Swarm Tools

Tools for data simulation and analysis for HERMES mission

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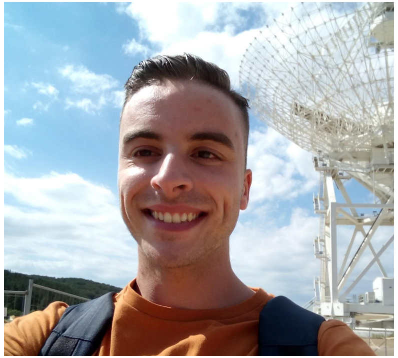
The team (in addition to the usual suspects)

Alessio Anitra
(testing)

Arianna Manca
(software development,
testing)



Carlo Cabras
(computer science)

Nicola Deiosso
(simulations)

GTools Library (provisory name)

In-house C library

Provides an high level, mission-agnostic interface to FITSIO event files, specially tailored for rapid timing analysis.

Capable of:

- data selection by time intervals, energy
- timing analysis (epoch folding, epoch folding search, barycentering, FFT-like analysis)
- Lightcurve creation and analysis

Swarm Tools

A set of software tools to simulate and analyze datasets from a swarm of detectors (like HERMES-SP)

Simulator:
swarm_sim

Analysis:
swarm_pos
swarm_to_xspec

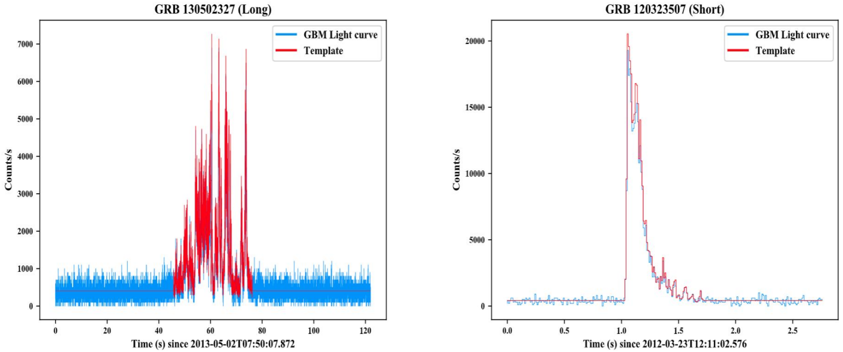
Simulator: general characteristics

What can we simulate?

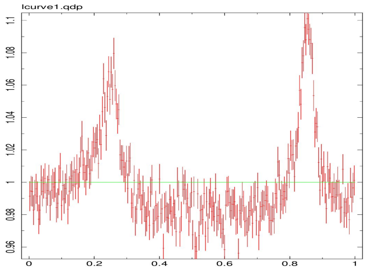
Periodic and aperiodic sources, f.e. a signal from a GRB or a pulsar, seen by an arbitrary number of detectors arbitrarily placed and oriented in space.

Takes into account both temporal and spectral characteristics of the source

GRBs

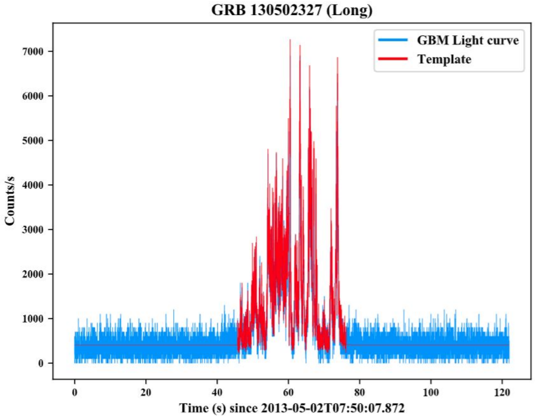


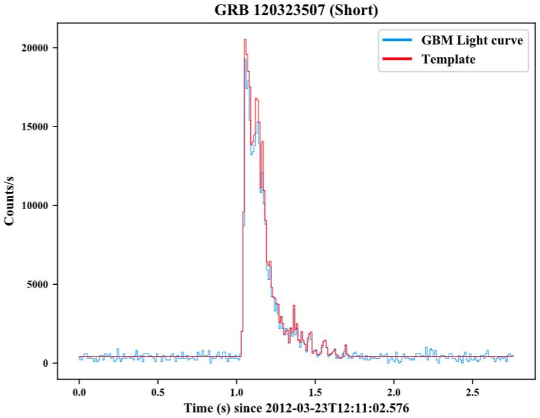
Pulsars



Simulator: timing characteristics

Lightcurve is simulated using a template. Input can be a synthetic sum of FRSD shots, event data or a binned lightcurve


