Z_DL_spline_ptr)
- double Z_from_DL_interp (double DL, gsl_interp_accel *Z_DL_accel_ptr, gsl_spline *Z_DL_spline_ptr)
- double Z_from_DL (double DL, std::string cosmology)

  Calculates the redshift given the luminosity distance.
- double DL_from_Z (double Z, std::string cosmology)

  Calculates the luminosity distance given the redshift.
- double cosmology_interpolation_function (double x, double *coeffs, int interp_degree)

  Custom interpolation function used in the cosmology calculations.
- double cosmology_lookup (std::string cosmology)

  Helper function for mapping cosmology name to an internal index.
- adouble Z_from_DL (adouble DL, std::string cosmology)

  Calculates the redshift given the luminosity distance adouble version for ADOL-C implementation.
- adouble DL_from_Z (adouble Z, std::string cosmology)

  Calculates the luminosity distance given the redshift adouble version for ADOL-C implementation.
- adouble cosmology_interpolation_function (adouble x, double *coeffs, int interp_degree)

  Custom interpolation function used in the cosmology calculations adouble version for ADOL-C.
- void printProgress (double percentage)

  routine to print the progress of a process to the terminal as a progress bar
- void allocate_FFTW_mem_forward (fftw_outline *plan, int length)

  Allocate memory for FFTW3 methods used in a lot of inner products input is a locally defined structure that houses all the pertinent data.
- void allocate_FFTW_mem_reverse (fftw_outline *plan, int length)

  Allocate memory for FFTW3 methods used in a lot of inner products –INVERSE input is a locally defined structure that houses all the pertinent data.
- void deallocate_FFTW_mem (fftw_outline *plan)

  deallocates the memory used for FFTW routines
- double ** allocate_2D_array (int dim1, int dim2)

  Utility to malloc 2D array.
- int ** **allocate_2D_array_int** (int dim1, int dim2)
- void deallocate_2D_array (double **array, int dim1, int dim2)

  Utility to free malloc'd 2D array.
- void **deallocate_2D_array** (int **array, int dim1, int dim2)
- double *** allocate_3D_array (int dim1, int dim2, int dim3)

  Utility to malloc 3D array.
- int *** **allocate_3D_array_int** (int dim1, int dim2, int dim3)
- void deallocate_3D_array (double ***array, int dim1, int dim2, int dim3)

  Utility to free malloc'd 2D array.
- void deallocate_3D_array (int ***array, int dim1, int dim2, int dim3)

  Utility to free malloc'd 2D array.
- void read_file (std::string filename, double **output, int rows, int cols)

  Utility to read in data.
- void read_file (std::string filename, double *output)

  Utility to read in data (single dimension vector)
- void read_LOSC_data_file (std::string filename, double *output, double *data_start_time, double *duration, double *fs)

  Read data file from LIGO Open Science Center.

- void read_LOSC_PSD_file (std::string filename, double ∗∗output, int rows, int cols)

  Read PSD file from LIGO Open Science Center.
- void allocate_LOSC_data (std::string ∗data_files, std::string psd_file, int num_detectors, int psd_length, int data_file_length, double trigger_time, std::complex< double > ∗∗data, double ∗∗psds, double ∗∗freqs)

  Prepare data for MCMC directly from LIGO Open Science Center.
- void free_LOSC_data (std::complex< double > ∗∗data, double ∗∗psds, double ∗∗freqs, int num_detectors, int length)
- void tukey_window (double ∗window, int length, double alpha)

  Tukey window function for FFTs.
- void write_file (std::string filename, double ∗∗input, int rows, int cols)

  Utility to write 2D array to file.
- void write_file (std::string filename, double ∗input, int length)

  Utility to write 1D array to file.
- double calculate_eta (double mass1, double mass2)

  Calculates the symmetric mass ration from the two component masses.
- adouble **calculate_eta** (adouble mass1, adouble mass2)
- double calculate_chirpmass (double mass1, double mass2)

  Calculates the chirp mass from the two component masses.
- adouble **calculate_chirpmass** (adouble mass1, adouble mass2)
- double calculate_mass1 (double chirpmass, double eta)

  Calculates the larger mass given a chirp mass and symmetric mass ratio.
- adouble **calculate_mass1** (adouble chirpmass, adouble eta)
- double calculate_mass2 (double chirpmass, double eta)

  Calculates the smaller mass given a chirp mass and symmetric mass ratio.
- adouble **calculate_mass2** (adouble chirpmass, adouble eta)
- void celestial_horizon_transform (double RA, double DEC, double gps_time, double LONG, double LAT, double ∗phi, double ∗theta)

  Utility to transform from celestial coord RA and DEC to local horizon coord for detector response functions.
- double gps_to_GMST (double gps_time)

  Utility to transform from gps time to GMST `https://aa.usno.navy.mil/faq/docs/GAST.php`.
- double gps_to_JD (double gps_time)

  Utility to transform from gps to JD.
- void transform_cart_sph (double ∗cartvec, double ∗sphvec)

  utility to transform a vector from cartesian to spherical (radian)
- void transform_sph_cart (double ∗sphvec, double ∗cartvec)

  utility to transform a vector from spherical (radian) to cartesian
- template< class T >
  T trapezoidal_sum_uniform (double delta_x, int length, T ∗integrand)

  Trapezoidal sum rule to approximate discrete integral - Uniform spacing.
- template< class T >
  T trapezoidal_sum (double ∗delta_x, int length, T ∗integrand)

  Trapezoidal sum rule to approximate discrete integral - Non-Uniform spacing.
- template< class T >
  T simpsons_sum (double delta_x, int length, T ∗integrand)

  Simpsons sum rule to approximate discrete integral - Uniform spacing.
- long factorial (long num)

  Local function to calculate a factorial.
- double pow_int (double base, int power)

  Local power function, specifically for integer powers.
- adouble **pow_int** (adouble base, int power)
- template< class T >
  std::complex< T > **cpolar** (T mag, T phase)

- template< class T >
  std::complex< T > XLALSpinWeightedSphericalHarmonic (T theta, T phi, int s, int l, int m)
- double cbrt_internal (double base)

  Fucntion that just returns the cuberoot.
- adouble cbrt_internal (adouble base)

  Fucntion that just returns the cuberoot ADOL-C doesn't have the cbrt function (which is faster), so have to use the power function.

Variables

- const double gamma_E = 0.577215664901532860606512090082402431042
- const double c = 299792458.
- const double G =6.674e-11∗(1.98855e30)
- const double MSOL_SEC =4.925491025543575903411922162094833998e-6
- const double MPC_SEC = 3.085677581491367278913937957796471611e22/c

9.16.1 Detailed Description

General utilities (functions and structures) independent of modelling method

9.16.2 Function Documentation

9.16.2.1 allocate_2D_array()

```
double** allocate_2D_array (
            int dim1,
            int dim2 )
```

Utility to malloc 2D array.

9.16.2.2 allocate_3D_array()

```
double*** allocate_3D_array (
            int dim1,
            int dim2,
            int dim3 )
```

Utility to malloc 3D array.

9.16.2.3 allocate_LOSC_data()

```
void allocate_LOSC_data (
            std::string * data_files,
            std::string psd_file,
            int num_detectors,
            int psd_length,
            int data_file_length,
            double trigger_time,
            std::complex< double > ** data,
            double ** psds,
            double ** freqs )
```

Prepare data for MCMC directly from LIGO Open Science Center.

Trims data for Tobs (determined by PSD file) 3/4∗Tobs in front of trigger, and 1/4∗Tobs behind

Currently, default to sampling frequency and observation time set by PSD – cannot be customized

Output is in order of PSD columns – string vector of detectos MUST match order of PSD cols

Output shapes– psds = [num_detectors][psd_length] data = [num_detectors][psd_length]

freqs = [num_detectors][psd_length]

Total observation time = 1/(freq[i] - freq[i-1]) (from PSD file)

Sampling frequency fs = max frequency from PSD file

ALLOCATES MEMORY – must be freed to prevent memory leak

Parameters

	data_files	Vector of strings for each detector file from LOSC
	psd_file	String of psd file from LOSC
	num_detectors	Number of detectors to use
	psd_length	Length of the PSD file (number of rows of DATA)
	data_file_length	Length of the data file (number of rows of DATA)
	trigger_time	Time for the signal trigger (GPS)
out	*data*	Output array of data for each detector
out	*psds*	Output array of psds for each detector
out	*freqs*	Output array of freqs for each detector

9.16.2.4 calculate_chirpmass()

```
double calculate_chirpmass (
            double mass1,
            double mass2 )
```

Calculates the chirp mass from the two component masses.

The output units are whatever units the input masses are

9.16.2.5 calculate_mass1()

```
double calculate_mass1 (
            double chirpmass,
            double eta )
```

Calculates the larger mass given a chirp mass and symmetric mass ratio.

Units of the output match the units of the input chirp mass

9.16.2.6 calculate_mass2()

```
double calculate_mass2 (
            double chirpmass,
            double eta )
```

Calculates the smaller mass given a chirp mass and symmetric mass ratio.

Units of the output match the units of the input chirp mass

9.16.2.7 celestial_horizon_transform()

```
void celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            double LONG,
            double LAT,
            double * phi,
            double * theta )
```

Utility to transform from celestial coord RA and DEC to local horizon coord for detector response functions.

Outputs are the spherical polar angles defined by North as 0 degrees azimuth and the normal to the earth as 0 degree polar

Parameters

	RA	Right acsension (rad)
	DEC	Declination (rad)
	gps_time	GPS time
	LONG	Longitude (rad)
	LAT	Latitude (rad)
out	*phi*	horizon azimuthal angle (rad)
out	*theta*	horizon polar angle (rad)

9.16.2.8 cosmology_interpolation_function()

```
double cosmology_interpolation_function (
```

```
double x,
double * coeffs,
int interp_degree )
```

Custom interpolation function used in the cosmology calculations.

Power series in half power increments of x, up to 11/2. powers of x

9.16.2.9 deallocate_2D_array()

```
void deallocate_2D_array (
            double ** array,
            int dim1,
            int dim2 )
```

Utility to free malloc'd 2D array.

9.16.2.10 deallocate_3D_array() [1/2]

```
void deallocate_3D_array (
            double *** array,
            int dim1,
            int dim2,
            int dim3 )
```

Utility to free malloc'd 2D array.

9.16.2.11 deallocate_3D_array() [2/2]

```
void deallocate_3D_array (
            int *** array,
            int dim1,
            int dim2,
            int dim3 )
```

Utility to free malloc'd 2D array.

9.16.2.12 DL_from_Z()

```
double DL_from_Z (
            double Z,
            std::string cosmology )
```

Calculates the luminosity distance given the redshift.

Based on Astropy.cosmology calculations – see python script in the ./data folder of the project – numerically calculated given astropy.cosmology's definitions (http://docs.astropy.org/en/stable/cosmology/) and used scipy.optimize to fit to a power series, stepping in half powers of Z. These coefficients are then output to a header file (D_Z_config.h) which are used here to calculate distance. Custom cosmologies etc can easily be acheived by editing the python script D_Z_config.py, the c++ functions do not need modification. They use whatever data is available in the header file. If the functional form of the fitting function changes, these functions DO need to change.

5 cosmological models are available (this argument must be spelled exactly):

PLANCK15, PLANCK13, WMAP9, WMAP7, WMAP5

9.16.2.13 free_LOSC_data()

```
void free_LOSC_data (
            std::complex< double > ** data,
            double ** psds,
            double ** freqs,
            int num_detectors,
            int length )
```

/brief Free data allocated by prep_LOSC_data function

9.16.2.14 initiate_LumD_Z_interp()

```
void initiate_LumD_Z_interp (
            gsl_interp_accel ** Z_DL_accel_ptr,
            gsl_spline ** Z_DL_spline_ptr )
```

Function that uses the GSL libraries to interpolate pre-calculated Z-D_L data.

Initiates the requried functions – GSL interpolation requires allocating memory before hand

9.16.2.15 pow_int()

```
double pow_int (
            double base,
            int power )
```

Local power function, specifically for integer powers.

Much faster than the std version, because this is only for integer powers

9.16.2.16 printProgress()

```
void printProgress (
            double percentage )
```

routine to print the progress of a process to the terminal as a progress bar

Call everytime you want the progress printed

9.16.2.17 read_file() [1/2]

```
void read_file (
            std::string filename,
            double ** output,
            int rows,
            int cols )
```

Utility to read in data.

Takes filename, and assigns to output[rows][cols]

File must be comma separated doubles

Parameters

	filename	input filename, relative to execution directory
out	*output*	array to store output, dimensions rowsXcols
	rows	first dimension
	cols	second dimension

9.16.2.18 read_file() [2/2]

```
void read_file (
            std::string filename,
            double * output )
```

Utility to read in data (single dimension vector)

Takes filename, and assigns to output[i∗rows + cols]

Output vector must be long enough, no check is done for the length

File must be comma separated doubles

Parameters

	filename	input filename, relative to execution directory
out	*output*	output array, assumed to have the proper length of total items

9.16.2.19 read_LOSC_data_file()

```
void read_LOSC_data_file (
            std::string filename,
            double * output,
            double * data_start_time,
            double * duration,
            double * fs )
```

Read data file from LIGO Open Science Center.

Convenience function for cutting off the first few lines of text

Parameters

	filename	input filename
out	*output*	Output data
out	*data_start_time*	GPS start time of the data in file
out	*duration*	Duration of the signal
out	*fs*	Sampling frequency of the data

9.16.2.20 read_LOSC_PSD_file()

```
void read_LOSC_PSD_file (
             std::string filename,
             double ** output,
             int rows,
             int cols )
```

Read PSD file from LIGO Open Science Center.

Convenience function for cutting off the first few lines of text

9.16.2.21 simpsons_sum()

```
template<class T >
T simpsons_sum (
             double delta_x,
             int length,
             T * integrand )
```

Simpsons sum rule to approximate discrete integral - Uniform spacing.

More accurate than the trapezoidal rule, but must be uniform

9.16.2.22 transform_cart_sph()

```
void transform_cart_sph (
             double * cartvec,
             double * sphvec )
```

utility to transform a vector from cartesian to spherical (radian)

order:

cart: x, y, z

spherical: r, polar, azimuthal

9.16.2.23 transform_sph_cart()

```
void transform_sph_cart (
             double * sphvec,
             double * cartvec )
```

utility to transform a vector from spherical (radian) to cartesian

order:

cart: x, y, z

spherical: r, polar, azimuthal

9.16.2.24 trapezoidal_sum()

```
template<class T >
T trapezoidal_sum (
            double * delta_x,
            int length,
            T * integrand )
```

Trapezoidal sum rule to approximate discrete integral - Non-Uniform spacing.

This version is slower than the uniform version, but will handle non-uniform spacing

9.16.2.25 trapezoidal_sum_uniform()

```
template<class T >
T trapezoidal_sum_uniform (
            double delta_x,
            int length,
            T * integrand )
```

Trapezoidal sum rule to approximate discrete integral - Uniform spacing.

This version is faster than the general version, as it has half the function calls

Something may be wrong with this function - had an overall offset for real data that was fixed by using the simpsons rule - not sure if this was because of a boost in accuracy or because something is off with the trapezoidal sum

9.16.2.26 tukey_window()

```
void tukey_window (
            double * window,
            int length,
            double alpha )
```

Tukey window function for FFTs.

As defined by https://en.wikipedia.org/wiki/Window_function

9.16.2.27 write_file() [1/2]

```
void write_file (
            std::string filename,
            double ** input,
            int rows,
            int cols )
```

Utility to write 2D array to file.

Grid of data, comma separated

Grid has rows rows and cols columns

Parameters

filename	Filename of output file, relative to execution directory
input	Input 2D array pointer array[rows][cols]
rows	First dimension of array
cols	second dimension of array

9.16.2.28 write_file() [2/2]

```
void write_file (
            std::string filename,
            double * input,
            int length )
```

Utility to write 1D array to file.

Single column of data

Parameters

filename	Filename of output file, relative to execution directory
input	input 1D array pointer array[length]
length	length of array

9.16.2.29 XLALSpinWeightedSphericalHarmonic()

```
template<class T >
std::complex<T> XLALSpinWeightedSphericalHarmonic (
            T theta,
            T phi,
            int s,
            int l,
            int m )
```

Shamelessly stolen from LALsuite

Parameters

theta	polar angle (rad)
phi	azimuthal angle (rad)
s	spin weight
l	mode number l
m	mode number m

9.16.2.30 Z_from_DL()

```
double Z_from_DL (
            double DL,
            std::string cosmology )
```

Calculates the redshift given the luminosity distance.

Based on Astropy.cosmology calculations – see python script in the ./data folder of the project – numerically calculated given astropy.cosmology's definitions (http://docs.astropy.org/en/stable/cosmology/) and used scipy.optimize to fit to a power series, stepping in half powers of DL. These coefficients are then output to a header file (D_Z_config.h) which are used here to calculate redshift. Custom cosmologies etc can easily be acheived by editing the python script D_Z_config.py, the c++ functions do not need modification. They use whatever data is available in the header file.

