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Cherenkov Telescope Array science data analysis using the *ctools*

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ABSTRACT

The *ctools* are a set of analysis executables that are being developed as a framework for analysing Cherenkov Telescope Array (CTA) high-level data products. The *ctools* are inspired by science analysis software available for existing high-energy astronomy instruments, and follow the modular *ftools* model developed by HEASARC. The *ctools* are based on GammaLib, a C++ library interfaced to Python that provides a framework for an instrument-independent analysis of gamma-ray data. We present the status of the software development, and illustrate its capabilities by using *ctools* for the analysis of simulated CTA data.

Keywords: Gamma-ray astronomy, Data Analysis, Cherenkov Telescope Array

1. INTRODUCTION

The field of gamma-ray astronomy has experienced a spectacular progress during the last decade, thanks to significant improvements in the performance of ground-based and space-based gamma-ray telescopes.^{?,?} Ground-based imaging atmospheric Cherenkov telescopes (IACTs), such as H.E.S.S., VERITAS and MAGIC, have detected more than 100 sources of gamma rays between a few tens of GeV up to ~ 10 TeV, unveiling cosmic particle acceleration in Galactic (PWN, SNR, gamma-ray binaries) and extragalactic objects (starburst galaxies and AGN). The Fermi Gamma-Ray Space Telescope, which explores the sky since 2008 at energies from 30 MeV to 300 GeV, has detected so far almost 2000 sources of gamma rays,[?] comprising large populations of pulsars and AGN in addition to PWN, SNR, gamma-ray binaries, globular clusters, normal galaxies, starburst galaxies and radio galaxies.

A comparable amount of sources is expected to be detected by the planned Cherenkov Telescope Array (CTA).[?] One of the major challenges of CTA is that it will be the first IACT being operated as an open observatory. CTA will accept observing proposals from Guest Observers and provide tools and support for data analysis that will be compliant with existing standards, such as for example the FITS data format[?] or HEASARC's FTOOLS.[?] This will considerably differ from practices used for data analysis of existing IACTs, where dedicated integrated analysis frameworks and custom data formats that are proprietary to the respective collaborations are the rule.

The general scheme of data processing and analysis that is foreseen for CTA is illustrated in Figure 1. Raw data are collected from the telescope arrays and injected into a processing pipeline that will calibrate the data, reconstruct the events and perform an event analysis comprising the selection of gamma-ray-like events. The latter step will also derive the instrument response function corresponding to the applied event selection cuts. The processing pipeline will then deliver event lists (EVT), instrument response functions (IRF) and auxiliary data (AUX), such as pointing information, through a Data Dissemination unit to the Guest Observer. The Guest Observer will then download the data and use a dedicated software, called the *Science Tools*, for doing his own science analysis. This includes generation of sky maps, spectra and lightcurves.

We're currently developing a software called *ctools* that we propose as the Science Tools software for CTA. *ctools* is a set of analysis executables that is largely inspired from HEASARC's FTOOLS[?] and Fermi's Science

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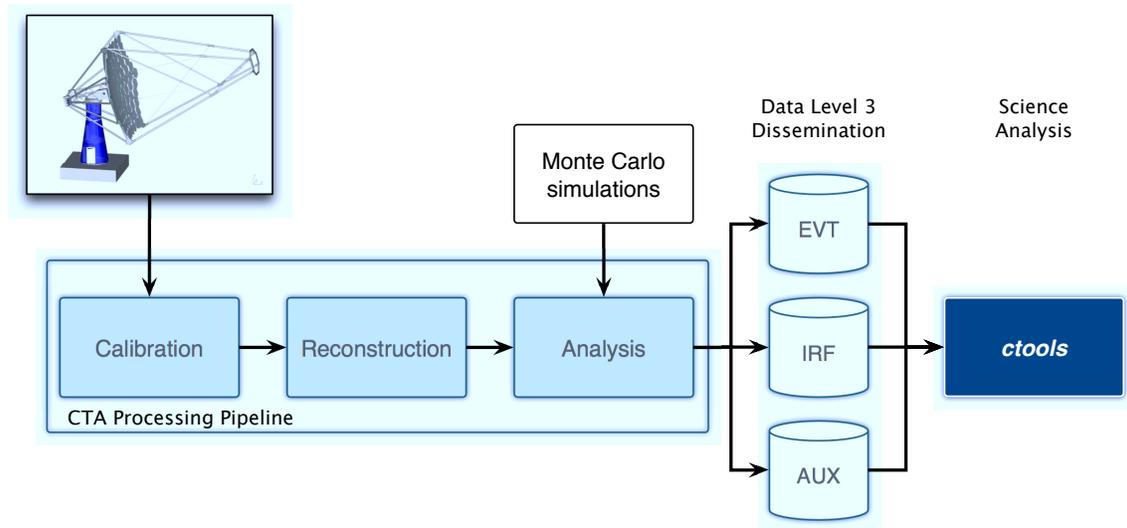


Figure 1. Overview over the CTA dataflow.

Tools, allowing the assembly of modular workflows for CTA data analyses. The *ctools* have been successfully tested on existing IACT data from H.E.S.S. and MAGIC, as well as on simulated data from CTA.⁷ *ctools* is based on GammaLib, an open source C++ library that implements a framework for high-level science analysis of astronomical gamma-ray data in an instrument-independent way. Using GammaLib puts *ctools* into a more global scope, allowing the joint analysis of CTA data and data from other high-energy telescopes, such as for example the Large Area Telescope (LAT) aboard Fermi.

2. PARTS OF MANUSCRIPT

2.1 Title and Author Information

2.2 Uppercase letters and special symbols in BibTeX

BibTeX tries to enforce standard publishing rules regarding article titles and authors' names; it sometimes changes uppercase letters to lower case. BibTeX also has trouble with umlauts, generally created in LaTeX with `\{o}`, because it is looking for the " to end the input line.

The general rule for overriding LaTeX's and BibTeX's reinterpretation of your input text is to put the items you wish to be unchanged in braces. Thus, to obtain an umlaut in an author's name or in an article title, or to force an uppercase letter, do something like the following:

```
@article{Kaczmarz37,
author = "S. Kaczmarz",
title = "Angen{\\"{a}}hrte {A}ufl{\\"{o}}sung von {S}ystemen linearer {G}leichungen",
journal= "Bull. Acad. Polon. Sci. Lett.",
volume = "A35",
pages = "355-357",
year = "1937" }
```

This example shows the use of both umlauts and uppercase letters.

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