GRB 130502327 (Long)


GRB 120323507 (Short)

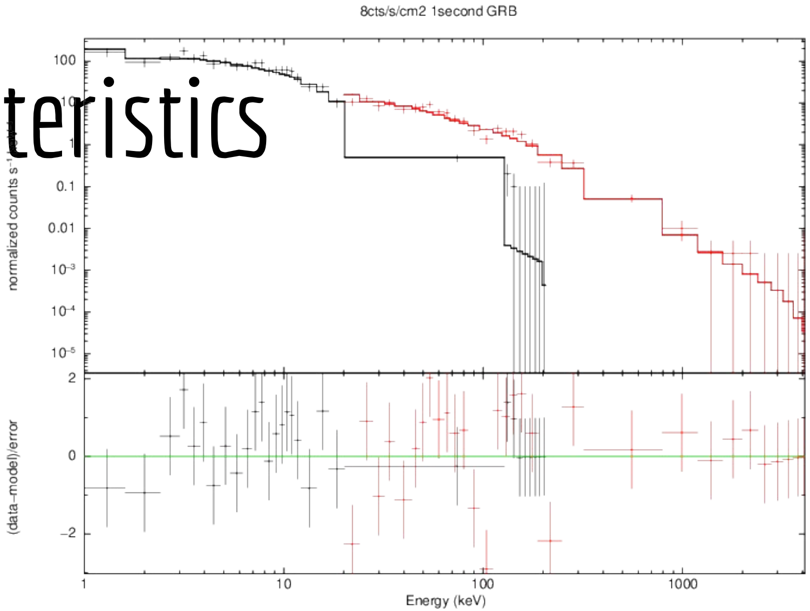
If the template is noisy on short timescales, it is smoothed to prevent artifacts due to statistical fluctuations

Simulator: timing characteristics (II)

The detectors can be placed anywhere in space and with any pointing. Position and pointing is specified (at the moment) via an input file

- Arbitrary number of detectors
- Arbitrary time resolution
- Arbitrary length of the simulation (RAM limited)

The simulator: spectral characteristics



Events generated using the Band function for the GRB (Band+93) and the CXB function for the background (Gruber+99).

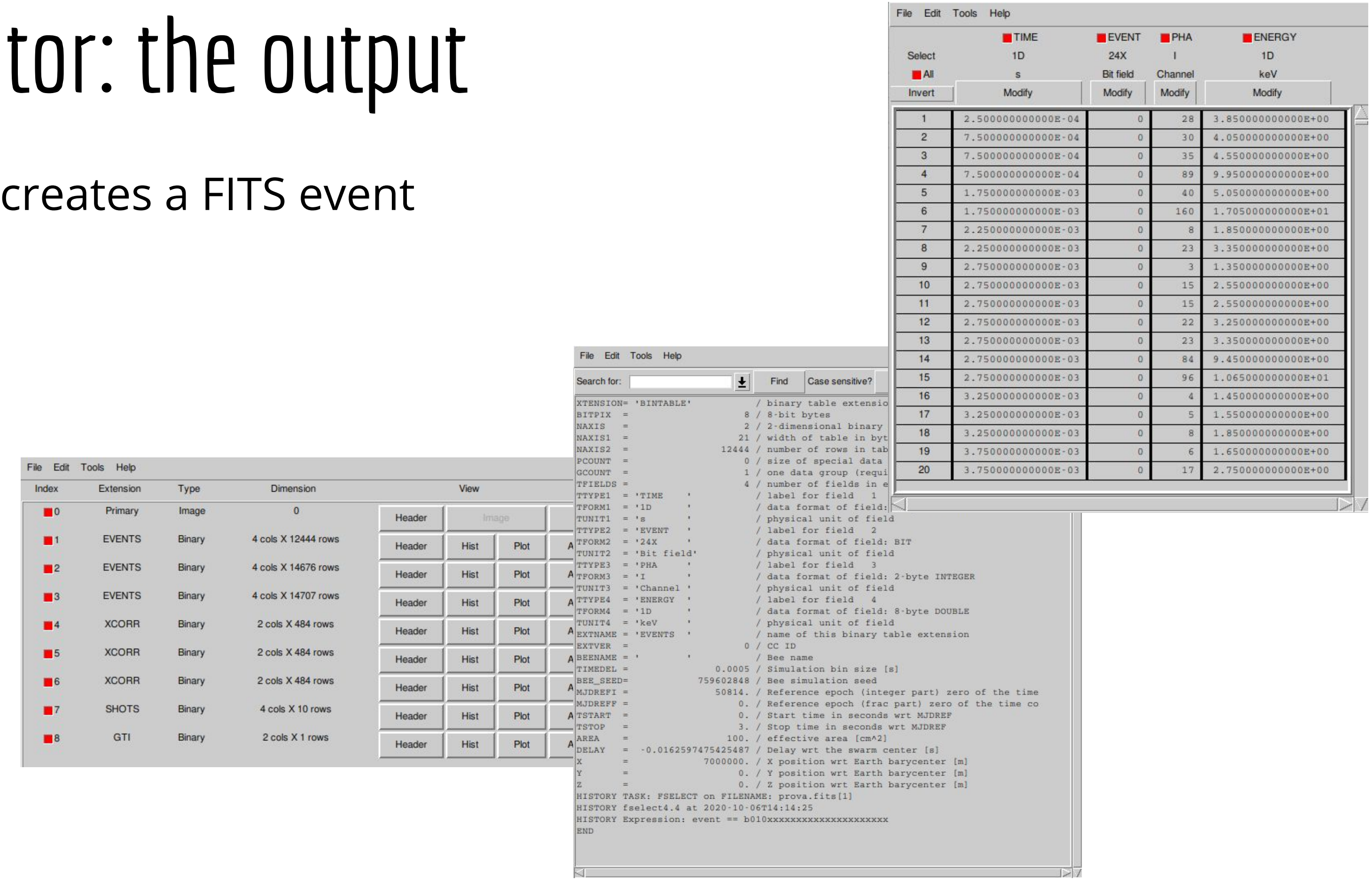
The addition of other models is very simple.