5 cosmological models are available (this argument must be spelled exactly, although case insensitive):

PLANCK15, PLANCK13, WMAP9, WMAP7, WMAP5

9.16.2.31 Z_from_DL_interp() [1/2]

```
adouble Z_from_DL_interp (
            adouble DL,
            gsl_interp_accel * Z_DL_accel_ptr,
            gsl_spline * Z_DL_spline_ptr )
```

Function that returns Z from a given luminosity Distance – only Planck15

adouble version for ADOL-C calculations

9.16.2.32 Z_from_DL_interp() [2/2]

```
double Z_from_DL_interp (
            double DL,
            gsl_interp_accel * Z_DL_accel_ptr,
            gsl_spline * Z_DL_spline_ptr )
```

Function that returns Z from a given luminosity Distance – only Planck15

9.16.3 Variable Documentation

9.16.3.1 c

```
const double c = 299792458.
```

Speed of light m/s

9.16.3.2 G

```
const double G =6.674e-11*(1.98855e30)
```

Gravitational constant in m∗∗3/(s∗∗2 SolMass)

9.16.3.3 gamma_E

```
const double gamma_E = 0.5772156649015328606065120900824024310421
```

Euler number

9.16.3.4 MPC_SEC

```
const double MPC_SEC = 3.085677581491367278913937957796471611e22/c
```

consts.kpc.to('m')∗1000/c Mpc in sec

9.16.3.5 MSOL_SEC

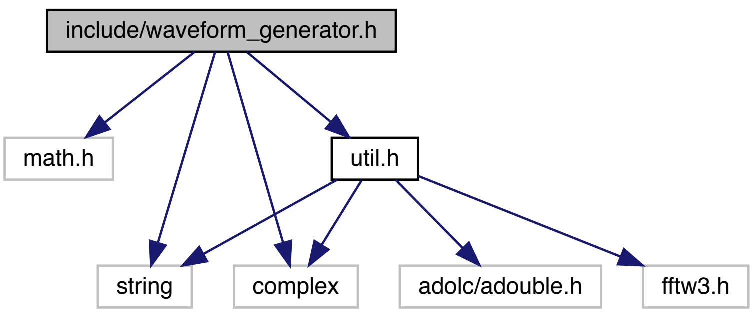
```
const double MSOL_SEC =4.925491025543575903411922162094833998e-6
```

G/c∗∗3 seconds per solar mass

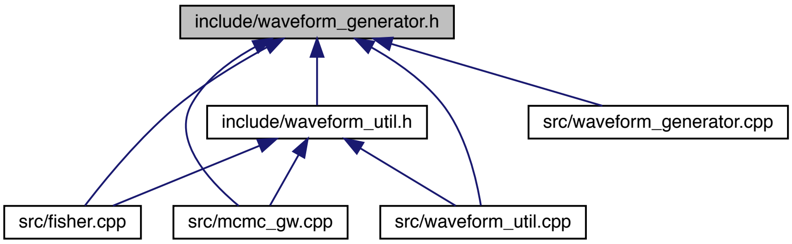
9.17 include/waveform_generator.h File Reference

```
#include <math.h>
#include "util.h"
#include <complex>
#include <string>
```

Include dependency graph for waveform_generator.h:



This graph shows which files directly or indirectly include this file:



Functions

- int **fourier_waveform** (double *frequencies, int length, std::complex< double > *waveform_plus, std::complex< double > *waveform_cross, std::string generation_method, gen_params *parameters)
- int **fourier_waveform** (double *frequencies, int length, double *waveform_plus_real, double *waveform_plus_imag, double *waveform_cross_real, double *waveform_cross_imag, std::string generation_method, gen_params *parameters)
- int **fourier_waveform** (double *frequencies, int length, std::complex< double > *waveform, std::string generation_method, gen_params *parameters)
- int **fourier_waveform** (double *frequencies, int length, double *waveform_real, double *waveform_imag, std::string generation_method, gen_params *parameters)
- int **fourier_amplitude** (double *frequencies, int length, double *amplitude, std::string generation_method, gen_params *parameters)
- int **fourier_phase** (double *frequencies, int length, double *phase, std::string generation_method, gen_params *parameters)

9.18 include/waveform_generator_C.h File Reference

Functions

- int **fourier_waveformC** (double *frequencies, int length, double *waveform_plus_real, double *waveform_plus_imag, double *waveform_cross_real, double *waveform_cross_imag, char *generation_method, double mass1, double mass2, double DL, double spin1x, double spin1y, double spin1z, double spin2x, double spin2y, double spin2z, double phic, double tc, double f_ref, double phiRef, double *ppE_beta, int *ppE_b, int Nmod, double incl_angle, double theta, double phi)
- int **fourier_amplitudeC** (double *frequencies, int length, double *amplitude, char *generation_method, double mass1, double mass2, double DL, double spin1x, double spin1y, double spin1z, double spin2x, double spin2y, double spin2z, double incl_angle, double theta, double phi)
- int **fourier_phaseC** (double *frequencies, int length, double *phase, char *generation_method, double mass1, double mass2, double DL, double spin1x, double spin1y, double spin1z, double spin2x, double spin2y, double spin2z, double phic, double tc, double f_ref, double phiRef, double *ppE_beta, int *ppE_b, int Nmod, double incl_angle, double theta, double phi)
- void **initiate_LumD_Z_interp_C** ()
- void **free_LumD_Z_interp_C** ()

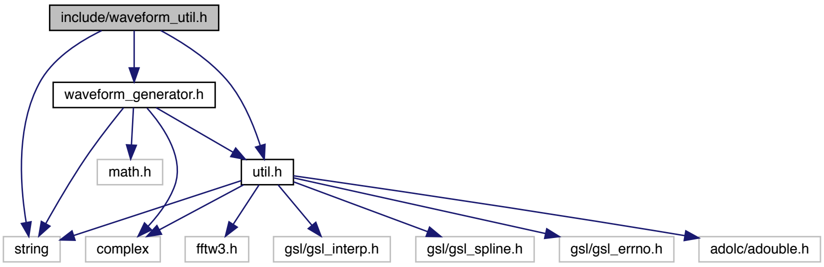
9.18.1 Detailed Description

Header file for the C wrapping of the waveform_generation.cpp

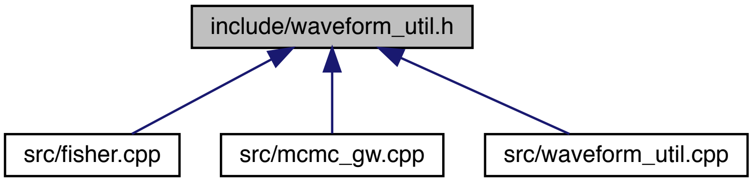
9.19 include/waveform_util.h File Reference

```
#include "waveform_generator.h"
#include "util.h"
#include <string>
```

Include dependency graph for waveform_util.h:



This graph shows which files directly or indirectly include this file:



Functions

- double data_snr_maximized_extrinsic (double ∗frequencies, int length, std::complex< double > ∗data, double ∗psd, std::string detector, std::string generation_method, gen_params ∗param)

  Utility to calculate the snr of a fourier transformed data stream while maximizing over the coalescence parameters phic and tc.
- double data_snr_maximized_extrinsic (double ∗frequencies, int length, double ∗data_real, double ∗data_imag, double ∗psd, std::string detector, std::string generation_method, gen_params ∗param)

  Light wrapper for the data_snr_maximized_extrinsic method.
- double calculate_snr (std::string detector, std::complex< double > ∗waveform, double ∗frequencies, int length)

  Caclulates the snr given a detector and waveform (complex) and frequencies.
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double theta, double phi, std::string detector)
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double theta, double phi, double psi, std::string detector)

- int fourier_detector_response_equatorial (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double ra, double dec, double psi, double gmst, std::string detector)
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗response, std::string detector, std::string generation_method, gen_params ∗parameters)

  Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary.
- int fourier_detector_response_equatorial (double ∗frequencies, int length, std::complex< double > ∗response, std::string detector, std::string generation_method, gen_params ∗parameters)

  Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary for equatorial coordinates.
- int fourier_detector_amplitude_phase (double ∗frequencies, int length, double ∗amplitude, double ∗phase, std::string detector, std::string generation_method, gen_params ∗parameters)

  Calculates the amplitude (magnitude) and phase (argument) of the response of a given detector.

9.19.1 Detailed Description

Header file for waveform specific utilites

9.19.2 Function Documentation

9.19.2.1 calculate_snr()

```
double calculate_snr (
            std::string detector,
            std::complex< double > * waveform,
            double * frequencies,
            int length )
```

Caclulates the snr given a detector and waveform (complex) and frequencies.

This function computes the un-normalized snr: \sqrt((H | H))

Parameters

detector	detector name - must match the string of populate_noise precisely
waveform	complex waveform
frequencies	double array of frequencies that the waveform is evaluated at
length	length of the above two arrays

9.19.2.2 data_snr_maximized_extrinsic() [1/2]

```
double data_snr_maximized_extrinsic (
            double * frequencies,
```

```
                int length,
                std::complex< double > * data,
                double * psd,
                std::string detector,
                std::string generation_method,
                gen_params * param )
```

Utility to calculate the snr of a fourier transformed data stream while maximizing over the coalescence parameters phic and tc.

The gen_params structure holds the parameters for the template to be used (the maximimum likelihood parameters)

Parameters

frequencies	Frequencies used by data
length	length of the data
data	input data in the fourier domain
psd	PSD for the detector that created the data
detector	Name of the detector –See noise_util for options
generation_method	Generation method for the template – See waveform_generation.cpp for options
param	gen_params structure for the template

9.19.2.3 data_snr_maximized_extrinsic() [2/2]

```
double data_snr_maximized_extrinsic (
                double * frequencies,
                int length,
                double * data_real,
                double * data_imag,
                double * psd,
                std::string detector,
                std::string generation_method,
                gen_params * param )
```

Light wrapper for the data_snr_maximized_extrinsic method.

Splits the data into real and imaginary, so all the arguments are C-safe

Parameters

frequencies	Frequencies used by data
length	length of the data
data_real	input data in the fourier domain – real part
data_imag	input data in the fourier domain – imaginary part
psd	PSD for the detector that created the data
detector	Name of the detector –See noise_util for options
generation_method	Generation method for the template – See waveform_generation.cpp for options
param	gen_params structure for the template

9.19.2.4 fourier_detector_amplitude_phase()

```
int fourier_detector_amplitude_phase (
            double * frequencies,
            int length,
            double * amplitude,
            double * phase,
            std::string detector,
            std::string generation_method,
            gen_params * parameters )
```

Calculates the amplitude (magnitude) and phase (argument) of the response of a given detector.

This is for general waveforms, and will work for precessing waveforms

Not as fast as non-precessing, but that can't be helped. MUST include plus/cross polarizations

9.19.2.5 fourier_detector_response() [1/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            std::complex< double > * detector_response,
            double theta,
            double phi,
            std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	theta	polar angle (rad) theta in detector frame
	phi	azimuthal angle (rad) phi in detector frame
	detector	detector - list of supported detectors in noise_util

9.19.2.6 fourier_detector_response() [2/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            std::complex< double > * detector_response,
            double theta,
            double phi,
            double psi,
            std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	theta	polar angle (rad) theta in detector frame
	phi	azimuthal angle (rad) phi in detector frame
	psi	polarization angle (rad) phi in detector frame
	detector	detector - list of supported detectors in noise_util

9.19.2.7 fourier_detector_response() [3/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * response,
            std::string detector,
            std::string generation_method,
            gen_params * parameters )
```

Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

This puts the responsibility on the user to pass the necessary parameters

Detector options include classic interferometers like LIGO/VIRGO (coming soon: ET and LISA)

This is a wrapper that combines generation with response functions: if producing mulitple responses for one waveform (ie stacking Hanford, Livingston, and VIRGO), it will be considerably more efficient to calculate the waveform once, then combine each response manually

Parameters

	frequencies	double array of frequencies for the waveform to be evaluated at
	length	integer length of all the arrays
out	*response*	complex array for the output plus polarization waveform
	generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
	parameters	structure containing all the source parameters

9.19.2.8 fourier_detector_response_equatorial() [1/2]

```
int fourier_detector_response_equatorial (
            double * frequencies,
```

```
             int length,
             std::complex< double > * hplus,
             std::complex< double > * hcross,
             std::complex< double > * detector_response,
             double ra,
             double dec,
             double psi,
             double gmst,
             std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	ra	Right Ascension in rad
	dec	Declination in rad
	psi	polarization angle (rad)
	gmst	greenwich mean sidereal time
	detector	detector - list of supported detectors in noise_util

9.19.2.9 fourier_detector_response_equatorial() [2/2]

```
int fourier_detector_response_equatorial (
             double * frequencies,
             int length,
             std::complex< double > * response,
             std::string detector,
             std::string generation_method,
             gen_params * parameters )
```

Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary for equatorial coordinates.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

This puts the responsibility on the user to pass the necessary parameters

Detector options include classic interferometers like LIGO/VIRGO (coming soon: ET and LISA)

This is a wrapper that combines generation with response functions: if producing mulitple responses for one waveform (ie stacking Hanford, Livingston, and VIRGO), it will be considerably more efficient to calculate the waveform once, then combine each response manually

Parameters

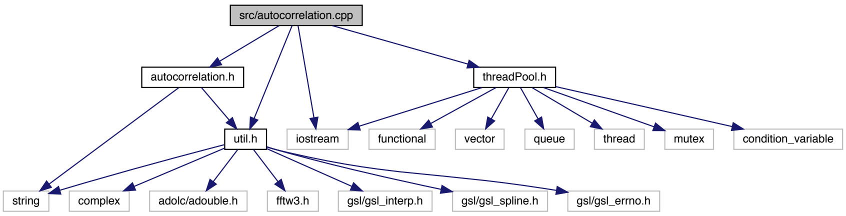
	frequencies	double array of frequencies for the waveform to be evaluated at
	length	integer length of all the arrays
out	*response*	complex array for the output plus polarization waveform
	generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
	parameters	structure containing all the source parameters

9.20 README.dox File Reference

9.21 src/autocorrelation.cpp File Reference

```
#include "autocorrelation.h"
#include "util.h"
#include "threadPool.h"
#include <iostream>
```

Include dependency graph for autocorrelation.cpp:



Macros

- #define MAX_SERIAL 200000

Functions

- void write_auto_corr_file_from_data_file (std::string autocorr_filename, std::string datafile, int length, int dimension, int num_segments, double target_corr, int num_threads)
- void write_auto_corr_file_from_data (std::string autocorr_filename, double ∗∗data, int length, int dimension, int num_segments, double target_corr, int num_threads)

    Writes the autocorrelation file from a data array.
- void auto_corr_from_data (double ∗∗data, int length, int dimension, int ∗∗output, int num_segments, double target_corr, int num_threads)

    Calculates the autocorrelation length for a set of data for a number of segments for each dimension – completely host code, utilitizes FFTW3 for longer chuncks of the chains.
- void threaded_ac_spectral (int thread, threaded_ac_jobs_fft job)

    Internal routine to calculate an spectral autocorrelation job.
- void threaded_ac_serial (int thread, threaded_ac_jobs_serial job)

    Internal routine to calculate an serial autocorrelation job.
- double auto_correlation_serial (double ∗arr, int length, int start, double target)

    Calculates the autocorrelation of a chain with the brute force method.
- void auto_correlation_spectral (double ∗chain, int length, double ∗autocorr, fftw_outline ∗plan_forw, fftw_outline ∗plan_rev)

    Wrapper function for convience – assumes the data array starts at 0.
- void auto_correlation_spectral (double ∗chain, int length, int start, double ∗autocorr, fftw_outline ∗plan_forw, fftw_outline ∗plan_rev)

    Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT – accepts FFTW plan as argument for plan reuse and multi-threaded applications.
- void auto_correlation_spectral (double ∗chain, int length, double ∗autocorr)

    Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT.

- double auto_correlation (double ∗arr, int length, double tolerance)
  OUTDATED – numerically finds autocorrelation length – not reliable.
- double auto_correlation_serial_old (double ∗arr, int length)
  OUTDATED Calculates the autocorrelation – less general version.
- double auto_correlation_grid_search (double ∗arr, int length, int box_num, int final_length, double target_↩ length)
  OUTDATED – Grid search method of computing the autocorrelation – unreliable.
- double auto_correlation_internal (double ∗arr, int length, int lag, double ave)
  Internal function to compute the auto correlation for a given lag.
- void auto_corr_intervals_outdated (double ∗data, int length, double ∗output, int num_segments, double accuracy)
  Function that computes the autocorrelation length on an array of data at set intervals to help determine convergence.
- void write_auto_corr_file_from_data (std::string auto_corr_filename, double ∗∗output, int intervals, int dimension, int N_steps)
  OUTDATED – writes autocorrelation lengths for a data array, but only with the serial method and only for a target correlation of .01.
- void write_auto_corr_file_from_data_file (std::string auto_corr_filename, std::string output_file, int intervals, int dimension, int N_steps)
  OUTDATED – writes autocorrelation lengths for a data file, but only with the serial method and only for a target correlation of .01.

9.21.1 Detailed Description

Turns out calculating the autocorrelation is more complicated if you want to do it fast, so it gets its own file now

9.21.2 Macro Definition Documentation

9.21.2.1 MAX_SERIAL

```
#define MAX_SERIAL 200000
```

Max length of array to use serial calculation

9.21.3 Function Documentation

9.21.3.1 auto_corr_from_data()

```
void auto_corr_from_data (
             double ** data,
             int length,
             int dimension,
             int ** output,
             int num_segments,
             double target_corr,
             int num_threads )
```

Calculates the autocorrelation length for a set of data for a number of segments for each dimension – completely host code, utilitizes FFTW3 for longer chuncks of the chains.

Takes in the data from a sampler, shape data[N_steps][dimension]

Outputs lags that correspond to the target_corr – shape output[dimension][num_segments]

Parameters

	data	Input data
	length	length of input data
	dimension	dimension of data
out	*output*	array that stores the auto-corr lengths – array[num_segments]
	num_segments	number of segements to compute the auto-corr length
	target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
	num_threads	Total number of threads to use

9.21.3.2 auto_corr_intervals_outdated()

```
void auto_corr_intervals_outdated (
            double * data,
            int length,
            double * output,
            int num_segments,
            double accuracy )
```

Function that computes the autocorrelation length on an array of data at set intervals to help determine convergence.

outdated version – new version uses FFTs

Parameters

	data	Input data
	length	length of input data
out	*output*	array that stores the auto-corr lengths – array[num_segments]
	num_segments	number of segements to compute the auto-corr length
	accuracy	longer chains are computed numerically, this specifies the tolerance

9.21.3.3 auto_correlation_grid_search()

```
double auto_correlation_grid_search (
            double * arr,
            int length,
            int box_num,
            int final_length,
            double target_length )
```

OUTDATED – Grid search method of computing the autocorrelation – unreliable.

