

GammaLib - a new framework for the analysis of Astronomical Gamma-Ray Data

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INTRODUCTION

The last decade has seen important progress in the field of gamma-ray astronomy, thanks to significant improvements in the performance of ground-based and space-based gamma-ray telescopes. Gamma-ray photons are nowadays studied over more than 8 decades in energy, from a few 100 keV up to more than 10 TeV.

Gamma-ray data are generally comprised of individual events that are characterised by an arrival time, a direction (either given in celestial coordinates for direct imaging devices or in detector coordinates for indirect imaging devices), and an energy estimate. Many telescopes provide these data in FITS format (e.g. CGRO, INTEGRAL, Fermi), although ground-based instruments (e.g. H.E.S.S., MAGIC, VERITAS, MILAGRO) generally use their own collaboration internal data formats. An increasing number of projects use analysis tools inspired by HEASARC's FTOOLS, and most (if not all) analysis methods imply at some point the fitting of parametric models by means of maximum likelihood optimisation.

Despite these common features, there exist no common tools yet for the scientific analysis of gamma-ray data. So far, each instrument comes with its proper suite of software tools, which often requires costly development cycles and maintenance efforts, and which puts the burden on the astronomer to learn how to use each of them for his studies. For X-ray astronomy, HEASARC has developed standards that unify the data analysis tasks, making X-ray data more accessible to the astronomical community at large. We propose here to follow a similar approach for gamma-ray astronomy.

WHAT IS GAMMALIB?

GammaLib is a self-contained, instrument independent, open source, multi-platform C++ library that implements all code required for high-level science analysis of astronomical gamma-ray data.

Self-contained means that GammaLib does not rely on any third-party software, with the only exception of the cfitsio library from HEASARC that is used to implement the FITS interface. This makes GammaLib basically independent of any other software package, increasing the maintainability and enhancing the portability of the library.

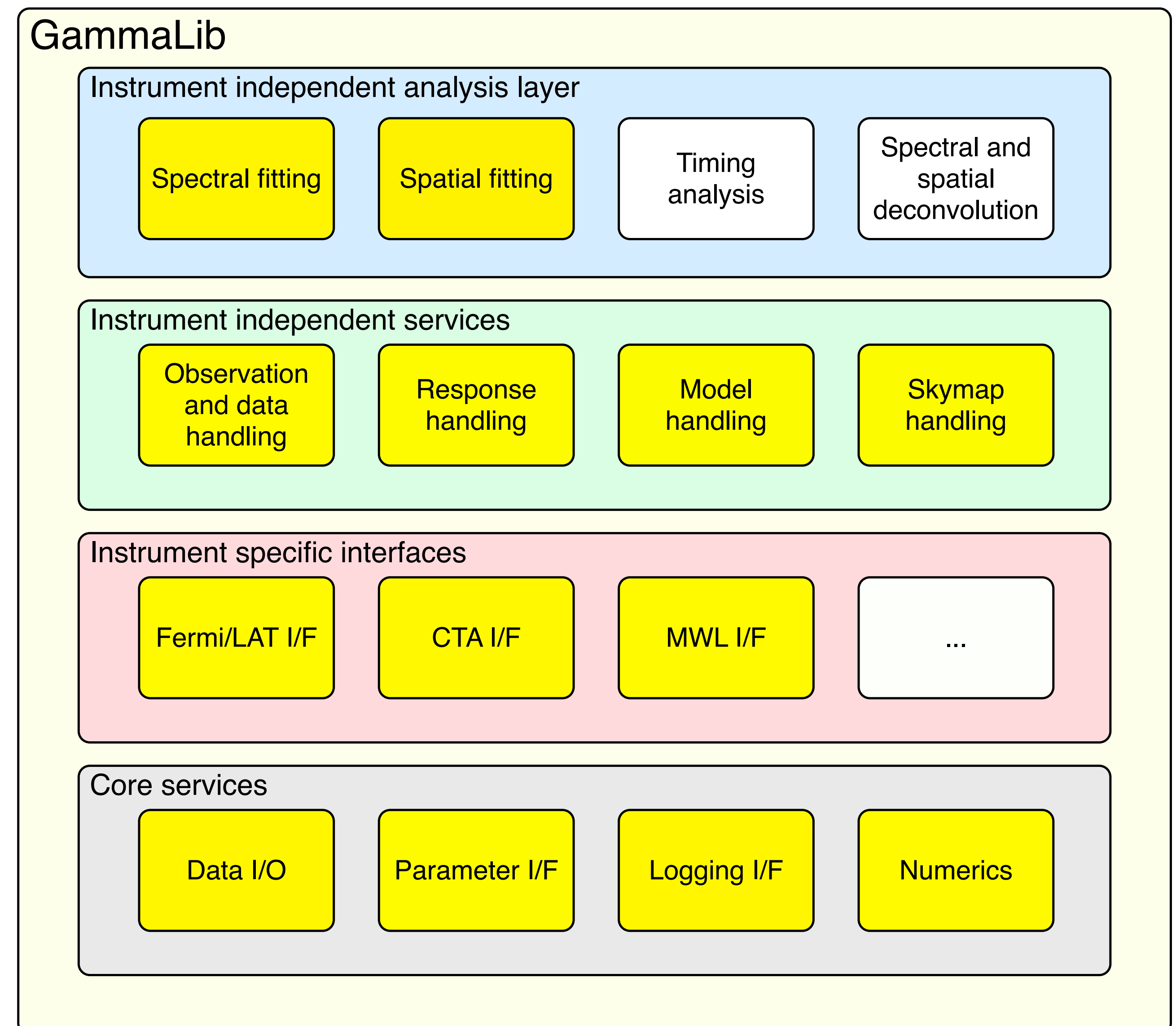
Instrument independent means that GammaLib potentially supports any gamma-ray astronomy instrument. Large parts of the code treat gamma-ray observations in an abstract representation, and do neither depend on the characteristics of the employed instrument, nor on the particular formats in which data and instrument response functions are delivered. Instrument specific aspects are implemented as isolated and well defined modules that interact with the rest of the library through a common interface. This philosophy also enables the joint analysis of data from different instruments, providing a framework that allows for consistent broad-band spectral fitting or imaging.