The effective area (ARF) is used to take into account the instrument response.

The *swarm_to_xspec* tools produces XSpec compliant files.

Simulator: the output

Simulator creates a FITS event



Index	Extension	Type	Dimension	View
🟥 0	Primary	Image	0	Header Image
🟥 1	EVENTS	Binary	4 cols X 12444 rows	Header Hist Plot
🟥 2	EVENTS	Binary	4 cols X 14676 rows	Header Hist Plot
🟥 3	EVENTS	Binary	4 cols X 14707 rows	Header Hist Plot
🟥 4	XCORR	Binary	2 cols X 484 rows	Header Hist Plot
🟥 5	XCORR	Binary	2 cols X 484 rows	Header Hist Plot
🟥 6	XCORR	Binary	2 cols X 484 rows	Header Hist Plot
🟥 7	SHOTS	Binary	4 cols X 10 rows	Header Hist Plot
🟥 8	GTI	Binary	2 cols X 1 rows	Header Hist Plot

```
XTENSION= 'BINTABLE'           / binary table extensio
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary
NAXIS1  =                   21 / width of table in byt
NAXIS2  =                12444 / number of rows in tab
PCOUNT  =                    0 / size of special data
GCOUNT  =                    1 / one data group (requi
TFIELDS =                    4 / number of fields in e
TTYPE1  = 'TIME    '           / label for field   1
TFORM1  = '1D      '           / data format of field:
TUNIT1  = 's       '           / physical unit of field
TTYPE2  = 'EVENT   '           / label for field   2
TFORM2  = '24X     '           / data format of field: BIT
TUNIT2  = 'Bit field'          / physical unit of field
TTYPE3  = 'PHA     '           / label for field   3
TFORM3  = 'I       '           / data format of field: 2-byte INTEGER
TUNIT3  = 'Channel '           / physical unit of field
TTYPE4  = 'ENERGY  '           / label for field   4
TFORM4  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT4  = 'keV     '           / physical unit of field
EXTNAME = 'EVENTS  '           / name of this binary table extension
EXTVER  =                    0 / CC ID
BEENAME = '        '           / Bee name
TIMEDEL =               0.0005 / Simulation bin size [s]
BEE_SEED=            759602848 / Bee simulation seed
MJDREFI =               50814. / Reference epoch (integer part) zero of the time
MJDREFF =                   0. / Reference epoch (frac part) zero of the time co
TSTART  =                   0. / Start time in seconds wrt MJDREF
TSTOP   =                   3. / Stop time in seconds wrt MJDREF
AREA    =                 100. / effective area [cm^2]
DELAY   =  -0.0162597475425487 / Delay wrt the swarm center [s]
X       =             7000000. / X position wrt Earth barycenter [m]
Y       =                   0. / Y position wrt Earth barycenter [m]
Z       =                   0. / Z position wrt Earth barycenter [m]
HISTORY TASK: FSELECT on FILENAME: prova.fits[1]
HISTORY fselect4.4 at 2020-10-06T14:14:25
HISTORY Expression: event == b010xxxxxxxxxxxxxxxxxxxxx
END
```