Hopefully more reliable than the box-search method, which can sometimes get caught in a recursive loop when the stepsize isn't tuned, but also faster than the basic linear, serial search

Parameters

arr	Input array to use for autocorrelation
length	Length of input array
box_num	number of boxes to use for each iteration, default is 10
final_length	number of elements per box at which the grid search ends and the serial calculation begins
target_length	target correlation that corresponds to the returned lag

9.21.3.4 auto_correlation_internal()

```
double auto_correlation_internal (
            double * arr,
            int length,
            int lag,
            double ave )
```

Internal function to compute the auto correlation for a given lag.

9.21.3.5 auto_correlation_serial()

```
double auto_correlation_serial (
            double * arr,
            int length,
            int start,
            double target )
```

Calculates the autocorrelation of a chain with the brute force method.

Parameters

arr	input array
length	Length of input array
start	starting index (probably 0)
target	Target autocorrelation for which `‘length'' is defined

9.21.3.6 auto_correlation_spectral() [1/2]

```
void auto_correlation_spectral (
            double * chain,
            int length,
            int start,
            double * autocorr,
```

```
fftw_outline * plan_forw,
fftw_outline * plan_rev )
```

Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT – accepts FFTW plan as argument for plan reuse and multi-threaded applications.

Based on the Wiener-Khinchin Theorem.

Algorithm used from https://lingpipe-blog.com/2012/06/08/autocorrelation-fft-kiss-eigen/

NOTE the length used in initializing the fftw plans should be L = pow(2, std::ceil(std::log2(length))) – the plans are padded so the total length is a power of two

Option to provide starting index for multi-dimension arrays in collapsed to one dimension

length is the length of the segment to be analyzed, not necessarily the dimension of the chain

9.21.3.7 auto_correlation_spectral() [2/2]

```
void auto_correlation_spectral (
            double * chain,
            int length,
            double * autocorr )
```

Faster approximation of the autocorrelation of a chain. Implements FFT/IFFT.

Based on the Wiener-Khinchin Theorem.

Algorithm used from https://lingpipe-blog.com/2012/06/08/autocorrelation-fft-kiss-eigen/

9.21.3.8 threaded_ac_serial()

```
void threaded_ac_serial (
            int thread,
            threaded_ac_jobs_serial job )
```

Internal routine to calculate an serial autocorrelation job.

Allows for a more efficient use of the threadPool class

9.21.3.9 threaded_ac_spectral()

```
void threaded_ac_spectral (
            int thread,
            threaded_ac_jobs_fft job )
```

Internal routine to calculate an spectral autocorrelation job.

Allows for a more efficient use of the threadPool class

9.21.3.10 write_auto_corr_file_from_data()

```
void write_auto_corr_file_from_data (
            std::string autocorr_filename,
            double ** data,
            int length,
            int dimension,
            int num_segments,
            double target_corr,
            int num_threads )
```

Writes the autocorrelation file from a data array.

Parameters

autocorr_filename	Name of the file to write the autocorrelation to
data	Input chains
length	length of input data
dimension	dimension of data
num_segments	number of segements to compute the auto-corr length
target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
num_threads	Total number of threads to use

9.21.3.11 write_auto_corr_file_from_data_file()

```
void write_auto_corr_file_from_data_file (
            std::string autocorr_filename,
            std::string datafile,
            int length,
            int dimension,
            int num_segments,
            double target_corr,
            int num_threads )
```

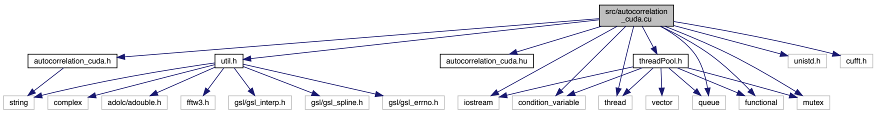
Parameters

length	length of input data
dimension	dimension of data
num_segments	number of segements to compute the auto-corr length
target_corr	Autocorrelation for which the autocorrelation length is defined (lag of autocorrelation for which it equals the target_corr)
num_threads	Total number of threads to use

9.22 src/autocorrelation_cuda.cu File Reference

```
#include "autocorrelation_cuda.h"
#include "autocorrelation_cuda.hu"
#include "util.h"
#include <iostream>
#include <condition_variable>
#include <thread>
#include <queue>
#include <functional>
#include <mutex>
#include <unistd.h>
#include <threadPool.h>
#include <cufft.h>
```

Include dependency graph for autocorrelation_cuda.cu:



Functions

- __device__ __host__ void auto_corr_internal (double ∗arr, int length, int lag, double average, double ∗corr, int start_id)

    Internal function to calculate the autocorrelation for a given lag Customized for the thread pool architecture, with extra arguments because of the way the memory is allocated.
- __global__ void auto_corr_internal_kernal (double ∗arr, int length, double average, int ∗rho_index, double target_corr, double var, int start_id)

    Internal function to launch the CUDA kernel for a range of autocorrelations.
- void write_file_auto_corr_from_data_file_accel (std::string acfile, std::string chains_file, int dimension, int N←_steps, int num_segments, double target_corr)

    Write data file for autocorrelation lengths of the data given a data file name, as written by the mcmc_sampler.
- void write_file_auto_corr_from_data_accel (std::string acfile, double ∗∗chains, int dimension, int N_steps, int num_segments, double target_corr)

    Write data file given output chains, as formatted by the mcmc_sampler.
- void auto_corr_from_data_accel (double ∗∗output, int dimension, int N_steps, int num_segments, double target_corr, double ∗∗autocorr)

    Find autocorrelation of data at different points in the chain length and output to autocorr.
- void ac_gpu_wrapper (int thread, int job_id)

    Wrapper function for the thread pool.
- void launch_ac_gpu (int device, int element, double ∗∗data, int length, int dimension, double target_corr, int num_segments)

    Launch the GPU kernel, formatted for the thread pool.
- void allocate_gpu_plan (GPUplan ∗plan, int data_length, int dimension, int num_segments)

    Allocates memory for autocorrelation–GPU structure.
- void deallocate_gpu_plan (GPUplan ∗plan, int data_length, int dimension, int num_segments)

    Deallocates memory for the autocorrelation–GPU structure.
- void copy_data_to_device (GPUplan ∗plan, double ∗∗input_data, int data_length, int dimension, int num_←segments)

    Copy data to device before starting kernels.

Variables

- GPUplan ∗ **plans_global**

9.22.1 Function Documentation

9.22.1.1 ac_gpu_wrapper()

```
void ac_gpu_wrapper (
            int thread,
            int job_id )
```

Wrapper function for the thread pool.

Parameters

thread	Host thread
job_id	Job ID

9.22.1.2 allocate_gpu_plan()

```
void allocate_gpu_plan (
            GPUplan * plan,
            int data_length,
            int dimension,
            int num_segments )
```

Allocates memory for autocorrelation–GPU structure.

Parameters

plan	Structure for GPU plan
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

9.22.1.3 auto_corr_from_data_accel()

```
void auto_corr_from_data_accel (
            double ** output,
            int dimension,
            int N_steps,
            int num_segments,
            double target_corr,
            double ** autocorr )
```

Find autocorrelation of data at different points in the chain length and output to autocorr.

Parameters

	output	Chain data input
	dimension	Dimension of the data
	N_steps	Number of steps in the data
	num_segments	number of segments to calculate the autocorrelation length
	target_corr	Target correlation ratio
out	*autocorr*	Autocorrelation lengths for the different segments

9.22.1.4 auto_corr_internal()

```
__device__ __host__ void auto_corr_internal (
            double * arr,
            int length,
            int lag,
            double average,
            double * corr,
            int start_id )
```

Internal function to calculate the autocorrelation for a given lag Customized for the thread pool architecture, with extra arguments because of the way the memory is allocated.

Parameters

	arr	Input array of data
	length	Length of input array
	lag	Lag to be used to calculate the correlation
	average	Average of the array arr
out	*corr*	output correlation
	start_id	ID of location to start calculation – input arrary arr is assumed to be contiguous for multiple dimensions

9.22.1.5 auto_corr_internal_kernal()

```
__global__ void auto_corr_internal_kernal (
            double * arr,
            int length,
            double average,
            int * rho_index,
            double target_corr,
            double var,
            int start_id )
```

Internal function to launch the CUDA kernel for a range of autocorrelations.

Correlation function used:

rho(lag) = 1 / (length - lag) \sum (arr[i+lag]-average) (arr[i]- average)

target_corr = rho(rho_index)/rho(0) = rho(rho_index)/var

Parameters

	arr	Input array of data
	length	Length of data array
	average	Average of input data
out	*rho_index*	Index of the lag that results ina correlation ratio target_corr
	target_corr	Target correlation ratio rho(lag)/rho(0) = target_corr
	var	Variance rho(0)
	start_id	Starting index to use for the data array arr

9.22.1.6 copy_data_to_device()

```
void copy_data_to_device (
            GPUplan * plan,
            double ** input_data,
            int data_length,
            int dimension,
            int num_segments )
```

Copy data to device before starting kernels.

Parameters

plan	GPU plan
input_data	Input chain data
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

9.22.1.7 deallocate_gpu_plan()

```
void deallocate_gpu_plan (
            GPUplan * plan,
            int data_length,
            int dimension,
            int num_segments )
```

Deallocates memory for the autocorrelation–GPU structure.

Parameters

plan	Structure for the GPU plan
data_length	Length of data
dimension	Dimension of the data
num_segments	Number of segments to calculate the autocorrelation length

9.22.1.8 write_file_auto_corr_from_data_accel()

```
void write_file_auto_corr_from_data_accel (
            std::string acfile,
            double ** chains,
            int dimension,
            int N_steps,
```

```
            int num_segments,
            double target_corr )
```

Write data file given output chains, as formatted by the mcmc_sampler.

Parameters

acfile	Output autocorrelation filename
chains	Chain data from MCMC_sampler
dimension	Dimension of the data
N_steps	Number of steps in the chain
num_segments	Number of segments to check the autocorrelation length for each dimension
target_corr	Target correlation ratio to use for the correlation length calculation

9.22.1.9 write_file_auto_corr_from_data_file_accel()

```
void write_file_auto_corr_from_data_file_accel (
            std::string acfile,
            std::string chains_file,
            int dimension,
            int N_steps,
            int num_segments,
            double target_corr )
```

Write data file for autocorrelation lengths of the data given a data file name, as written by the mcmc_sampler.

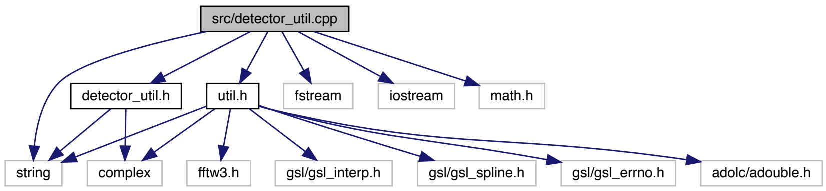
Parameters

acfile	Filename of the autocorrelation data
chains_file	Filename of the data file for the chains
dimension	Dimension of the data
N_steps	Number of steps in the chain
num_segments	Number of segments to check the autocorrelation length for each dimension
target_corr	Target correlation ratio to use for the correlation length calculation

9.23 src/detector_util.cpp File Reference

```
#include "detector_util.h"
#include "util.h"
#include <fstream>
#include <iostream>
#include <string>
#include <math.h>
```

Include dependency graph for detector_util.cpp:



Functions

- void populate_noise (double ∗frequencies, std::string detector, double ∗noise_root, int length)

  Function to populate the squareroot of the noise curve for various detectors.
- double aLIGO_analytic (double f)

  Analytic function approximating the PSD for aLIGO.
- double Hanford_O1_fitted (double f)

  Numerically fit PSD to the Hanford Detector's O1.
- std::complex< double > Q (double theta, double phi, double iota)

  Utility for the overall amplitude and phase shift for spin-aligned systems.
- double right_interferometer_plus (double theta, double phi)

  Response function of a 90 deg interferometer for plus polarization.
- double right_interferometer_cross (double theta, double phi)

  Response function of a 90 deg interferometer for cross polarization.
- void celestial_horizon_transform (double RA, double DEC, double gps_time, std::string detector, double ∗phi, double ∗theta)

  Transform from celestial coordinates to local horizontal coords.
- void derivative_celestial_horizon_transform (double RA, double DEC, double gps_time, std::string detector, double ∗dphi_dRA, double ∗dtheta_dRA, double ∗dphi_dDEC, double ∗dtheta_dDEC)

  Numerical derivative of the transformation.
- double DTOA (double theta1, double theta2, std::string detector1, std::string detector2)

  calculate difference in time of arrival (DTOA) for a given source location and 2 different detectors
- double radius_at_lat (double latitude, double elevation)
- void detector_response_functions_equatorial (double D[3][3], double ra, double dec, double psi, double gmst, double ∗Fplus, double ∗Fcross)

  Calculates the response coefficients for a detector with response tensor D for a source at RA, Dec, and psi.
- void detector_response_functions_equatorial (std::string detector, double ra, double dec, double psi, double gmst, double ∗Fplus, double ∗Fcross)

  Same as the other function, but for active detectors.

9.23.1 Detailed Description

Routines to construct noise curves for various detectors and for detector specific utilities for response functions and coordinate transformations

9.23.2 Function Documentation

9.23.2.1 aLIGO_analytic()

```
double aLIGO_analytic (
            double f )
```

Analytic function approximating the PSD for aLIGO.

CITE (Will?)

9.23.2.2 celestial_horizon_transform()

```
void celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            std::string detector,
            double * phi,
            double * theta )
```

Transform from celestial coordinates to local horizontal coords.

(RA,DEC) -> (altitude, azimuth)

Need gps_time of transformation, as the horizontal coords change in time

detector is used to specify the lat and long of the local frame

Parameters

RA	in RAD
DEC	in RAD
phi	in RAD
theta	in RAD

9.23.2.3 derivative_celestial_horizon_transform()

```
void derivative_celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            std::string detector,
            double * dphi_dRA,
            double * dtheta_dRA,
            double * dphi_dDEC,
            double * dtheta_dDEC )
```

Numerical derivative of the transformation.

Planned for use in Fisher calculations, but not currently implemented anywhere

Parameters

RA	in RAD
DEC	in RAD

9.23.2.4 detector_response_functions_equatorial() [1/2]

```
void detector_response_functions_equatorial (
            double D[3][3],
            double ra,
            double dec,
            double psi,
            double gmst,
            double * Fplus,
            double * Fcross )
```

Calculates the response coefficients for a detector with response tensor D for a source at RA, Dec, and psi.

Taken from LALSuite

The response tensor for each of the operational detectors is precomputed in detector_util.h, but to create a new tensor, follow the outline in Anderson et al 36 PRD 63 042003 (2001) Appendix B

Parameters

	D	Detector Response tensor (3x3)
	ra	Right ascension in rad
	dec	Declination in rad
	psi	polarization angle in rad
	gmst	Greenwich mean sidereal time (rad)
out	*Fplus*	Fplus response coefficient
out	*Fcross*	Fcross response coefficient

9.23.2.5 detector_response_functions_equatorial() [2/2]

```
void detector_response_functions_equatorial (
            std::string detector,
            double ra,
            double dec,
            double psi,
            double gmst,
            double * Fplus,
            double * Fcross )
```

Same as the other function, but for active detectors.

Parameters

	detector	Detector
	ra	Right ascension in rad
	dec	Declination in rad
	psi	polarization angle in rad
	gmst	Greenwich mean sidereal time (rad)
out	*Fplus*	Fplus response coefficient
out	*Fcross*	Fcross response coefficient

9.23.2.6 DTOA()

```
double DTOA (
            double theta1,
            double theta2,
            std::string detector1,
            std::string detector2 )
```

calculate difference in time of arrival (DTOA) for a given source location and 2 different detectors

Parameters

theta1	spherical polar angle for detector 1 in RAD
theta2	spherical polar angle for detector 2 in RAD
detector1	name of detector one
detector2	name of detector two

9.23.2.7 Hanford_O1_fitted()

```
double Hanford_O1_fitted (
            double f )
```

Numerically fit PSD to the Hanford Detector's O1.

CITE (Yunes?)

9.23.2.8 populate_noise()

```
void populate_noise (
            double * frequencies,
            std::string detector,
            double * noise_root,
            int length )
```

Function to populate the squareroot of the noise curve for various detectors.

If frequencies are left as NULL, standard frequency spacing is applied and the frequencies are returned, in which case the frequencies argument becomes an output array

Detector names must be spelled exactly

Detectors include: aLIGO_analytic, Hanford_O1_fitted

Parameters

frequencies	double array of frquencies (NULL)
detector	String to designate the detector noise curve to be used
noise_root	ouptput double array for the square root of the PSD of the noise of the specified detector
length	integer length of the output and input arrays

9.23.2.9 Q()

```
std::complex<double> Q (
            double theta,
            double phi,
            double iota )
```

Utility for the overall amplitude and phase shift for spin-aligned systems.

For spin aligned, all the extrinsic parameters have the effect of an overall amplitude modulation and phase shift

9.23.2.10 radius_at_lat()

```
double radius_at_lat (
            double latitude,
            double elevation )
```

/brief Analytic approximation of the radius from the center of earth to a given location

Just the raidus as a function of angles, modelling an oblate spheroid

Parameters

latitude	latitude in degrees
elevation	elevation in meters

9.23.2.11 right_interferometer_cross()

```
double right_interferometer_cross (
            double theta,
            double phi )
```

Response function of a 90 deg interferometer for cross polarization.