Open source means that the GammaLib source code is freely available under the GNU General Public license version 3. The latest source code can be downloaded from <https://sourceforge.net/projects/gammlib/> which also provides bug trackers and mailing lists. Further information and documentation on GammaLib can be found on <http://gammlib.sourceforge.net/>.

Multi-platform means that GammaLib is designed to compile on any POSIX compliant platform. So far, GammaLib has been successfully compiled and tested on Mac OS X, OpenBSD, OpenSolaris (using the gcc compiler) and many Linux flavours. We are currently setting up an automated continuous build system based on virtual machine technology to guarantee multi-platform compliance throughout the continuing development process. Pre-packed binary versions of the code will become available soon.

C++ library means that GammaLib makes heavily use of C++ classes. Instrument independency is achieved by using abstract virtual base classes, which are implemented as derived classes in the instrument specific modules.

ORGANISATION OF GAMMALIB



GammaLib is organised into four software layers, each of which comprises a number of modules. Modules shown in yellow exist already as prototypes, while modules shown in white are planned. The top layer provides support for instrument independent high-level data analysis, enabling spectral and spatial fitting by forwards folding of parametric source and background models. The second layer provides an instrument independent interface to data products, comprising information related to observations (event data, pointing and exposure information), instrument response functions, parametric source and background models used for model fitting, and sky maps. The modules of the third layer implement interfaces for specific gamma-ray instruments, which support so far Fermi/LAT and CTA data analysis. A general multi-wavelength interface allows adding non-gamma-ray flux points to spectral fits, enabling joint broad-band multi-wavelength fitting of spectral energy distributions. The fourth layer provides core services for GammaLib (data input/output in FITS or CSV format, IRAF and XML parameter interfaces, information logging, numerical algorithms and methods needed for data analysis).

USING GAMMALIB

GammaLib implements an Application Programming Interface (API) that can be used to bind functionalities into specific analysis executables. In particular, GammaLib supports the creation of new FTOOLS, which are implemented by deriving new classes from the GApplication base class. A very simple C++ executable that reads source model definitions from a file named "source.xml" and prints them to the console would look like this:

```
#include <iostream>
#include "GammaLib.hpp"
int main(void) {
    GModels models("source.xml");
    std::cout << models << std::endl;
    return 0;
}
```

GammaLib C++ classes are also wrapped into Python using SWIG, providing a Python module that can be used to create analysis scripts or to perform interactive analysis.

We currently use GammaLib to implement a set of prototype FTOOLS (<http://cta.irap.omp.eu/ctools/>) for the scientific analysis of data from the next generation ground-based Cherenkov Telescope Array (CTA). CTA is currently in the preparatory phase with an envisioned first light in 2015.