Select	🟥 TIME	🟥 EVENT	🟥 PHA	🟥 ENERGY
	1D	24X	I	1D
🟥 All	s	Bit field	Channel	keV
Invert	Modify	Modify	Modify	Modify
1	2.500000000000E-04	0	28	3.850000000000E+00
2	7.500000000000E-04	0	30	4.050000000000E+00
3	7.500000000000E-04	0	35	4.550000000000E+00
4	7.500000000000E-04	0	89	9.950000000000E+00
5	1.750000000000E-03	0	40	5.050000000000E+00
6	1.750000000000E-03	0	160	1.705000000000E+01
7	2.250000000000E-03	0	8	1.850000000000E+00
8	2.250000000000E-03	0	23	3.350000000000E+00
9	2.750000000000E-03	0	3	1.350000000000E+00
10	2.750000000000E-03	0	15	2.550000000000E+00
11	2.750000000000E-03	0	15	2.550000000000E+00
12	2.750000000000E-03	0	22	3.250000000000E+00
13	2.750000000000E-03	0	23	3.350000000000E+00
14	2.750000000000E-03	0	84	9.450000000000E+00
15	2.750000000000E-03	0	96	1.065000000000E+01
16	3.250000000000E-03	0	4	1.450000000000E+00
17	3.250000000000E-03	0	5	1.550000000000E+00
18	3.250000000000E-03	0	8	1.850000000000E+00
19	3.750000000000E-03	0	6	1.650000000000E+00
20	3.750000000000E-03	0	17	2.750000000000E+00

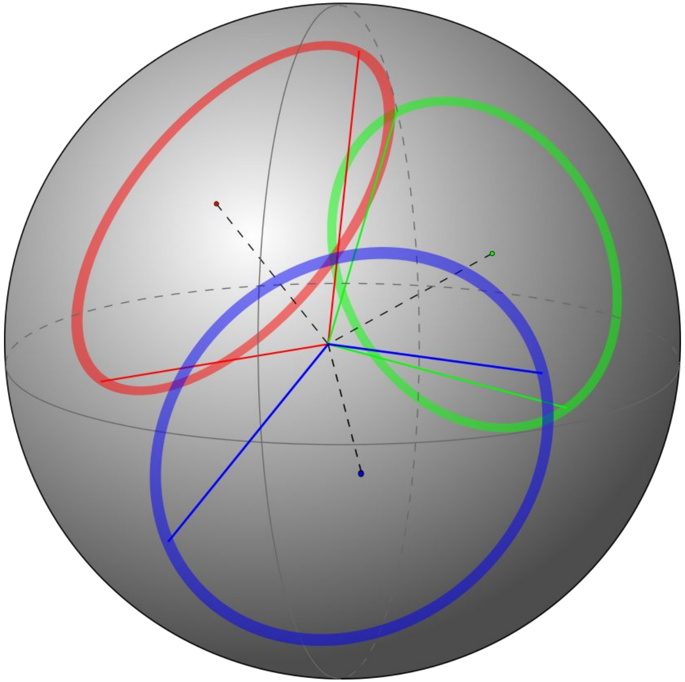
Positioning the source

Two methods implemented so far:

- Triangulation via measuring delays (see e.g. Pal’shin+13)
- Kevin Hurley method (Hurley 2020)