Theta and phi are local, horizontal coordinates relative to the detector

9.23.2.12 right_interferometer_plus()

```
double right_interferometer_plus (
            double theta,
            double phi )
```

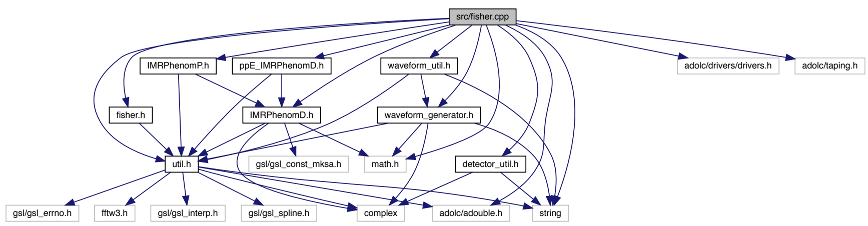
Response function of a 90 deg interferometer for plus polarization.

Theta and phi are local, horizontal coordinates relative to the detector

9.24 src/fisher.cpp File Reference

```
#include <fisher.h>
#include <adolc/adouble.h>
#include <adolc/drivers/drivers.h>
#include <adolc/taping.h>
#include <math.h>
#include <string>
#include "util.h"
#include "detector_util.h"
#include "IMRPhenomD.h"
#include "IMRPhenomP.h"
#include "ppE_IMRPhenomD.h"
#include "waveform_generator.h"
#include "waveform_util.h"
```

Include dependency graph for fisher.cpp:



Functions

- void fisher (double ∗frequency, int length, string generation_method, string detector, double ∗∗output, int dimension, gen_params ∗parameters, int ∗amp_tapes, int ∗phase_tapes, double ∗noise)

  Calculates the fisher matrix for the given arguments.
- void calculate_derivatives (double ∗∗amplitude_deriv, double ∗∗phase_deriv, double ∗amplitude, double ∗frequencies, int length, string detector, string gen_method, gen_params ∗parameters)

  Abstraction layer for handling the case separation for the different waveforms.
- void fisher_autodiff (double ∗frequency, int length, string generation_method, string detector, double ∗∗output, int dimension, gen_params ∗parameters, int ∗amp_tapes, int ∗phase_tapes, double ∗noise)

  Calculates the fisher matrix for the given arguments to within numerical error using automatic differention - slower than the numerical version.

9.24.1 Detailed Description

All subroutines associated with waveform differentiation and Fisher analysis

9.24.2 Function Documentation

9.24.2.1 calculate_derivatives()

```
void calculate_derivatives (
            double ** amplitude_deriv,
            double ** phase_deriv,
            double * amplitude,
            double * frequencies,
            int length,
            string detector,
            string gen_method,
            gen_params * parameters )
```

Abstraction layer for handling the case separation for the different waveforms.

9.24.2.2 fisher()

```
void fisher (
            double * frequency,
            int length,
            string generation_method,
            string detector,
            double ** output,
            int dimension,
            gen_params * parameters,
            int * amp_tapes,
            int * phase_tapes,
            double * noise )
```

Calculates the fisher matrix for the given arguments.

Parameters

length	if 0, standard frequency range for the detector is used
output	double [dimension][dimension]
amp_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method
phase_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method

9.24.2.3 fisher_autodiff()

```
void fisher_autodiff (
            double * frequency,
            int length,
            string generation_method,
            string detector,
            double ** output,
            int dimension,
            gen_params * parameters,
            int * amp_tapes,
            int * phase_tapes,
            double * noise )
```

Calculates the fisher matrix for the given arguments to within numerical error using automatic differention - slower than the numerical version.

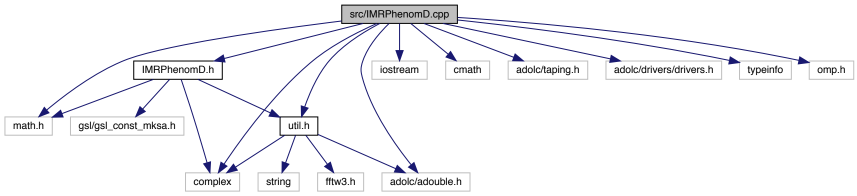
Parameters

length	if 0, standard frequency range for the detector is used
output	double [dimension][dimension]
amp_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method
phase_tapes	if speed is required, precomputed tapes can be used - assumed the user knows what they're doing, no checks done here to make sure that the number of tapes matches the requirement by the generation_method

9.25 src/IMRPhenomD.cpp File Reference

```
#include "IMRPhenomD.h"
#include "util.h"
#include <math.h>
#include <iostream>
#include <complex>
#include <cmath>
#include <adolc/adouble.h>
#include <adolc/taping.h>
#include <adolc/drivers/drivers.h>
#include <typeinfo>
#include <omp.h>
```

Include dependency graph for IMRPhenomD.cpp:



Macros

- #define **omp** ignore

Variables

- double **log_64** = 4.15888308336

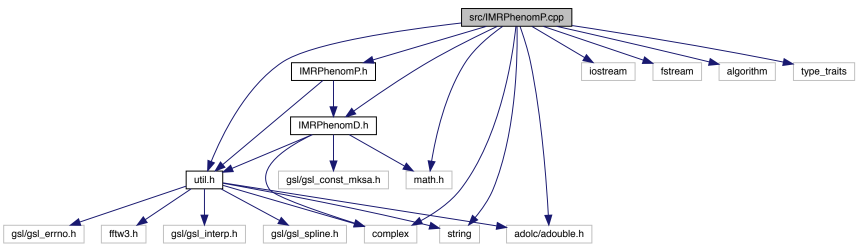
9.25.1 Detailed Description

File that includes all the low level functions that go into constructing the waveform

9.26 src/IMRPhenomP.cpp File Reference

```
#include "IMRPhenomP.h"
#include <iostream>
#include <fstream>
#include <string>
#include <complex>
#include "IMRPhenomD.h"
#include "util.h"
#include <adolc/adouble.h>
#include <math.h>
#include <algorithm>
#include <type_traits>
```

Include dependency graph for IMRPhenomP.cpp:



Macros

- #define **ROTATEZ**(angle, vx, vy, vz)
- #define **ROTATEY**(angle, vx, vy, vz)

Variables

- const double **sqrt_6** = 2.44948974278317788

9.26.1 Detailed Description

Source code for IMRPhenomP

9.26.2 Macro Definition Documentation

9.26.2.1 ROTATEY

```
#define ROTATEY(
              angle,
              vx,
              vy,
              vz )
```

Value:

```
tmp1 = vx*cos(angle) + vz*sin(angle);\
tmp2 = - vx*sin(angle) + vz*cos(angle);\
vx = tmp1;\
vz = tmp2
```

9.26.2.2 ROTATEZ

```
#define ROTATEZ(
              angle,
              vx,
              vy,
              vz )
```

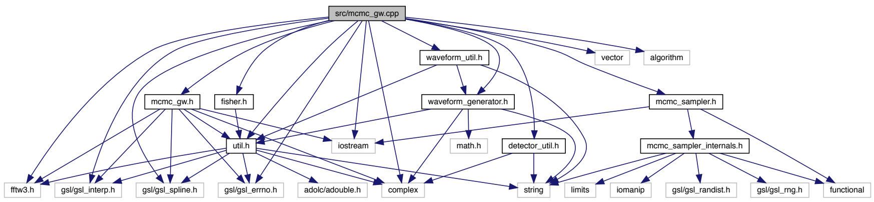
Value:

```
tmp1 = vx*cos(angle) - vy*sin(angle);\
tmp2 = vx*sin(angle) + vy*cos(angle);\
vx = tmp1;\
vy = tmp2
```

9.27 src/mcmc_gw.cpp File Reference

```
#include "mcmc_gw.h"
#include "waveform_generator.h"
#include "util.h"
#include "detector_util.h"
#include "waveform_util.h"
#include "fisher.h"
#include "mcmc_sampler.h"
#include <iostream>
#include <vector>
#include <complex>
#include <fftw3.h>
#include <algorithm>
#include <gsl/gsl_interp.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_errno.h>
```

Include dependency graph for mcmc_gw.cpp:



Functions

- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, int length, std::complex< double > ∗data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag, fftw_outline ∗plan)

  Function to calculate the log Likelihood as defined by -1/2 (d-h|d-h) maximized over the extrinsic parameters phic and tc.
- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag)
- double maximized_coal_log_likelihood_IMRPhenomD (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double SNR, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, bool NSflag, fftw_outline ∗plan)
- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, int length, std::complex< double > ∗data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag, fftw_outline ∗plan)
- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag)
- double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (double ∗frequencies, size_t length, double ∗real_data, double ∗imag_data, double ∗noise, double chirpmass, double symmetric_mass_ratio, double spin1, double spin2, double Luminosity_Distance, double theta, double phi, double iota, bool NSflag, fftw_outline ∗plan)
- double maximized_Log_Likelihood (std::complex< double > ∗data, double ∗psd, double ∗frequencies, size_t length, gen_params ∗params, std::string detector, std::string generation_method, fftw_outline ∗plan)

routine to maximize over all extrinsic quantities and return the log likelihood

- double **maximized_Log_Likelihood** (double *data_real, double *data_imag, double *psd, double *frequencies, size_t length, gen_params *params, std::string detector, std::string generation_method, fftw_outline *plan)
- double maximized_coal_Log_Likelihood (std::complex< double > *data, double *psd, double *frequencies, size_t length, gen_params *params, std::string detector, std::string generation_method, fftw_outline *plan, double *tc, double *phic)

    Function to maximize only over coalescence variables tc and phic, returns the maximum values used.
- double **maximized_coal_Log_Likelihood_internal** (std::complex< double > *data, double *psd, double *frequencies, std::complex< double > *detector_response, size_t length, fftw_outline *plan, double *tc, double *phic)
- double Log_Likelihood (std::complex< double > *data, double *psd, double *frequencies, size_t length, gen_params *params, std::string detector, std::string generation_method, fftw_outline *plan)

    Unmarginalized log of the likelihood.
- double maximized_Log_Likelihood_aligned_spin_internal (std::complex< double > *data, double *psd, double *frequencies, std::complex< double > *detector_response, size_t length, fftw_outline *plan)

    Maximized match over coalescence variables - returns log likelihood NOT NORMALIZED for aligned spins.
- double maximized_Log_Likelihood_unaligned_spin_internal (std::complex< double > *data, double *psd, double *frequencies, std::complex< double > *hplus, std::complex< double > *hcross, size_t length, fftw_outline *plan)

    log likelihood function that maximizes over extrinsic parameters tc, phic, D, and phiRef, the reference frequency - for unaligned spins
- double Log_Likelihood_internal (std::complex< double > *data, double *psd, double *frequencies, std::complex< double > *detector_response, int length, fftw_outline *plan)

    Internal function for the unmarginalized log of the likelihood.
- void PTMCMC_MH_GW (double ***output, int dimension, int N_steps, int chain_N, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, double(*log_prior)(double *param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > **data, double **noise_psd, double **frequencies, int *data_length, double gps_time, std::string *detectors, int Nmod, int *bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)

    Wrapper for the MCMC_MH function, specifically for GW analysis.
- void PTMCMC_MH_dynamic_PT_alloc_GW (double ***output, int dimension, int N_steps, int chain_N, int max_chain_N_thermo_ensemble, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, int t0, int nu, std::string chain_distribution_scheme, double(*log_prior)(double *param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > **data, double **noise_psd, double **frequencies, int *data_length, double gps_time, std::string *detectors, int Nmod, int *bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_filename)

    Takes in an MCMC checkpoint file and continues the chain.
- void continue_PTMCMC_MH_GW (std::string start_checkpoint_file, double ***output, int dimension, int N_steps, int swp_freq, double(*log_prior)(double *param, int dimension, int chain_id), int numThreads, bool pool, bool show_prog, int num_detectors, std::complex< double > **data, double **noise_psd, double **frequencies, int *data_length, double gps_time, std::string *detectors, int Nmod, int *bppe, std::string generation_method, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string final_checkpoint_filename)

    Takes in an MCMC checkpoint file and continues the chain.
- void PTMCMC_method_specific_prep (std::string generation_method, int dimension, double *seeding_var, bool local_seeding)

    Unpacks MCMC parameters for method specific initiation.
- void MCMC_fisher_wrapper (double *param, int dimension, double **output, int chain_id)

    Fisher function for MCMC for GW.
- double **MCMC_likelihood_extrinisic** (bool save_waveform, gen_params *parameters, std::string generation_method, int *data_length, double **frequencies, std::complex< double > **data, double **psd, std::string *detectors, fftw_outline *fftw_plans, int num_detectors, double RA, double DEC, double gps_time)

- double MCMC_likelihood_wrapper (double *param, int dimension, int chain_id)
  log likelihood function for MCMC for GW

9.27.1 Detailed Description

Routines for implementation in MCMC algorithms specific to GW CBC analysis

9.27.2 Function Documentation

9.27.2.1 continue_PTMCMC_MH_GW()

```
void continue_PTMCMC_MH_GW (
            std::string start_checkpoint_file,
            double *** output,
            int dimension,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string final_checkpoint_filename )
```

Takes in an MCMC checkpoint file and continues the chain.

Obviously, the user must be sure to correctly match the dimension, number of chains, the generation_method, the prior function, the data, psds, freqs, and the detectors (number and name), and the gps_time to the previous run, otherwise the behavior of the sampler is undefined.

numThreads and pool do not necessarily have to be the same

9.27.2.2 Log_Likelihood()

```
double Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan )
```

Unmarginalized log of the likelihood.

9.27.2.3 Log_Likelihood_internal()

```
double Log_Likelihood_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * detector_response,
            int length,
            fftw_outline * plan )
```

Internal function for the unmarginalized log of the likelihood.

.5 $*$ ((h | h) - 2 (D | h))

9.27.2.4 maximized_coal_Log_Likelihood()

```
double maximized_coal_Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan,
            double * tc,
            double * phic )
```

Function to maximize only over coalescence variables tc and phic, returns the maximum values used.

9.27.2.5 maximized_coal_log_likelihood_IMRPhenomD() [1/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
            int length,
            std::complex< double > * data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag,
            fftw_outline * plan )
```

Function to calculate the log Likelihood as defined by -1/2 (d-h|d-h) maximized over the extrinsic parameters phic and tc.

frequency array must be uniform spacing - this shouldn't be a problem when working with real data as DFT return uniform spacing

Parameters

chirpmass	in solar masses

9.27.2.6 maximized_coal_log_likelihood_IMRPhenomD() [2/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag )
```

Parameters

chirpmass	in solar masses

9.27.2.7 maximized_coal_log_likelihood_IMRPhenomD() [3/3]

```
double maximized_coal_log_likelihood_IMRPhenomD (
            double * frequencies,
```

```
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double SNR,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.27.2.8 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [1/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            int length,
            std::complex< double > * data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            double Luminosity_Distance,
            double theta,
            double phi,
            double iota,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.27.2.9 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [2/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
```

```
double spin2,
double Luminosity_Distance,
double theta,
double phi,
double iota,
bool NSflag )
```

Parameters

chirpmass	in solar masses

9.27.2.10 maximized_coal_log_likelihood_IMRPhenomD_Full_Param() [3/3]

```
double maximized_coal_log_likelihood_IMRPhenomD_Full_Param (
            double * frequencies,
            size_t length,
            double * real_data,
            double * imag_data,
            double * noise,
            double chirpmass,
            double symmetric_mass_ratio,
            double spin1,
            double spin2,
            double Luminosity_Distance,
            double theta,
            double phi,
            double iota,
            bool NSflag,
            fftw_outline * plan )
```

Parameters

chirpmass	in solar masses

9.27.2.11 maximized_Log_Likelihood()

```
double maximized_Log_Likelihood (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            size_t length,
            gen_params * params,
            std::string detector,
            std::string generation_method,
            fftw_outline * plan )
```

routine to maximize over all extrinsic quantities and return the log likelihood

IMRPhenomD – maximizes over DL, phic, tc, \iota, \phi, \theta IMRPhenomP – maximizes over DL, phic,tc, \psi, \phi , \theta

9.27.2.12 maximized_Log_Likelihood_aligned_spin_internal()

```
double maximized_Log_Likelihood_aligned_spin_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * detector_response,
            size_t length,
            fftw_outline * plan )
```

Maximized match over coalescence variables - returns log likelihood NOT NORMALIZED for aligned spins.

Note: this function is not properly normalized for an absolute comparison. This is made for MCMC sampling, so to minimize time, constant terms like (Data|Data), which would cancel in the Metropolis-Hasting ratio, are left out for efficiency

9.27.2.13 maximized_Log_Likelihood_unaligned_spin_internal()

```
double maximized_Log_Likelihood_unaligned_spin_internal (
            std::complex< double > * data,
            double * psd,
            double * frequencies,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            size_t length,
            fftw_outline * plan )
```

log likelihood function that maximizes over extrinsic parameters tc, phic, D, and phiRef, the reference frequency - for unaligned spins

Ref: arXiv 1603.02444v2

9.27.2.14 MCMC_fisher_wrapper()

```
void MCMC_fisher_wrapper (
            double * param,
            int dimension,
            double ** output,
            int chain_id )
```

Fisher function for MCMC for GW.

Wraps the fisher calculation in src/fisher.cpp and unpacks parameters correctly for common GW analysis

Supports all the method/parameter combinations found in MCMC_MH_GW

9.27.2.15 MCMC_likelihood_wrapper()

```
double MCMC_likelihood_wrapper (
            double * param,
            int dimension,
            int chain_id )
```

log likelihood function for MCMC for GW

Wraps the above likelihood functions and unpacks parameters correctly for common GW analysis

Supports all the method/parameter combinations found in MCMC_MH_GW

9.27.2.16 PTMCMC_method_specific_prep()

```
void PTMCMC_method_specific_prep (
            std::string generation_method,
            int dimension,
            double * seeding_var,
            bool local_seeding )
```

Unpacks MCMC parameters for method specific initiation.

Populates seeding vector if non supplied, populates mcmc_Nmod, populates mcmc_log_beta, populates mcmc_↩
intrinsic

9.27.2.17 PTMCMC_MH_dynamic_PT_alloc_GW()

```
void PTMCMC_MH_dynamic_PT_alloc_GW (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_filename )
```

Takes in an MCMC checkpoint file and continues the chain.