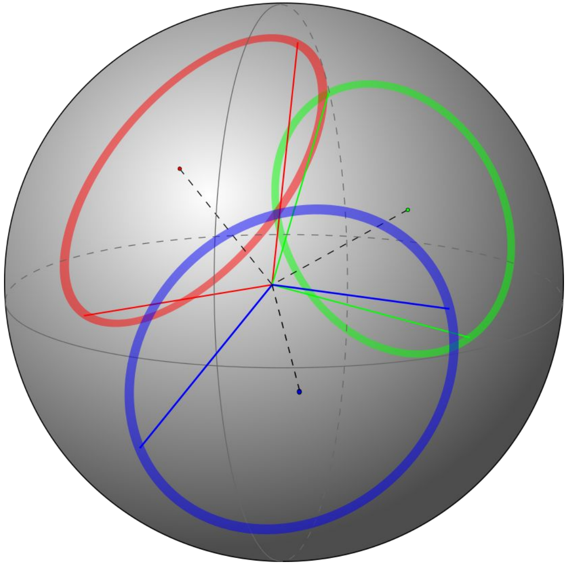
Possible future implementations

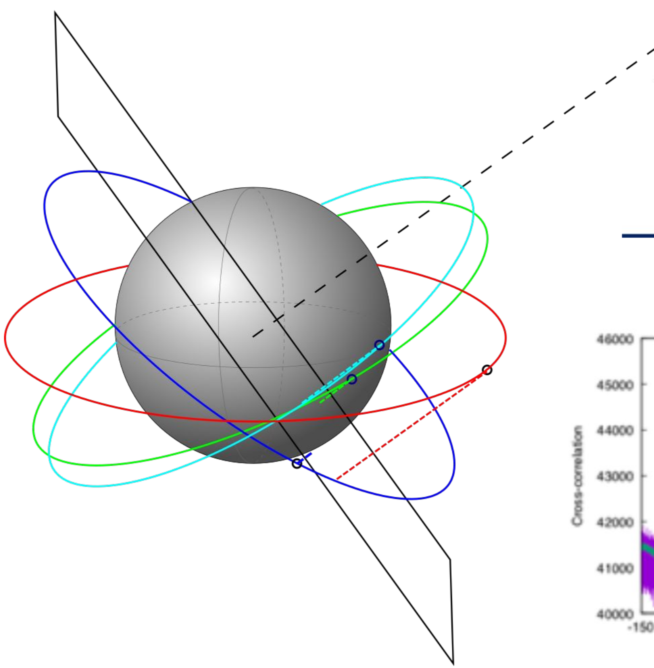
- Nazgul (Burgess+20)

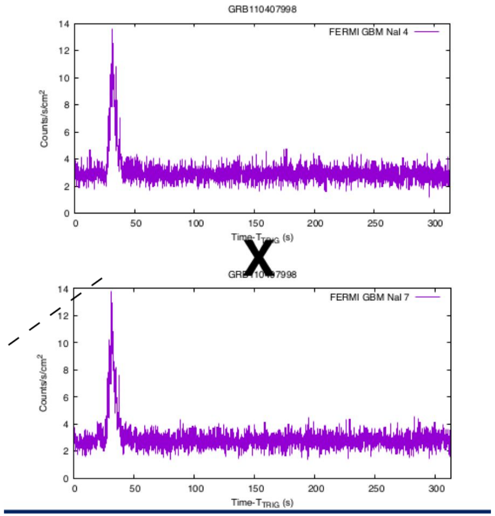


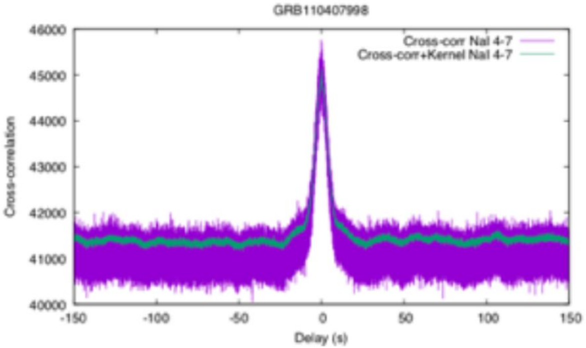
Positioning the source

$$\chi^2(\hat{\boldsymbol{d}}) = \sum_{i=0}^{n-2} \sum_{j=i+1}^{n-1} \frac{(\Delta\tau_{ij} - \Delta t_{ij}(\hat{\boldsymbol{d}}))^2}{\delta\Delta\tau_{ij}^2 + \delta\Delta t_{ij}^2},$$