Obviously, the user must be sure to correctly match the dimension, number of chains, the generation_method, the prior function, the data, psds, freqs, and the detectors (number and name), and the gps_time to the previous run, otherwise the behavior of the sampler is undefined.

numThreads and pool do not necessarily have to be the same

9.27.2.18 PTMCMC_MH_GW()

```
void PTMCMC_MH_GW (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            int numThreads,
            bool pool,
            bool show_prog,
            int num_detectors,
            std::complex< double > ** data,
            double ** noise_psd,
            double ** frequencies,
            int * data_length,
            double gps_time,
            std::string * detectors,
            int Nmod,
            int * bppe,
            std::string generation_method,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Wrapper for the MCMC_MH function, specifically for GW analysis.

Handles the details of setting up the MCMC sampler and wraps the fisher and log likelihood to conform to the format of the sampler

NOTE – This sampler is NOT thread safe. There is global memory declared for each call to MCMC_MH_GW, so separate samplers should not be run in the same process space

Supported parameter combinations:

IMRPhenomD - 4 dimensions – ln chirpmass, eta, chi1, chi2

IMRPhenomD - 7 dimensions – ln D_L, tc, phic, ln chirpmass, eta, chi1, chi2

IMRPhenomD - 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2

dCS_IMRPhenomD_log - 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, ln \alpha^2 (the coupling parameter)

dCS_IMRPhenomD- 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, \alpha^2 (the coupling parameter)

dCS_IMRPhenomD_root_alpha- 8 dimensions – cos inclination, RA, DEC, ln D_L, ln chirpmass, eta, chi1, chi2, \sqrt \alpha (in km) (the coupling parameter)

IMRPhenomPv2 - 9 dimensions – cos J_N, ln chirpmass, eta, |chi1|, |chi1|, theta_1, theta_2, phi_1, phi_2

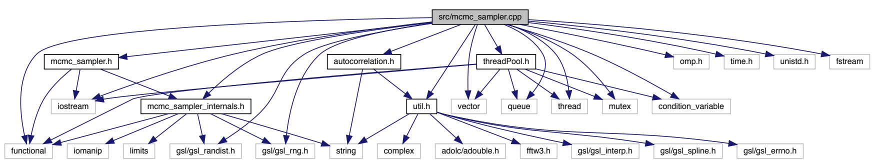
Parameters

statistics_filename	Filename to output sampling statistics, if empty string, not output
chain_filename	Filename to output data (chain 0 only), if empty string, not output
auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28 src/mcmc_sampler.cpp File Reference

```
#include "mcmc_sampler.h"
#include "autocorrelation.h"
#include "util.h"
#include "mcmc_sampler_internals.h"
#include "threadPool.h"
#include <iostream>
#include <gsl/gsl_rng.h>
#include <gsl/gsl_randist.h>
#include <omp.h>
#include <time.h>
#include <condition_variable>
#include <mutex>
#include <thread>
#include <vector>
#include <queue>
#include <functional>
#include <unistd.h>
#include <fstream>
```

Include dependency graph for mcmc_sampler.cpp:



Classes

- class Comparator

  Class to facilitate the comparing of chains for priority.
- class Comparatorswap
- class ThreadPool

Macros

- #define **omp** ignore

Functions

- void RJPTMCMC_MH_internal (double ***output, int ***parameter_status, int max_dimension, int min_dimension, int N_steps, int chain_N, double *initial_pos, int *initial_status, double *seeding_var, double *chain_temps, int swp_freq, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, std::function< void(double *, double *, int *, int *, int, int)> RJ_proposal, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)

    Generic reversable jump sampler, where the likelihood, prior, and reversable jump proposal are parameters supplied by the user.
- void PTMCMC_MH_dynamic_PT_alloc_internal (double ***output, int dimension, int N_steps, int chain_N, int max_chain_N_thermo_ensemble, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, int t0, int nu, std::string chain_distribution_scheme, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_file)

    Dyanmically tunes an MCMC for optimal spacing. step width, and chain number.
- void PTMCMC_MH_internal (double ***output, int dimension, int N_steps, int chain_N, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)

    Generic sampler, where the likelihood, prior are parameters supplied by the user.
- void continue_PTMCMC_MH_internal (std::string start_checkpoint_file, double ***output, int N_steps, int swp_freq, std::function< double(double *, int *, int, int)> log_prior, std::function< double(double *, int *, int, int)> log_likelihood, std::function< void(double *, int *, int, double **, int)>fisher, int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string end_checkpoint_file)

    Routine to take a checkpoint file and begin a new chain at said checkpoint.
- void PTMCMC_MH_step_incremental (sampler *sampler, int increment)

    Internal function that runs the actual loop for the sampler – increment version.
- void PTMCMC_MH_loop (sampler *sampler)

    Internal function that runs the actual loop for the sampler.
- void **mcmc_step_threaded** (int j)
- void **mcmc_swap_threaded** (int i, int j)
- void PTMCMC_MH (double ***output, int dimension, int N_steps, int chain_N, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, double(*log_prior)(double *param, int dimension), double(*log_likelihood)(double *param, int dimension), void(*fisher)(double *param, int dimension, double **fisher), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void PTMCMC_MH (double ***output, int dimension, int N_steps, int chain_N, double *initial_pos, double *seeding_var, double *chain_temps, int swp_freq, double(*log_prior)(double *param, int dimension, int chain_id), double(*log_likelihood)(double *param, int dimension, int chain_id), void(*fisher)(double *param, int dimension, double **fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void continue_PTMCMC_MH (std::string start_checkpoint_file, double ***output, int N_steps, int swp_freq, double(*log_prior)(double *param, int dimension, int chain_id), double(*log_likelihood)(double *param, int dimension, int chain_id), void(*fisher)(double *param, int dimension, double **fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string end_checkpoint_file)
- void continue_PTMCMC_MH (std::string start_checkpoint_file, double ***output, int N_steps, int swp_freq, double(*log_prior)(double *param, int dimension), double(*log_likelihood)(double *param, int dimension), void(*fisher)(double *param, int dimension, double **fisher), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string end_checkpoint_file)

- void PTMCMC_MH_dynamic_PT_alloc (double ∗∗∗output, int dimension, int N_steps, int chain_N, int max↩_chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp_↩freq, int t0, int nu, std::string chain_distribution_scheme, double(∗log_prior)(double ∗param, int dimension), double(∗log_likelihood)(double ∗param, int dimension), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_↩filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void PTMCMC_MH_dynamic_PT_alloc (double ∗∗∗output, int dimension, int N_steps, int chain_N, int max↩_chain_N_thermo_ensemble, double ∗initial_pos, double ∗seeding_var, double ∗chain_temps, int swp↩_freq, int t0, int nu, std::string chain_distribution_scheme, double(∗log_prior)(double ∗param, int dimension, int chain_id), double(∗log_likelihood)(double ∗param, int dimension, int chain_id), void(∗fisher)(double ∗param, int dimension, double ∗∗fisher, int chain_id), int numThreads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string likelihood_log_filename, std::string checkpoint_file)
- void RJPTMCMC_MH (double ∗∗∗output, int ∗∗∗parameter_status, int max_dimension, int min_dimension, int N_steps, int chain_N, double ∗initial_pos, int ∗initial_status, double ∗seeding_var, double ∗chain_temps, int swp_freq, double(∗log_prior)(double ∗param, int ∗status, int max_dimension, int chain_id), double(∗log↩_likelihood)(double ∗param, int ∗status, int max_dimension, int chain_id), void(∗fisher)(double ∗param, int ∗status, int max_dimension, double ∗∗fisher, int chain_id), void(∗RJ_proposal)(double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int max_dimension, int chain_id), int num↩Threads, bool pool, bool show_prog, std::string statistics_filename, std::string chain_filename, std::string auto_corr_filename, std::string likelihood_log_filename, std::string checkpoint_file)

Variables

- const gsl_rng_type ∗ **T**
- gsl_rng ∗ **r**
- sampler ∗ **samplerptr**
- ThreadPool ∗ **poolptr**

9.28.1 Detailed Description

Source file for the sampler foundation

Source file for generic MCMC sampler. Sub routines that are application agnostic are housed in mcmc_sampler↩_internals

9.28.2 Function Documentation

9.28.2.1 continue_PTMCMC_MH() [1/2]

```
void continue_PTMCMC_MH (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
```

```
bool show_prog,
std::string statistics_filename,
std::string chain_filename,
std::string auto_corr_filename,
std::string likelihood_log_filename,
std::string end_checkpoint_file )
```

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use
	pool	Boolean for whether to use `deterministic'' vs`stochastic" sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.28.2.2 continue_PTMCMC_MH() [2/2]

```
void continue_PTMCMC_MH (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string end_checkpoint_file )
```

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use

Parameters

	pool	Boolean for whether to use `deterministic'' vs`stochastic" sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.28.2.3 continue_PTMCMC_MH_internal()

```
void continue_PTMCMC_MH_internal (
            std::string start_checkpoint_file,
            double *** output,
            int N_steps,
            int swp_freq,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string end_checkpoint_file )
```

Routine to take a checkpoint file and begin a new chain at said checkpoint.

See MCMC_MH_internal for more details of parameters (pretty much all the same)

Parameters

	start_checkpoint_file	File for starting checkpoint
out	*output*	output array, dimensions: output[chain_N][N_steps][dimension]
	N_steps	Number of new steps to take
	swp_freq	frequency of swap attempts between temperatures
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id
	numThreads	Number of threads to use
	pool	Boolean for whether to use `deterministic'' vs`stochastic" sampling
	show_prog	Boolean for whether to show progress or not (turn off for cluster runs

Parameters

	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	end_checkpoint_file	Filename to output data for checkpoint at the end of the continued run, if empty string, not saved

9.28.2.4 PTMCMC_MH() [1/2]

```
void PTMCMC_MH (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)

Parameters

	show_prog	boolean whether to print out progress (for example, should be set to `'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.5 PTMCMC_MH() [2/2]

```
void PTMCMC_MH (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)

Parameters

	show_prog	boolean whether to print out progress (for example, should be set to ‘‘false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.6 PTMCMC_MH_dynamic_PT_alloc() [1/2]

```
void PTMCMC_MH_dynamic_PT_alloc (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension) log_prior,
            double(*)(double *param, int dimension) log_likelihood,
            void(*)(double *param, int dimension, double **fisher) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]

Parameters

	chain_temps	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics ($\sim$1000)
	nu	Initial amplitude of the dynamics ($\sim$100)
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`\`false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.7 PTMCMC_MH_dynamic_PT_alloc() [2/2]

```
void PTMCMC_MH_dynamic_PT_alloc (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            double(*)(double *param, int dimension, int chain_id) log_prior,
            double(*)(double *param, int dimension, int chain_id) log_likelihood,
            void(*)(double *param, int dimension, double **fisher, int chain_id) fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]

Parameters

	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics (∼1000)
	nu	Initial amplitude of the dynamics (∼100)
	log_prior	Funcion pointer for the log_prior
	log_likelihood	Function pointer for the log_likelihood
	fisher	Function pointer for the fisher - if NULL, fisher steps are not used
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to `‘false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.8 PTMCMC_MH_dynamic_PT_alloc_internal()

```
void PTMCMC_MH_dynamic_PT_alloc_internal (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            int max_chain_N_thermo_ensemble,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            int t0,
            int nu,
            std::string chain_distribution_scheme,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
```

```
bool show_prog,
std::string statistics_filename,
std::string chain_filename,
std::string likelihood_log_filename,
std::string checkpoint_file )
```

Dyanmically tunes an MCMC for optimal spacing. step width, and chain number.

NOTE: nu, and t0 parameters determine the dynamics, so these are important quantities. nu is related to how many swap attempts it takes to substantially change the temperature ladder, why t0 determines the length of the total dyanimcally period. Moderate initial choices would be 10 and 1000, respectively.

Based on arXiv:1501.05823v3

Currently, Chain number is fixed

max_chain_N_thermo_ensemble sets the maximium number of chains to use to in successively hotter chains to cover the likelihood surface while targeting an optimal swap acceptance target_swp_acc.

max_chain_N determines the total number of chains to run once thermodynamic equilibrium has been reached. This results in chains being added after the initial PT dynamics have finished according to chain_distribution_↩ scheme.

If no preference, set max_chain_N_thermo_ensemble = max_chain_N = numThreads = (number of cores (number of threads if hyperthreaded))– this will most likely be the most optimal configuration. If the number of cores on the system is low, you may want to use n∗numThreads for some integer n instead, depending on the system.

chain_distribution_scheme:

"cold": All chains are added at T=1 (untempered)

"refine": Chains are added between the optimal temps geometrically – this may be a good option as it will be a good approximation of the ideal distribution of chains, while keeping the initial dynamical time low

"double": Chains are added in order of rising temperature that mimic the distribution achieved by the earier PT dynamics

"half_ensemble": For every cold chain added, half of the ensemble is added again. Effectively, two cold chains for every ensemble

Parameters

out	*output*	Output chains, shape is double[max_chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain AFTER chain allocation
	chain_N	Maximum number of chains to use
	max_chain_N_thermo_ensemble	Maximum number of chains to use in the thermodynamic ensemble (may use less)
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
out	*chain_temps*	Final chain temperatures used – should be shape double[chain_N]
	swp_freq	the frequency with which chains are swapped
	t0	Time constant of the decay of the chain dynamics (∼1000)

Parameters

	nu	Initial amplitude of the dynamics (∼100)
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`'false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.9 PTMCMC_MH_internal()

```
void PTMCMC_MH_internal (
            double *** output,
            int dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            std::function< double(double *, int *, int, int)> log_prior,
            std::function< double(double *, int *, int, int)> log_likelihood,
            std::function< void(double *, int *, int, double **, int)> fisher,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Generic sampler, where the likelihood, prior are parameters supplied by the user.

Base of the sampler, generic, with user supplied quantities for most of the samplers properties

Uses the Metropolis-Hastings method, with the option for Fisher/MALA steps if the Fisher routine is supplied.

3 modes to use -

single threaded (numThreads = 1) runs single threaded multi-threaded `‘deterministic'' (numThreads>1 ; pool = false) progresses each chain in parallel for swp_freq steps, then waits for all threads to complete before swapping temperatures in sequenctial order (j, j+1) then (j+1, j+2) etc (sequenctially)

multi-threaded `‘stochastic'' (numThreads>2 ; pool = true) progresses each chain in parallel by queueing each temperature and evaluating them in the order they were submitted. Once finished, the threads are queued to swap, where they swapped in the order they are submitted. This means the chains are swapped randomly, and the chains do NOT finish at the same time. The sampler runs until the the 0th chain reaches the step number

Note on limits: In the prior function, if a set of parameters should be disallowed, return -std::numeric_↩ limits<double>::infinity() – (this is in the <limits> file in std)

Format for the auto_corr file (compatable with csv, dat, txt extensions): each row is a dimension of the cold chain, with the first row being the lengths used for the auto-corr calculation:

lengths: length1 , length2 ...

dim1: length1 , length2 ...

Format for the chain file (compatable with csv, dat, txt extensions): each row is a step, each column a dimension:

Step1: dim1 , dim2 , ...

Step2: dim1 , dim2 , ...

Statistics_filename : should be txt extension

checkpoint_file : This file saves the final position of all the chains, as well as other metadata, and can be loaded by the function <FUNCTION> to continue the chain from the point it left off. Not meant to be read by humans, the data order is custom to this software library. An empty string ("") means no checkpoint will be saved. For developers, the contents are:

dimension, # of chains

temps of chains

Stepping widths of all chains

Final position of all chains

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
	dimension	dimension of the parameter space being explored
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[dimension]
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	std::function for the log_prior function – takes double ∗position, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double ∗position, int dimension, int chain_id
	fisher	std::function for the fisher function – takes double ∗position, int dimension, double ∗∗output_fisher, int chain_id

Parameters

	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to \`\`false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.10 PTMCMC_MH_loop()

```
void PTMCMC_MH_loop (
            sampler * sampler )
```

Internal function that runs the actual loop for the sampler.

9.28.2.11 PTMCMC_MH_step_incremental()

```
void PTMCMC_MH_step_incremental (
            sampler * sampler,
            int increment )
```

Internal function that runs the actual loop for the sampler – increment version.

The regular loop function runs for the entire range, this increment version will only step \`\`increment'' steps – asynchronous: steps are measured by the cold chains NEEDS TO CHANGE

9.28.2.12 RJPTMCMC_MH()

```
void RJPTMCMC_MH (
            double *** output,
            int *** parameter_status,
            int max_dimension,
            int min_dimension,
            int N_steps,
            int chain_N,
            double * initial_pos,
            int * initial_status,
            double * seeding_var,
            double * chain_temps,
            int swp_freq,
            double(*)(double *param, int *status, int max_dimension, int chain_id) log_prior,
```

```
            double(*)(double *param, int *status, int max_dimension, int chain_id) log_↩
likelihood,
            void(*)(double *param, int *status, int max_dimension, double **fisher, int chain↩
_id) fisher,
            void(*)(double *current_param, double *proposed_param, int *current_status, int
*proposed_status, int max_dimension, int chain_id) RJ_proposal,
            int numThreads,
            bool pool,
            bool show_prog,
            std::string statistics_filename,
            std::string chain_filename,
            std::string auto_corr_filename,
            std::string likelihood_log_filename,
            std::string checkpoint_file )
```

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
out	*parameter_status*	Parameter status for each step corresponding to the output chains, shape is double[chain_N, N_steps,dimension]
	max_dimension	maximum dimension of the parameter space being explored – only consideration is memory, as memory scales with dimension. Keep this reasonable, unless memory is REALLY not an issue
	min_dimension	minimum dimension of the parameter space being explored >=1
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	initial_status	Initial status of the parameters in the initial position in parameter space - shape int[max_dim]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[max_dimension] – initial seeding of zero corresponds to the dimension turned off initially
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	RJ_proposal	std::function for the log_likelihood function – takes double ∗position, int ∗param_status,int dimension, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)
	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to ''false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.28.2.13 RJPTMCMC_MH_internal()

```
void RJPTMCMC_MH_internal (
            double *** output,
```

```
int *** parameter_status,
int max_dimension,
int min_dimension,
int N_steps,
int chain_N,
double * initial_pos,
int * initial_status,
double * seeding_var,
double * chain_temps,
int swp_freq,
std::function< double(double *, int *, int, int)> log_prior,
std::function< double(double *, int *, int, int)> log_likelihood,
std::function< void(double *, int *, int, double **, int)> fisher,
std::function< void(double *, double *, int *, int *, int, int)> RJ_proposal,
int numThreads,
bool pool,
bool show_prog,
std::string statistics_filename,
std::string chain_filename,
std::string auto_corr_filename,
std::string likelihood_log_filename,
std::string checkpoint_file )
```

Generic reversable jump sampler, where the likelihood, prior, and reversable jump proposal are parameters supplied by the user.