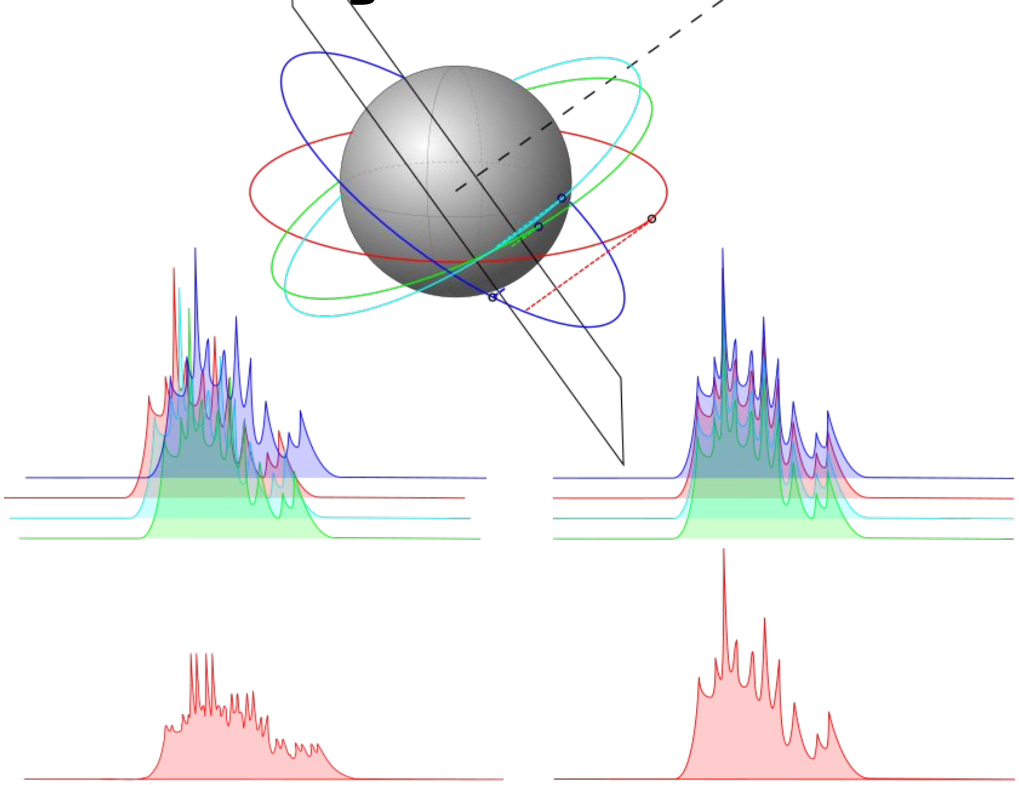


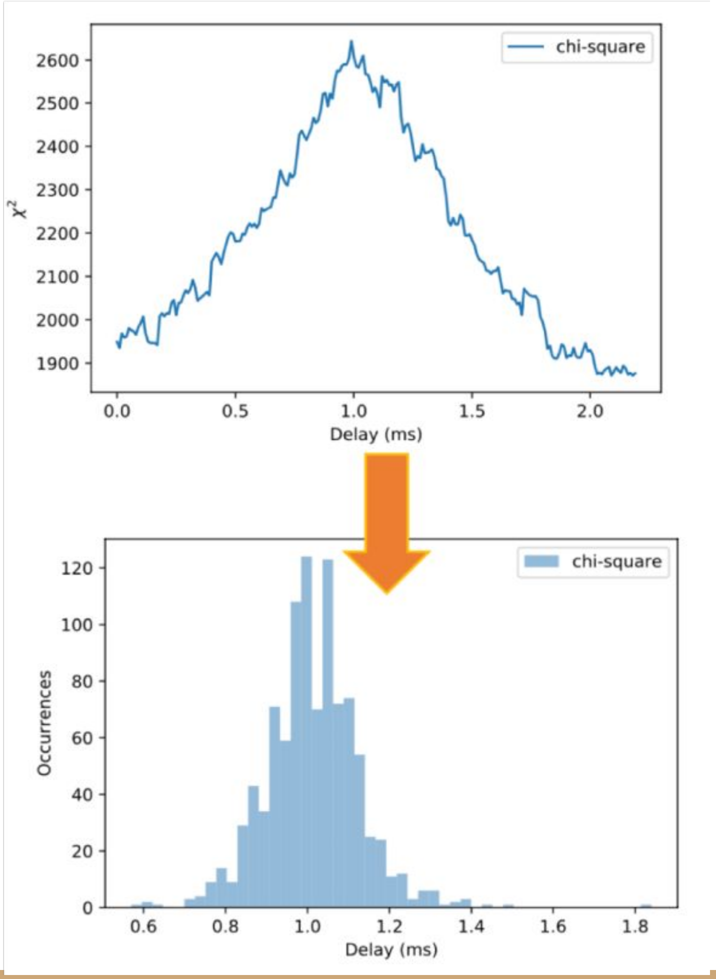






Positioning the source





Current status of the software

The software is in an advanced stage and nearly ready for a beta release.

At the moment we are concentrated in

- testing procedures
- Hurley method statistical properties
- Developing a GUI (too much input parameters!)

A lot of simulations!

To Do List (Not in a specific order)

- Find a robust algorithm for automatic cross-correlation fitting and source position determination (specially confidence regions).
- Response matrix-aware simulations (not important at the expected HERMES SP count-rates.)
- Satellite position and pointing dependent background, Earth albedo (see f.e. Campana+13)
- Dead time pruning of generated event lists.
- Moving satellites (not important for short GRBs, but relevant for long GRBs and mostly pulsar). We need to know the format of the orbit files.
- Any suggestions?

Technical stuff

Developed using standard Posix C99. Working on Linux (tested on Debian-like distributions) and Mac OS X

...

The code in numbers

Lines of Code: 7443

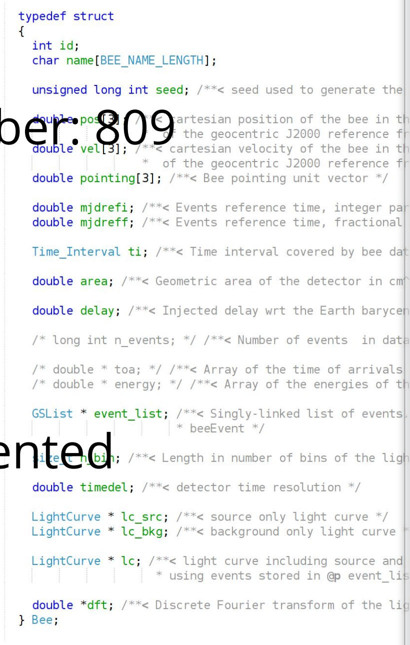
Lines of Comment: 2821

McCabe's Cyclomatic Number: 809

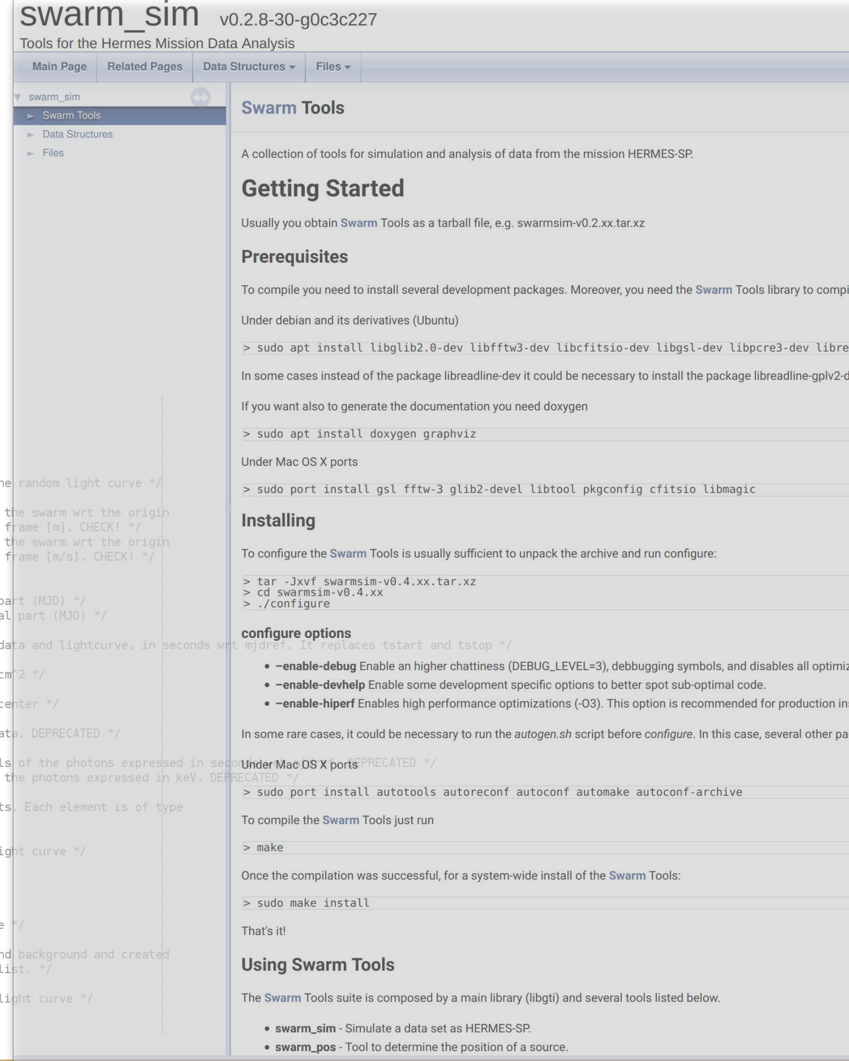
LOC/COM: 2.6

MVG/COM: 0.29

The source code is documented using Doxygen



```
typedef struct
{
  int id;
  char name[BEE_NAME_LENGTH];

  unsigned long int seed; /**< seed used to generate the random light curve */

  double pos[3]; /**< cartesian position of the bee in the swarm wrt the origin
                  *  of the geocentric J2000 reference frame [m]. CHECK! */
  double vel[3]; /**< cartesian velocity of the bee in the swarm wrt the origin
                  *  of the geocentric J2000 reference frame [m/s]. CHECK! */
  double pointing[3]; /**< Bee pointing unit vector */

  double mjdrefi; /**< Events reference time, integer part (MJD) */
  double mjdreff; /**< Events reference time, fractional part (MJD) */

  Time_Interval ti; /**< Time interval covered by bee data and lightcurve. in seconds wrt mjdref. It replaces tstart and tstop */

  double area; /**< Geometric area of the detector in cm^2 */

  double delay; /**< Injected delay wrt the Earth barycenter */

  /* long int n_events; */ /**< Number of events  in data. DEPRECATED */

  /* double * toa; */ /**< Array of the time of arrivals of the photons expressed in seconds wrt mjdref. DEPRECATED */
  /* double * energy; */ /**< Array of the energies of the photons expressed in keV. DEPRECATED */

  GSList * event_list; /**< Singly-linked list of events. Each element is of type
                        * beeEvent */