Note: Using a min_dimension tells the sampler that there is a `base model'', and that the dimensions from min_dim to max_dim are`small'' corrections to that model. This helps inform some of the proposal algorithms and speeds up computation. If using discrete models with no overlap of variables (ie model A or model B), set min_dim to 0. Even if reusing certain parameters, if the extra dimensions don't describe `‘small'' deviations, it's probably best to set min_dim to 0.

Currently, no dynamic PT option, as it would be too many free parameters for the sampler to converge to a reasonable temperature distribution in a reasonable amount of time. Best use case, use the PTMCMC_MH_dyanmic_PT for the `‘base'' dimension space, and use that temperature ladder.

Base of the sampler, generic, with user supplied quantities for most of the samplers properties

Uses the Metropolis-Hastings method, with the option for Fisher/MALA steps if the Fisher routine is supplied.

3 modes to use -

single threaded (numThreads = 1) runs single threaded

multi-threaded `‘deterministic'' (numThreads>1 ; pool = false) progresses each chain in parallel for swp_freq steps, then waits for all threads to complete before swapping temperatures in sequenctial order (j, j+1) then (j+1, j+2) etc (sequenctially)

multi-threaded `‘stochastic'' (numThreads>2 ; pool = true) progresses each chain in parallel by queueing each temperature and evaluating them in the order they were submitted. Once finished, the threads are queued to swap, where they swapped in the order they are submitted. This means the chains are swapped randomly, and the chains do NOT finish at the same time. The sampler runs until the the 0th chain reaches the step number

Note on limits: In the prior function, if a set of parameters should be disallowed, return -std::numeric_limits<double>::infinity() – (this is in the <limits> file in std)

The parameter array uses the dimensions [0,min_dim] always, and [min_dim, max_dim] in RJPTMCMC fashion

Format for the auto_corr file (compatable with csv, dat, txt extensions): each row is a dimension of the cold chain, with the first row being the lengths used for the auto-corr calculation:

lengths: length1 , length2 ...

dim1: length1 , length2 ...

Format for the chain file (compatable with csv, dat, txt extensions): each row is a step, each column a dimension:

Step1: dim1 , dim2 , ..., max_dim, param_status1, param_status2, ...

Step2: dim1 , dim2 , ..., max_dim, param_status1, param_status2, ...

Statistics_filename : should be txt extension

checkpoint_file : This file saves the final position of all the chains, as well as other metadata, and can be loaded by the function <FUNCTION> to continue the chain from the point it left off. Not meant to be read by humans, the data order is custom to this software library. An empty string ("") means no checkpoint will be saved. For developers, the contents are:

dimension, # of chains

temps of chains

Stepping widths of all chains

Final position of all chains

Parameters

out	*output*	Output chains, shape is double[chain_N, N_steps,dimension]
out	*parameter_status*	Parameter status for each step corresponding to the output chains, shape is double[chain_N, N_steps,dimension]
	max_dimension	maximum dimension of the parameter space being explored – only consideration is memory, as memory scales with dimension. Keep this reasonable, unless memory is REALLY not an issue
	min_dimension	minimum dimension of the parameter space being explored >=1
	N_steps	Number of total steps to be taken, per chain
	chain_N	Number of chains
	initial_pos	Initial position in parameter space - shape double[dimension]
	initial_status	Initial status of the parameters in the initial position in parameter space - shape int[max_dim]
	seeding_var	Variance of the normal distribution used to seed each chain higher than 0 - shape double[max_dimension] – initial seeding of zero corresponds to the dimension turned off initially
	chain_temps	Double array of temperatures for the chains
	swp_freq	the frequency with which chains are swapped
	log_prior	std::function for the log_prior function – takes double *position, int *param_status, int dimension, int chain_id
	log_likelihood	std::function for the log_likelihood function – takes double *position, int *param_status,int dimension, int chain_id
	fisher	std::function for the fisher function – takes double *position, int *param_status,int dimension, double **output_fisher, int chain_id
	RJ_proposal	std::function for the log_likelihood function – takes double *position, int *param_status,int dimension, int chain_id
	numThreads	Number of threads to use (=1 is single threaded)

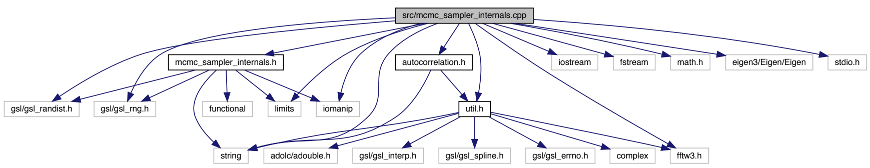
Parameters

	pool	boolean to use stochastic chain swapping (MUST have >2 threads)
	show_prog	boolean whether to print out progress (for example, should be set to ``false'' if submitting to a cluster)
	statistics_filename	Filename to output sampling statistics, if empty string, not output
	chain_filename	Filename to output data (chain 0 only), if empty string, not output
	auto_corr_filename	Filename to output auto correlation in some interval, if empty string, not output
	likelihood_log_filename	Filename to write the log_likelihood and log_prior at each step – use empty string to skip
	checkpoint_file	Filename to output data for checkpoint, if empty string, not saved

9.29 src/mcmc_sampler_internals.cpp File Reference

```
#include "mcmc_sampler_internals.h"
#include "autocorrelation.h"
#include "util.h"
#include <iostream>
#include <fstream>
#include <string>
#include <math.h>
#include <gsl/gsl_randist.h>
#include <gsl/gsl_rng.h>
#include <eigen3/Eigen/Eigen>
#include <limits>
#include <iomanip>
#include <fftw3.h>
#include <stdio.h>
```

Include dependency graph for mcmc_sampler_internals.cpp:



Functions

- int mcmc_step (sampler ∗sampler, double ∗current_param, double ∗next_param, int ∗current_status, int ∗next_status, int chain_number)

    interface function between the sampler and the internal step functions

- void gaussian_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_←status, int ∗proposed_status, int chain_id)

    Straight gaussian step.

- void fisher_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_index)

    Fisher informed gaussian step.

- void **update_fisher** (sampler ∗sampler, double ∗current_param, int ∗param_status, int chain_index)
- void mmala_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status)

  MMALA informed step – Currently not supported.
- void diff_ev_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_id)

  differential evolution informed step
- void RJ_smooth_history (sampler ∗sampler, double ∗current_param, int ∗current_param_status, int base_←history_id, double ∗eff_history_coord, int ∗eff_history_status, int chain_id)
- void RJ_step (sampler ∗sampler, double ∗current_param, double ∗proposed_param, int ∗current_status, int ∗proposed_status, int chain_number)

  RJ-proposal step for trans-dimensional MCMCs.
- void chain_swap (sampler ∗sampler, double ∗∗∗output, int ∗∗∗param_status, int step_num, int ∗swp_←accepted, int ∗swp_rejected)

  subroutine to perform chain comparison for parallel tempering
- int single_chain_swap (sampler ∗sampler, double ∗chain1, double ∗chain2, int ∗chain1_status, int ∗chain2←_status, int T1_index, int T2_index)

  subroutine to actually swap two chains
- void assign_probabilities (sampler ∗sampler, int chain_index)

  update and initiate probabilities for each variety of step
- void transfer_chain (sampler ∗samplerptr_dest, sampler ∗samplerptr_source, int id_dest, int id_source, bool transfer_output)

  Copies contents of one chain to another.
- bool check_sampler_status (sampler ∗samplerptr)

  Checks the status of a sampler for the stochastic sampling.
- void update_step_widths (sampler ∗samplerptr, int chain_id)

  Updates the step widths, shooting for 20% acceptance ratios for each type of step.
- void **allocate_sampler_mem** (sampler ∗sampler)
- void **deallocate_sampler_mem** (sampler ∗sampler)
- void **update_history** (sampler ∗sampler, double ∗new_params, int ∗new_param_status, int chain_index)
- void **write_stat_file** (sampler ∗sampler, std::string filename)
- void write_checkpoint_file (sampler ∗sampler, std::string filename)

  Routine that writes metadata and final positions of a sampler to a checkpoint file.
- void load_temps_checkpoint_file (std::string check_file, double ∗temps, int chain_N)

  load temperatures from checkpoint file
- void load_checkpoint_file (std::string check_file, sampler ∗sampler)

  load checkpoint file into sampler struct
- void **assign_ct_p** (sampler ∗sampler, int step, int chain_index)
- void **assign_ct_m** (sampler ∗sampler, int step, int chain_index)
- void **assign_initial_pos** (sampler ∗samplerptr, double ∗initial_pos, int ∗initial_status, double ∗seeding_var)
- double PT_dynamical_timescale (int t0, int nu, int t)

  Timescale of the PT dynamics.
- void update_temperatures (sampler ∗samplerptr, int t0, int nu, int t)

  updates the temperatures for a sampler such that all acceptance rates are equal
- void initiate_full_sampler (sampler ∗sampler_new, sampler ∗sampler_old, int chain_N_thermo_ensemble, int chain_N, std::string chain_allocation_scheme)

  For the dynamic PT sampler, this is the function that starts the full sampler with the max number of chains.

9.29.1 Detailed Description

File containing definitions for all the internal, generic mcmc subroutines

9.29.2 Function Documentation

9.29.2.1 assign_probabilities()

```
void assign_probabilities (
            sampler * sampler,
            int chain_index )
```

update and initiate probabilities for each variety of step

Type 0: Gaussian step

Type 1: Differential Evolution step

Type 2: MMALA step (currently not supported)

Type 3: Fisher step

9.29.2.2 chain_swap()

```
void chain_swap (
            sampler * sampler,
            double *** output,
            int *** param_status,
            int step_num,
            int * swp_accepted,
            int * swp_rejected )
```

subroutine to perform chain comparison for parallel tempering

The total output file is passed, and the chains are swapped sequentially

This is the routine for `'Deterministic'' sampling (parallel or sequential, but not pooled)

Parameters

sampler	sampler struct
output	output vector containing chains
param_status	Parameter status
step_num	current step number

9.29.2.3 check_sampler_status()

```
bool check_sampler_status (
            sampler * samplerptr )
```

Checks the status of a sampler for the stochastic sampling.

Just loops through the ref_chain_status variables

9.29.2.4 diff_ev_step()

```
void diff_ev_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_id )
```

differential evolution informed step

Differential evolution uses the past history of the chain to inform the proposed step:

Take the difference of two random, accepted previous steps and step along that with some step size, determined by a gaussian

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.29.2.5 fisher_step()

```
void fisher_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_index )
```

Fisher informed gaussian step.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.29.2.6 gaussian_step()

```
void gaussian_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
```

```
int * current_status,
int * proposed_status,
int chain_id )
```

Straight gaussian step.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.29.2.7 initiate_full_sampler()

```
void initiate_full_sampler (
            sampler * sampler_new,
            sampler * sampler_old,
            int chain_N_thermo_ensemble,
            int chain_N,
            std::string chain_allocation_scheme )
```

For the dynamic PT sampler, this is the function that starts the full sampler with the max number of chains.

The output file will be reused, but the positions are set back to zero (copying the current position to position zero)

Assumes the output, chain_temps have been allocated in memory for the final number of chains chain_N and steps N_steps

Allocates memory for the new sampler sampler_new -> it's the user's responsibility to deallocate with deallocate↩ _sampler_mem

Parameters

sampler_old	Dynamic sampler
chain_N_thermo_ensemble	Number of chains used in the thermodynamic ensemble
chain_N	Number of chains to use in the static sampler
chain_allocation_scheme	Scheme to use to allocate any remaining chains

9.29.2.8 load_checkpoint_file()

```
void load_checkpoint_file (
            std::string check_file,
            sampler * sampler )
```

load checkpoint file into sampler struct

NOTE – allocate_sampler called in function – MUST deallocate manually

NOTE – sampler->chain_temps allocated internally – MUST free manually

9.29.2.9 load_temps_checkpoint_file()

```
void load_temps_checkpoint_file (
            std::string check_file,
            double * temps,
            int chain_N )
```

load temperatures from checkpoint file

Assumed the temps array is already allocated in memory for the correct number of chains

Just a utility routine to read temperatures from checkpoint file

It would be easy to read in the chain number and allocate memory in the function, but I prefer to leave allocation/deallocation up to the client

9.29.2.10 mmala_step()

```
void mmala_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status )
```

MMALA informed step – Currently not supported.

Parameters

	sampler	Sampler struct
	current_param	current position in parameter space
out	*proposed_param*	Proposed position in parameter space

9.29.2.11 PT_dynamical_timescale()

```
double PT_dynamical_timescale (
            int t0,
            int nu,
            int t )
```

Timescale of the PT dynamics.

kappa in the the language of arXiv:1501.05823v3

Parameters

t0	Timescale of the dyanmics
nu	Initial amplitude (number of steps to base dynamics on)
t	current time

9.29.2.12 RJ_smooth_history()

```
void RJ_smooth_history (
            sampler * sampler,
            double * current_param,
            int * current_param_status,
            int base_history_id,
            double * eff_history_coord,
            int * eff_history_status,
            int chain_id )
```

Parameters

	sampler	Current sampler
	current_param	Current parameters to match
	current_param_status	Current parameters to match
	base_history_id	Original history element
out	*eff_history_coord*	Modified history coord
out	*eff_history_status*	Modified History status
	chain_id	Chain ID of the current chain

9.29.2.13 RJ_step()

```
void RJ_step (
            sampler * sampler,
            double * current_param,
            double * proposed_param,
            int * current_status,
            int * proposed_status,
            int chain_number )
```

RJ-proposal step for trans-dimensional MCMCs.

This extra step may seem unnecessary, I'm just adding it in in case the extra flexibility is useful in the future for preprocessing of the chain before sending it to the user's RJ_proposal

Parameters

	sampler	sampler
	current_param	current coordinates in parameter space
out	*proposed_param*	Proposed coordinates in parameter space
	current_status	Current status of parameters
out	*proposed_status*	Proposed status of parameters
	chain_number	chain mumber

9.29.2.14 single_chain_swap()

```
int single_chain_swap (
            sampler * sampler,
            double * chain1,
            double * chain2,
            int * chain1_status,
            int * chain2_status,
            int T1_index,
            int T2_index )
```

subroutine to actually swap two chains

This is the more general subroutine, which just swaps the two chains passed to the function

Parameters

sampler	sampler structure
chain1	parameter position of chain that could be changed
chain2	chain that is not swapped, but provides parameters to be swapped by the other chain
chain1_status	Parameter status array for chain1
chain2_status	Parameter status array for chain2
T1_index	number of chain swappe in chain_temps
T2_index	number of chain swapper in chain_temps

9.29.2.15 transfer_chain()

```
void transfer_chain (
            sampler * samplerptr_dest,
            sampler * samplerptr_source,
            int id_dest,
            int id_source,
            bool transfer_output )
```

Copies contents of one chain to another.

Transfers id_source in samplerptr_source to id_dest samplerptr_dest

NOTE: This copies the VALUE, not the reference. This could be expensive, so use with caution

id_dest is ERASED

samplerptr_dest and samplerptr_source MUST have the same dimension, the same sampling details (like having or not having a fisher) etc

samplerptr_dest must be previously allocated properly

As output is the largest transfer by far, the transfer_output flag can be used to allow the user to handle that manually.

9.29.2.16 update_temperatures()

```
void update_temperatures (
            sampler * samplerptr,
            int t0,
            int nu,
            int t )
```

updates the temperatures for a sampler such that all acceptance rates are equal

Follows the algorithm outlined in arXiv:1501.05823v3

Fixed temperatures for the first and last chain

used in MCMC_MH_dynamic_PT_alloc_internal

For defined results, this should be used while the sampler is using non-pooling methods

9.29.2.17 write_checkpoint_file()

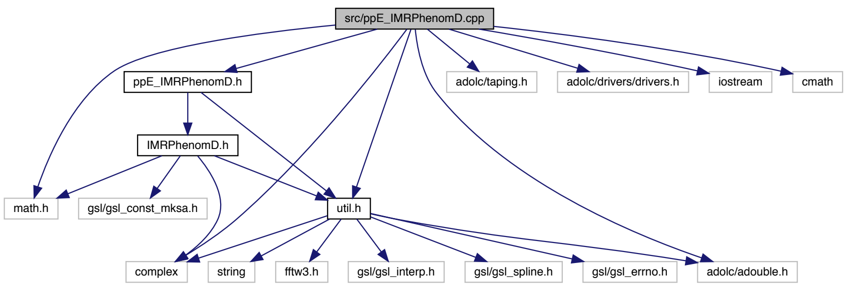
```
void write_checkpoint_file (
            sampler * sampler,
            std::string filename )
```

Routine that writes metadata and final positions of a sampler to a checkpoint file.

9.30 src/ppE_IMRPhenomD.cpp File Reference

```
#include "ppE_IMRPhenomD.h"
#include <math.h>
#include <adolc/adouble.h>
#include <adolc/taping.h>
#include <adolc/drivers/drivers.h>
#include <iostream>
#include <cmath>
#include <complex>
#include "util.h"
```

Include dependency graph for ppE_IMRPhenomD.cpp:



9.30.1 Detailed Description

File for the implementation of the ppE formalism for testing GR

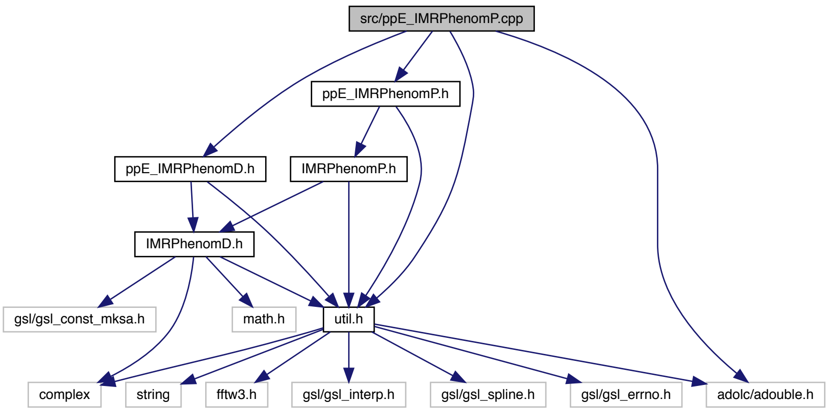
Extends the IMRPhenomD template to include non-GR phase terms

Supported waveforms: ppE Inspiral, ppE IMR, dCS, EdGB

9.31 src/ppE_IMRPhenomP.cpp File Reference

```
#include "ppE_IMRPhenomP.h"
#include "ppE_IMRPhenomD.h"
#include "util.h"
#include <adolc/adouble.h>
```

Include dependency graph for ppE_IMRPhenomP.cpp:



Macros

- #define **ROTATEZ**(angle, vx, vy, vz)
- #define **ROTATEY**(angle, vx, vy, vz)

Variables

- const double **sqrt_6** = 2.44948974278317788

9.31.1 Detailed Description

Source code file for parameterized post Einsteinian Modifications to the precessing waveform model IMRPhenomP

9.31.2 Macro Definition Documentation

9.31.2.1 ROTATEY

```
#define ROTATEY(
        angle,
        vx,
        vy,
        vz )
```

Value:

```
tmp1 = vx*cos(angle) + vz*sin(angle);\
tmp2 = - vx*sin(angle) + vz*cos(angle);\
vx = tmp1;\
vz = tmp2
```

9.31.2.2 ROTATEZ

```
#define ROTATEZ(
        angle,
        vx,
        vy,
        vz )
```

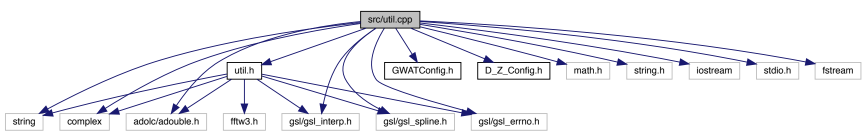
Value:

```
tmp1 = vx*cos(angle) - vy*sin(angle);\
tmp2 = vx*sin(angle) + vy*cos(angle);\
vx = tmp1;\
vy = tmp2
```

9.32 src/util.cpp File Reference

```
#include "util.h"
#include "GWATConfig.h"
#include "D_Z_Config.h"
#include <math.h>
#include <string>
#include <string.h>
#include <complex>
#include <iostream>
#include <stdio.h>
#include <fstream>
#include <adolc/adouble.h>
#include <gsl/gsl_interp.h>
#include <gsl/gsl_spline.h>
#include <gsl/gsl_errno.h>
```

Include dependency graph for util.cpp:



Functions

- void initiate_LumD_Z_interp (gsl_interp_accel **Z_DL_accel_ptr, gsl_spline **Z_DL_spline_ptr)

  Function that uses the GSL libraries to interpolate pre-calculated Z-D_L data.
- void free_LumD_Z_interp (gsl_interp_accel **Z_DL_accel_ptr, gsl_spline **Z_DL_spline_ptr)

  Frees the allocated interpolation function.
- adouble Z_from_DL_interp (adouble DL, gsl_interp_accel *Z_DL_accel_ptr, gsl_spline *Z_DL_spline_ptr)
- double Z_from_DL_interp (double DL, gsl_interp_accel *Z_DL_accel_ptr, gsl_spline *Z_DL_spline_ptr)
- double Z_from_DL (double DL, std::string cosmology)

  Calculates the redshift given the luminosity distance.
- adouble Z_from_DL (adouble DL, std::string cosmology)

  Calculates the redshift given the luminosity distance adouble version for ADOL-C implementation.
- double DL_from_Z (double Z, std::string cosmology)

  Calculates the luminosity distance given the redshift.
- adouble DL_from_Z (adouble Z, std::string cosmology)

  Calculates the luminosity distance given the redshift adouble version for ADOL-C implementation.
- double cosmology_interpolation_function (double x, double *coeffs, int interp_degree)

  Custom interpolation function used in the cosmology calculations.
- adouble cosmology_interpolation_function (adouble x, double *coeffs, int interp_degree)

  Custom interpolation function used in the cosmology calculations adouble version for ADOL-C.
- double cosmology_lookup (std::string cosmology)

  Helper function for mapping cosmology name to an internal index.
- void printProgress (double percentage)

  routine to print the progress of a process to the terminal as a progress bar
- void allocate_FFTW_mem_forward (fftw_outline *plan, int length)

  Allocate memory for FFTW3 methods used in a lot of inner products input is a locally defined structure that houses all the pertinent data.
- void allocate_FFTW_mem_reverse (fftw_outline *plan, int length)

  Allocate memory for FFTW3 methods used in a lot of inner products –INVERSE input is a locally defined structure that houses all the pertinent data.
- void deallocate_FFTW_mem (fftw_outline *plan)

  deallocates the memory used for FFTW routines
- double calculate_chirpmass (double mass1, double mass2)

  Calculates the chirp mass from the two component masses.
- adouble **calculate_chirpmass** (adouble mass1, adouble mass2)
- double calculate_eta (double mass1, double mass2)

  Calculates the symmetric mass ration from the two component masses.
- adouble **calculate_eta** (adouble mass1, adouble mass2)
- double calculate_mass1 (double chirpmass, double eta)

  Calculates the larger mass given a chirp mass and symmetric mass ratio.
- adouble **calculate_mass1** (adouble chirpmass, adouble eta)
- double calculate_mass2 (double chirpmass, double eta)

  Calculates the smaller mass given a chirp mass and symmetric mass ratio.
- adouble **calculate_mass2** (adouble chirpmass, adouble eta)
- long factorial (long num)

  Local function to calculate a factorial.
- double pow_int (double base, int power)

  Local power function, specifically for integer powers.
- adouble **pow_int** (adouble base, int power)
- double cbrt_internal (double base)

  Fucntion that just returns the cuberoot.
- adouble cbrt_internal (adouble base)

Fucntion that just returns the cuberoot ADOL-C doesn't have the cbrt function (which is faster), so have to use the power function.

- double ∗∗ allocate_2D_array (int dim1, int dim2)

  Utility to malloc 2D array.
- int ∗∗ **allocate_2D_array_int** (int dim1, int dim2)
- void deallocate_2D_array (double ∗∗array, int dim1, int dim2)

  Utility to free malloc'd 2D array.
- void **deallocate_2D_array** (int ∗∗array, int dim1, int dim2)
- double ∗∗∗ allocate_3D_array (int dim1, int dim2, int dim3)

  Utility to malloc 3D array.
- int ∗∗∗ **allocate_3D_array_int** (int dim1, int dim2, int dim3)
- void deallocate_3D_array (double ∗∗∗array, int dim1, int dim2, int dim3)

  Utility to free malloc'd 2D array.
- void deallocate_3D_array (int ∗∗∗array, int dim1, int dim2, int dim3)

  Utility to free malloc'd 2D array.
- void read_file (std::string filename, double ∗∗output, int rows, int cols)

  Utility to read in data.
- void read_file (std::string filename, double ∗output)

  Utility to read in data (single dimension vector)
- void read_LOSC_data_file (std::string filename, double ∗output, double ∗data_start_time, double ∗duration, double ∗fs)

  Read data file from LIGO Open Science Center.
- void read_LOSC_PSD_file (std::string filename, double ∗∗output, int rows, int cols)

  Read PSD file from LIGO Open Science Center.
- void allocate_LOSC_data (std::string ∗data_files, std::string psd_file, int num_detectors, int psd_length, int data_file_length, double trigger_time, std::complex< double > ∗∗data, double ∗∗psds, double ∗∗freqs)

  Prepare data for MCMC directly from LIGO Open Science Center.
- void free_LOSC_data (std::complex< double > ∗∗data, double ∗∗psds, double ∗∗freqs, int num_detectors, int length)
- void tukey_window (double ∗window, int length, double alpha)

  Tukey window function for FFTs.
- void write_file (std::string filename, double ∗∗input, int rows, int cols)

  Utility to write 2D array to file.
- void write_file (std::string filename, double ∗input, int length)

  Utility to write 1D array to file.
- void celestial_horizon_transform (double RA, double DEC, double gps_time, double LONG, double LAT, double ∗phi, double ∗theta)

  Utility to transform from celestial coord RA and DEC to local horizon coord for detector response functions.
- double gps_to_GMST (double gps_time)

  Utility to transform from gps time to GMST `https://aa.usno.navy.mil/faq/docs/GAST.php`.
- double gps_to_JD (double gps_time)

  Utility to transform from gps to JD.
- void transform_cart_sph (double ∗cartvec, double ∗sphvec)

  utility to transform a vector from cartesian to spherical (radian)
- void transform_sph_cart (double ∗sphvec, double ∗cartvec)

  utility to transform a vector from spherical (radian) to cartesian
- template< class T >
  std::complex< T > **cpolar** (T mag, T phase)
- template< class T >
  std::complex< T > XLALSpinWeightedSphericalHarmonic (T theta, T phi, int s, int l, int m)
- template std::complex< double > **XLALSpinWeightedSphericalHarmonic**< **double** > (double, double, int, int, int)

- template std::complex< adouble > **XLALSpinWeightedSphericalHarmonic< adouble >** (adouble, adouble, int, int, int)
- template std::complex< double > **cpolar< double >** (double, double)
- template std::complex< adouble > **cpolar< adouble >** (adouble, adouble)

9.32.1 Detailed Description

General utilities that are not necessarily specific to any part of the project at large

9.32.2 Function Documentation

9.32.2.1 allocate_2D_array()

```
double** allocate_2D_array (
             int dim1,
             int dim2 )
```

Utility to malloc 2D array.

9.32.2.2 allocate_3D_array()

```
double*** allocate_3D_array (
             int dim1,
             int dim2,
             int dim3 )
```

Utility to malloc 3D array.

9.32.2.3 allocate_LOSC_data()

```
void allocate_LOSC_data (
             std::string * data_files,
             std::string psd_file,
             int num_detectors,
             int psd_length,
             int data_file_length,
             double trigger_time,
             std::complex< double > ** data,
             double ** psds,
             double ** freqs )
```

Prepare data for MCMC directly from LIGO Open Science Center.

Trims data for Tobs (determined by PSD file) 3/4∗Tobs in front of trigger, and 1/4∗Tobs behind

Currently, default to sampling frequency and observation time set by PSD – cannot be customized

Output is in order of PSD columns – string vector of detectos MUST match order of PSD cols

Output shapes– psds = [num_detectors][psd_length] data = [num_detectors][psd_length]

freqs = [num_detectors][psd_length]

Total observation time = 1/(freq[i] - freq[i-1]) (from PSD file)

Sampling frequency fs = max frequency from PSD file

ALLOCATES MEMORY – must be freed to prevent memory leak

Parameters

	data_files	Vector of strings for each detector file from LOSC
	psd_file	String of psd file from LOSC
	num_detectors	Number of detectors to use
	psd_length	Length of the PSD file (number of rows of DATA)
	data_file_length	Length of the data file (number of rows of DATA)
	trigger_time	Time for the signal trigger (GPS)
out	*data*	Output array of data for each detector
out	*psds*	Output array of psds for each detector
out	*freqs*	Output array of freqs for each detector

9.32.2.4 calculate_chirpmass()

```
double calculate_chirpmass (
            double mass1,
            double mass2 )
```

Calculates the chirp mass from the two component masses.

The output units are whatever units the input masses are

9.32.2.5 calculate_mass1()

```
double calculate_mass1 (
            double chirpmass,
            double eta )
```

Calculates the larger mass given a chirp mass and symmetric mass ratio.

Units of the output match the units of the input chirp mass

9.32.2.6 calculate_mass2()

```
double calculate_mass2 (
            double chirpmass,
            double eta )
```

Calculates the smaller mass given a chirp mass and symmetric mass ratio.

Units of the output match the units of the input chirp mass

9.32.2.7 celestial_horizon_transform()

```
void celestial_horizon_transform (
            double RA,
            double DEC,
            double gps_time,
            double LONG,
            double LAT,
            double * phi,
            double * theta )
```

Utility to transform from celestial coord RA and DEC to local horizon coord for detector response functions.

Outputs are the spherical polar angles defined by North as 0 degrees azimuth and the normal to the earth as 0 degree polar

Parameters

	RA	Right acsension (rad)
	DEC	Declination (rad)
	gps_time	GPS time
	LONG	Longitude (rad)
	LAT	Latitude (rad)
out	*phi*	horizon azimuthal angle (rad)
out	*theta*	horizon polar angle (rad)

9.32.2.8 cosmology_interpolation_function()

```
double cosmology_interpolation_function (
            double x,
            double * coeffs,
            int interp_degree )
```

Custom interpolation function used in the cosmology calculations.

Power series in half power increments of x, up to 11/2. powers of x

9.32.2.9 deallocate_2D_array()

```
void deallocate_2D_array (
            double ** array,
            int dim1,
            int dim2 )
```

Utility to free malloc'd 2D array.

9.32.2.10 deallocate_3D_array() [1/2]

```
void deallocate_3D_array (
            double *** array,
            int dim1,
            int dim2,
            int dim3 )
```

Utility to free malloc'd 2D array.

9.32.2.11 deallocate_3D_array() [2/2]

```
void deallocate_3D_array (
            int *** array,
            int dim1,
            int dim2,
            int dim3 )
```

Utility to free malloc'd 2D array.

9.32.2.12 DL_from_Z()

```
double DL_from_Z (
            double Z,
            std::string cosmology )
```

Calculates the luminosity distance given the redshift.

Based on Astropy.cosmology calculations – see python script in the ./data folder of the project – numerically calculated given astropy.cosmology's definitions (http://docs.astropy.org/en/stable/cosmology/) and used scipy.optimize to fit to a power series, stepping in half powers of Z. These coefficients are then output to a header file (D_Z_config.h) which are used here to calculate distance. Custom cosmologies etc can easily be acheived by editing the python script D_Z_config.py, the c++ functions do not need modification. They use whatever data is available in the header file. If the functional form of the fitting function changes, these functions DO need to change.

5 cosmological models are available (this argument must be spelled exactly):

PLANCK15, PLANCK13, WMAP9, WMAP7, WMAP5

9.32.2.13 free_LOSC_data()

```
void free_LOSC_data (
            std::complex< double > ** data,
            double ** psds,
            double ** freqs,
            int num_detectors,
            int length )
```

/brief Free data allocated by prep_LOSC_data function

9.32.2.14 initiate_LumD_Z_interp()

```
void initiate_LumD_Z_interp (
            gsl_interp_accel ** Z_DL_accel_ptr,
            gsl_spline ** Z_DL_spline_ptr )
```

Function that uses the GSL libraries to interpolate pre-calculated Z-D_L data.

Initiates the requried functions – GSL interpolation requires allocating memory before hand

9.32.2.15 pow_int()

```
double pow_int (
            double base,
            int power )
```

Local power function, specifically for integer powers.

Much faster than the std version, because this is only for integer powers

9.32.2.16 printProgress()

```
void printProgress (
            double percentage )
```

routine to print the progress of a process to the terminal as a progress bar

Call everytime you want the progress printed

9.32.2.17 read_file() [1/2]

```
void read_file (
            std::string filename,
            double ** output,
            int rows,
            int cols )
```

Utility to read in data.

Takes filename, and assigns to output[rows][cols]

File must be comma separated doubles

Parameters

	filename	input filename, relative to execution directory
out	*output*	array to store output, dimensions rowsXcols
	rows	first dimension
	cols	second dimension

9.32.2.18 read_file() [2/2]

```
void read_file (
            std::string filename,
            double * output )
```

Utility to read in data (single dimension vector)

Takes filename, and assigns to output[i∗rows + cols]

Output vector must be long enough, no check is done for the length

File must be comma separated doubles

Parameters

	filename	input filename, relative to execution directory
out	*output*	output array, assumed to have the proper length of total items

9.32.2.19 read_LOSC_data_file()

```
void read_LOSC_data_file (
            std::string filename,
            double * output,
            double * data_start_time,
            double * duration,
            double * fs )
```

Read data file from LIGO Open Science Center.

Convenience function for cutting off the first few lines of text

Parameters

	filename	input filename
out	*output*	Output data
out	*data_start_time*	GPS start time of the data in file
out	*duration*	Duration of the signal
out	*fs*	Sampling frequency of the data

9.32.2.20 read_LOSC_PSD_file()

```
void read_LOSC_PSD_file (
            std::string filename,
            double ** output,
            int rows,
            int cols )
```

Read PSD file from LIGO Open Science Center.