  size_t n_bin; /**< Length in number of bins of the light curve */

  double timedel; /**< detector time resolution */

  LightCurve * lc_src; /**< source only light curve */
  LightCurve * lc_bkg; /**< background only light curve */

  LightCurve * lc; /**< light curve including source and background and created
                    * using events stored in @p event_list. */

  double *dft; /**< Discrete Fourier transform of the light curve */
} Bee;
```



Swarm Tools

A collection of tools for simulation and analysis of data from the mission HERMES-SP.

Getting Started

Usually you obtain Swarm Tools as a tarball file, e.g. swarmsim-v0.2.xx.tar.xz

Prerequisites

To compile you need to install several development packages. Moreover, you need the Swarm Tools library to compi

Under debian and its derivatives (Ubuntu)

```
> sudo apt install libglib2.0-dev libfftw3-dev libcfitsio-dev libgsl-dev libpcre3-dev libre
```

In some cases instead of the package libreadline-dev it could be necessary to install the package libreadline-gplv2-d

If you want also to generate the documentation you need doxygen

```
> sudo apt install doxygen graphviz
```

Under Mac OS X ports

```
> sudo port install gsl fftw-3 glib2-devel libtool pkgconfig cfitsio libmagic
```

Installing

To configure the Swarm Tools is usually sufficient to unpack the archive and run configure:

```
> tar -Jxvf swarmsim-v0.4.xx.tar.xz
> cd swarmsim-v0.4.xx
> ./configure
```

configure options

- **−enable-debug** Enable an higher chattiness (DEBUG_LEVEL=3), debbugging symbols, and disables all optimiz
- **−enable-devhelp** Enable some development specific options to better spot sub-optimal code.
- **−enable-hiperf** Enables high performance optimizations (-O3). This option is recommended for production in

In some rare cases, it could be necessary to run the *autogen.sh* script before *configure*. In this case, several other pa

Under Mac OS X ports

```
> sudo port install autotools autoreconf autoconf automake autoconf-archive
```

To compile the Swarm Tools just run

```
> make
```

Once the compilation was successful, for a system-wide install of the Swarm Tools:

```
> sudo make install
```

That's it!

Using Swarm Tools

The Swarm Tools suite is composed by a main library (libgti) and several tools listed below.

- **swarm_sim** - Simulate a data set as HERMES-SP.
- **swarm_pos** - Tool to determine the position of a source.