Convenience function for cutting off the first few lines of text

9.32.2.21 transform_cart_sph()

```
void transform_cart_sph (
            double * cartvec,
            double * sphvec )
```

utility to transform a vector from cartesian to spherical (radian)

order:

cart: x, y, z

spherical: r, polar, azimuthal

9.32.2.22 transform_sph_cart()

```
void transform_sph_cart (
            double * sphvec,
            double * cartvec )
```

utility to transform a vector from spherical (radian) to cartesian

order:

cart: x, y, z

spherical: r, polar, azimuthal

9.32.2.23 tukey_window()

```
void tukey_window (
            double * window,
            int length,
            double alpha )
```

Tukey window function for FFTs.

As defined by https://en.wikipedia.org/wiki/Window_function

9.32.2.24 write_file() [1/2]

```
void write_file (
            std::string filename,
            double ** input,
            int rows,
            int cols )
```

Utility to write 2D array to file.

Grid of data, comma separated

Grid has rows rows and cols columns

Parameters

filename	Filename of output file, relative to execution directory
input	Input 2D array pointer array[rows][cols]
rows	First dimension of array
cols	second dimension of array

9.32.2.25 write_file() [2/2]

```
void write_file (
            std::string filename,
```

```
            double * input,
            int length )
```

Utility to write 1D array to file.

Single column of data

Parameters

filename	Filename of output file, relative to execution directory
input	input 1D array pointer array[length]
length	length of array

9.32.2.26 XLALSpinWeightedSphericalHarmonic()

```
template<class T >
std::complex<T> XLALSpinWeightedSphericalHarmonic (
            T theta,
            T phi,
            int s,
            int l,
            int m )
```

Shamelessly stolen from LALsuite

Parameters

theta	polar angle (rad)
phi	azimuthal angle (rad)
s	spin weight
l	mode number l
m	mode number m

9.32.2.27 Z_from_DL()

```
double Z_from_DL (
            double DL,
            std::string cosmology )
```

Calculates the redshift given the luminosity distance.

Based on Astropy.cosmology calculations – see python script in the ./data folder of the project – numerically calculated given astropy.cosmology's definitions (http://docs.astropy.org/en/stable/cosmology/) and used scipy.optimize to fit to a power series, stepping in half powers of DL. These coefficients are then output to a header file (D_Z_config.h) which are used here to calculate redshift. Custom cosmologies etc can easily be acheived by editing the python script D_Z_config.py, the c++ functions do not need modification. They use whatever data is available in the header file.

5 cosmological models are available (this argument must be spelled exactly, although case insensitive):

PLANCK15, PLANCK13, WMAP9, WMAP7, WMAP5

9.32.2.28 Z_from_DL_interp() [1/2]

```
adouble Z_from_DL_interp (
            adouble DL,
            gsl_interp_accel * Z_DL_accel_ptr,
            gsl_spline * Z_DL_spline_ptr )
```

Function that returns Z from a given luminosity Distance – only Planck15

adouble version for ADOL-C calculations

9.32.2.29 Z_from_DL_interp() [2/2]

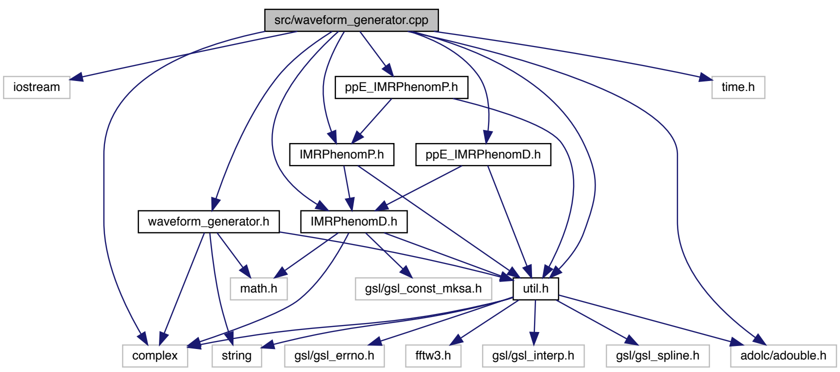
```
double Z_from_DL_interp (
            double DL,
            gsl_interp_accel * Z_DL_accel_ptr,
            gsl_spline * Z_DL_spline_ptr )
```

Function that returns Z from a given luminosity Distance – only Planck15

9.33 src/waveform_generator.cpp File Reference

```
#include <iostream>
#include "waveform_generator.h"
#include "IMRPhenomD.h"
#include "IMRPhenomP.h"
#include "ppE_IMRPhenomD.h"
#include "ppE_IMRPhenomP.h"
#include "util.h"
#include <complex>
#include <time.h>
#include <adolc/adouble.h>
```

Include dependency graph for waveform_generator.cpp:



Functions

- int fourier_waveform (double ∗frequencies, int length, std::complex< double > ∗waveform_plus, std↩ ::complex< double > ∗waveform_cross, string generation_method, gen_params ∗parameters)

    Function to produce the plus/cross polarizations of an quasi-circular binary.
- int fourier_waveform (double ∗frequencies, int length, double ∗waveform_plus_real, double ∗waveform↩ _plus_imag, double ∗waveform_cross_real, double ∗waveform_cross_imag, string generation_method, gen_params ∗parameters)
- int fourier_waveform (double ∗frequencies, int length, std::complex< double > ∗waveform, string generation_method, gen_params ∗parameters)

    Function to produce the (2,2) mode of an quasi-circular binary.
- int fourier_waveform (double ∗frequencies, int length, double ∗waveform_real, double ∗waveform_imag, string generation_method, gen_params ∗parameters)
- int fourier_amplitude (double ∗frequencies, int length, double ∗amplitude, string generation_method, gen_params ∗parameters)

    Function to produce the amplitude of the (2,2) mode of an quasi-circular binary.
- int fourier_phase (double ∗frequencies, int length, double ∗phase, string generation_method, gen_params ∗parameters)

    Function to produce the phase of the (2,2) mode of an quasi-circular binary.

9.33.1 Detailed Description

File that handles the construction of the (2,2) waveform as described by IMRPhenomD by Khan et. al.

Builds a waveform for given DETECTOR FRAME parameters

9.33.2 Function Documentation

9.33.2.1 fourier_amplitude()

```
int fourier_amplitude (
            double * frequencies,
            int length,
            double * amplitude,
            string generation_method,
            gen_params * parameters )
```

Function to produce the amplitude of the (2,2) mode of an quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

Parameters

frequencies	double array of frequencies for the waveform to be evaluated at
length	integer length of all the arrays
amplitude	output array for the amplitude
generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY

9.33.2.2 fourier_phase()

```
int fourier_phase (
            double * frequencies,
            int length,
            double * phase,
            string generation_method,
            gen_params * parameters )
```

Function to produce the phase of the (2,2) mode of an quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

Parameters

frequencies	double array of frequencies for the waveform to be evaluated at
length	integer length of all the arrays
phase	output array for the phase
generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY

9.33.2.3 fourier_waveform() [1/4]

```
int fourier_waveform (
            double * frequencies,
            int length,
            std::complex< double > * waveform_plus,
            std::complex< double > * waveform_cross,
            string generation_method,
            gen_params * parameters )
```

Function to produce the plus/cross polarizations of an quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

This puts the responsibility on the user to pass the necessary parameters

NEED TO OUTLINE OPTIONS FOR EACH METHOD IN DEPTH

NEW PHASE OPTIONS for

PHENOMD ONLY:

If phic is assigned, the reference frequency and reference phase are IGNORED.

If Phic is unassigned, a reference phase AND a reference frequency are looked for.If no options are found, both are set to 0.

If tc is assigned, it is used.

If tc is unassigned, the waveform is shifted so the merger happens at 0.

PhenomPv2:

PhiRef and f_ref are required, phic is not an option.

tc, if specified, is used with the use of interpolation. If not, tc is set such that coalescence happens at t=0

Parameters

	frequencies	double array of frequencies for the waveform to be evaluated at
	length	integer length of all the arrays
out	*waveform_plus*	complex array for the output plus polarization waveform
out	*waveform_cross*	complex array for the output cross polarization waveform
	generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
	parameters	structure containing all the source parameters

9.33.2.4 fourier_waveform() [2/4]

```
int fourier_waveform (
            double * frequencies,
            int length,
            double * waveform_plus_real,
            double * waveform_plus_imag,
            double * waveform_cross_real,
            double * waveform_cross_imag,
            string generation_method,
            gen_params * parameters )
```

Parameters

frequencies	double array of frequencies for the waveform to be evaluated at
length	integer length of all the arrays
waveform_plus_real	complex array for the output waveform
waveform_plus_imag	complex array for the output waveform
waveform_cross_real	complex array for the output waveform
waveform_cross_imag	complex array for the output waveform
generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
parameters	structure containing all the source parameters

9.33.2.5 fourier_waveform() [3/4]

```
int fourier_waveform (
            double * frequencies,
            int length,
            std::complex< double > * waveform,
            string generation_method,
            gen_params * parameters )
```

Function to produce the (2,2) mode of an quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

Parameters

frequencies	double array of frequencies for the waveform to be evaluated at
length	integer length of all the arrays
waveform	complex array for the output waveform
generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
parameters	structure containing all the source parameters

9.33.2.6 fourier_waveform() [4/4]

```
int fourier_waveform (
            double * frequencies,
            int length,
            double * waveform_real,
            double * waveform_imag,
            string generation_method,
            gen_params * parameters )
```

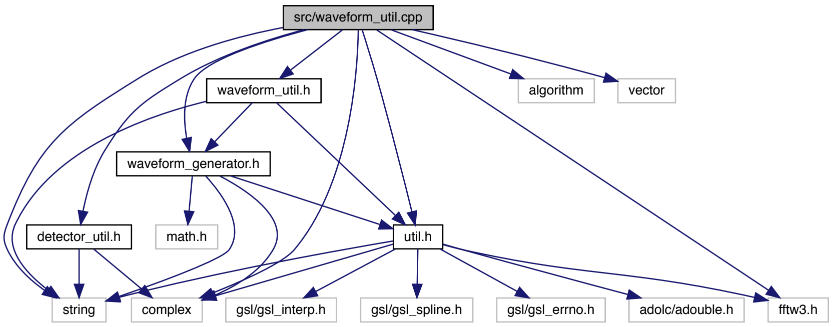
Parameters

frequencies	double array of frequencies for the waveform to be evaluated at
length	integer length of all the arrays
waveform_real	complex array for the output waveform
waveform_imag	complex array for the output waveform
generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
parameters	structure containing all the source parameters

9.34 src/waveform_util.cpp File Reference

```
#include "waveform_util.h"
#include "util.h"
#include "waveform_generator.h"
#include "detector_util.h"
#include <fftw3.h>
#include <algorithm>
#include <complex>
#include <vector>
#include <string>
```

Include dependency graph for waveform_util.cpp:



Functions

- double data_snr_maximized_extrinsic (double ∗frequencies, int length, std::complex< double > ∗data, double ∗psd, std::string detector, std::string generation_method, gen_params ∗param)

  Utility to calculate the snr of a fourier transformed data stream while maximizing over the coalescence parameters phic and tc.
- double data_snr_maximized_extrinsic (double ∗frequencies, int length, double ∗data_real, double ∗data_imag, double ∗psd, std::string detector, std::string generation_method, gen_params ∗param)

  Light wrapper for the data_snr_maximized_extrinsic method.
- double calculate_snr (std::string detector, std::complex< double > ∗waveform, double ∗frequencies, int length)

  Caclulates the snr given a detector and waveform (complex) and frequencies.
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double theta, double phi, std::string detector)
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double theta, double phi, double psi, std::string detector)
- int fourier_detector_response_equatorial (double ∗frequencies, int length, std::complex< double > ∗hplus, std::complex< double > ∗hcross, std::complex< double > ∗detector_response, double ra, double dec, double psi, double gmst, std::string detector)
- int fourier_detector_response (double ∗frequencies, int length, std::complex< double > ∗response, std::string detector, std::string generation_method, gen_params ∗parameters)

  Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary.
- int fourier_detector_response_equatorial (double ∗frequencies, int length, std::complex< double > ∗response, std::string detector, std::string generation_method, gen_params ∗parameters)

  Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary for equatorial coordinates.
- int fourier_detector_amplitude_phase (double ∗frequencies, int length, double ∗amplitude, double ∗phase, std::string detector, std::string generation_method, gen_params ∗parameters)

  Calculates the amplitude (magnitude) and phase (argument) of the response of a given detector.

9.34.1 Detailed Description

Utilities for waveforms - SNR calculation and detector response

includes snr and detector response

9.34.2 Function Documentation

9.34.2.1 calculate_snr()

```
double calculate_snr (
            std::string detector,
            std::complex< double > * waveform,
            double * frequencies,
            int length )
```

Caclulates the snr given a detector and waveform (complex) and frequencies.

This function computes the un-normalized snr: \sqrt((H | H))

Parameters

detector	detector name - must match the string of populate_noise precisely
waveform	complex waveform
frequencies	double array of frequencies that the waveform is evaluated at
length	length of the above two arrays

9.34.2.2 data_snr_maximized_extrinsic() [1/2]

```
double data_snr_maximized_extrinsic (
            double * frequencies,
            int length,
            std::complex< double > * data,
            double * psd,
            std::string detector,
            std::string generation_method,
            gen_params * param )
```

Utility to calculate the snr of a fourier transformed data stream while maximizing over the coalescence parameters phic and tc.

The gen_params structure holds the parameters for the template to be used (the maximimum likelihood parameters)

Parameters

frequencies	Frequencies used by data
length	length of the data
data	input data in the fourier domain
psd	PSD for the detector that created the data
detector	Name of the detector –See noise_util for options
generation_method	Generation method for the template – See waveform_generation.cpp for options
param	gen_params structure for the template

9.34.2.3 data_snr_maximized_extrinsic() [2/2]

```
double data_snr_maximized_extrinsic (
            double * frequencies,
            int length,
            double * data_real,
            double * data_imag,
            double * psd,
            std::string detector,
            std::string generation_method,
            gen_params * param )
```

Light wrapper for the data_snr_maximized_extrinsic method.

Splits the data into real and imaginary, so all the arguments are C-safe

Parameters

frequencies	Frequencies used by data
length	length of the data
data_real	input data in the fourier domain – real part
data_imag	input data in the fourier domain – imaginary part
psd	PSD for the detector that created the data
detector	Name of the detector –See noise_util for options
generation_method	Generation method for the template – See waveform_generation.cpp for options
param	gen_params structure for the template

9.34.2.4 fourier_detector_amplitude_phase()

```
int fourier_detector_amplitude_phase (
            double * frequencies,
            int length,
            double * amplitude,
            double * phase,
            std::string detector,
            std::string generation_method,
            gen_params * parameters )
```

Calculates the amplitude (magnitude) and phase (argument) of the response of a given detector.

This is for general waveforms, and will work for precessing waveforms

Not as fast as non-precessing, but that can't be helped. MUST include plus/cross polarizations

9.34.2.5 fourier_detector_response() [1/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            std::complex< double > * detector_response,
            double theta,
            double phi,
            std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	theta	polar angle (rad) theta in detector frame
	phi	azimuthal angle (rad) phi in detector frame
	detector	detector - list of supported detectors in noise_util

9.34.2.6 fourier_detector_response() [2/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            std::complex< double > * detector_response,
            double theta,
            double phi,
            double psi,
            std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	theta	polar angle (rad) theta in detector frame
	phi	azimuthal angle (rad) phi in detector frame
	psi	polarization angle (rad) phi in detector frame
	detector	detector - list of supported detectors in noise_util

9.34.2.7 fourier_detector_response() [3/3]

```
int fourier_detector_response (
            double * frequencies,
            int length,
            std::complex< double > * response,
            std::string detector,
            std::string generation_method,
            gen_params * parameters )
```

Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

This puts the responsibility on the user to pass the necessary parameters

Detector options include classic interferometers like LIGO/VIRGO (coming soon: ET and LISA)

This is a wrapper that combines generation with response functions: if producing mulitple responses for one waveform (ie stacking Hanford, Livingston, and VIRGO), it will be considerably more efficient to calculate the waveform once, then combine each response manually

Parameters

	frequencies	double array of frequencies for the waveform to be evaluated at
	length	integer length of all the arrays
out	*response*	complex array for the output plus polarization waveform
	generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
	parameters	structure containing all the source parameters

9.34.2.8 fourier_detector_response_equatorial() [1/2]

```
int fourier_detector_response_equatorial (
            double * frequencies,
            int length,
            std::complex< double > * hplus,
            std::complex< double > * hcross,
            std::complex< double > * detector_response,
            double ra,
            double dec,
            double psi,
            double gmst,
            std::string detector )
```

Parameters

	frequencies	array of frequencies corresponding to waveform
	length	length of frequency/waveform arrays
	hcross	precomputed cross polarization of the waveform
out	*detector_response*	detector response
	ra	Right Ascension in rad

Parameters

	dec	Declination in rad
	psi	polarization angle (rad)
	gmst	greenwich mean sidereal time
	detector	detector - list of supported detectors in noise_util

9.34.2.9 fourier_detector_response_equatorial() [2/2]

```
int fourier_detector_response_equatorial (
            double * frequencies,
            int length,
            std::complex< double > * response,
            std::string detector,
            std::string generation_method,
            gen_params * parameters )
```

Function to produce the detector response caused by impinging gravitational waves from a quasi-circular binary for equatorial coordinates.

By using the structure parameter, the function is allowed to be more flexible in using different method of waveform generation - not all methods use the same parameters

This puts the responsibility on the user to pass the necessary parameters

Detector options include classic interferometers like LIGO/VIRGO (coming soon: ET and LISA)

This is a wrapper that combines generation with response functions: if producing mulitple responses for one waveform (ie stacking Hanford, Livingston, and VIRGO), it will be considerably more efficient to calculate the waveform once, then combine each response manually

Parameters

	frequencies	double array of frequencies for the waveform to be evaluated at
	length	integer length of all the arrays
out	*response*	complex array for the output plus polarization waveform
	generation_method	String that corresponds to the generation method - MUST BE SPELLED EXACTLY
	parameters	structure containing all the source parameters

Index