Pulsar Analysis Package for CELESTE

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1 Introduction

This package is used by the CELESTE Cerenkov experiment for pulsar gamma event dating. As the energy threshold of CELESTE is around $30GeV$ and as CELESTE lies in the Nothern Hemisphere, this code has been applied on only two high energy gamma ray pulsar candidates, Crab and PSR B1951+32, which are single pulsars. This means that this code is not adapted for binary pulsars as it doesn't take into account relative motion in the pulsar system.

Important. Three very short test programs are joined to the package. Results are displayed using the ROOT package [2], nevertheless a text output is also performed. If the ROOT package is installed, the "$(CPPROOTFLAGS)" option has to be enabled in the "compile" line at the end of the Makefile and the "$(ROOTLIBS)" has to appear in the "link" lines (commented lines must be used to enable the ROOT display of the test results).

1.1 What does this package do?

This package computes the arrival time of an event in the solar system barycentric frame, knowing its GPS arrival time at the detector. As this code is only devoted to the study of very high energy pulsed emission, the only corrections taken into account are Roemer, Einstein and Shapiro delays (the interstellar medium dispersion correction is negligible for the studied wavelength).

This package can also compute the corresponding pulse phase knowing the pulsar parameters (reference date of the pulsar pulse, period of the pulsar, and at least its first derivative).

1.2 What does this package not do?

As stated in the introduction, this package is unable to compute barycentric corrections for binary pulsars.

This package is also unable to discover a pulsed signal, knowing nothing about the source except its position.

1.3 Package contents

data/	Run33450.dat	CELESTE Optical Crab 23/03/2001	
	Run34311.dat	CELESTE Optical Crab 16/12/2001	
	Run34313.dat	CELESTE Optical Crab 16/12/2001	
	Run34647.dat	CELESTE Optical Crab 08/02/2002	
Ephem/	jpleph200	JPL DE200 Planetary Ephemerides	
	taiutc.dat	TAI⟶UTC conversion data file	
	Crab.eph	Crab ephemeris ("Jodrell Bank format") (no FDDOT)	
	PSR1951.eph	PSRB1951 ephemeris (with an FDDOT column)	
include/	Global/	GlobalDefines.h	
	ToolBox/	Barycentror.h	
		CelTime.h	
		Ephem.h	
		JPLEphem.h	
		Messages.h	
		Observatory.h	
		Source.h	
		Tdbtra1.h	
		Tdbtra1_undef.h	
ini/	testbary.ini		
src/	Test/	baryCorrections.C	
		baryJodrellTest.C	
		baryOpticalCrab.C	
	ToolBox/	Barycentror.C	
		CelTime.C	
		Ephem.C	
		JPLEphem.C	
		Messages.C	
		Observatory.C	
		Source.C	
Makefile			
.cppProfile.Linux	**must be executed before making test program**		

2 Class Structure

2.1 Dating events

2.1.1 TCelTime

This class is described in CelTime.C. (header CelTime.h)

TCelTime class is used to manage the time information and to execute calculations with dates (e.g. comparison, sum, difference...), this class also gives complementary time information like corresponding MJD, and other useful informations for barycentric correction computation.

TCelTime keeps the int32[2] format for the date in the computationsas as much as feasible, in order to obtain more precise results.

2.1.2 TBarycentror

This class is described in Barycentror.C (header Barycentror.h)

The TBarycentror class is the central class for the barycentric correction computation.

Given the source and the observatory position and the local GPS date of the event, TBarycentror computes the date of the event in the Solar System barycentric frame.

! In order to save computation time, the barycentric correction is not calculated for each event, but only if the difference between the date of the current event and the date of the previous computation is greater than 1s (bchange, TCelTime::SetIniDate(TCelTime &tct)).

2.1.3 JPL Ephemeris Classes: TJPLTarget, TJPLEphem

These classes are described in JPLEphem.C (header JPLEphem.h)

These two classes are used to read the JPL DE200 planetary ephemeride and return the ephemerides parameters for the date of the event.

2.1.4 TObservatory, TSource

These classes are described in Observatory.C, Source.C (header Observatory.h, Source.h).

These two classes only contain the observatory and the source coordinates.

2.1.5 Tdbtra1.h

Contains the sine development for the TDB transformation.

2.2 Phase Computation

2.2.1 TEphem

This class is described in Ephem.C.

TEphem reads pulsar ephemerides written with the "Jodrell Crab Ephemeris" format. Knowing the event MJD, it finds the corresponding line in the ".eph" file and extracts the pulsar parameters.

2.2.2 TBary

This class is described in Ephem.C

Given a pulse date in the barycentric frame and using the TEphem information, this class computes the date nearest pulsar pulse before this date and the local period of the pulsar.

2.3 Input files and Ephemeris

- **jpleph200**, JPL DE200 Ephemerides
- **taiutc.dat**, **Important:** this file must be updated every six month in order to take into account changes in the TAI to UTC conversion. (see : http://www.bipm.fr/enus/5_Scientific/c_time/time_server.html). An obsolete taiutc.dat (e.g. for a pulse date out of the taiutc.dat dates range) produces a "segmentation fault message".
- **xxxx.eph**, pulsar radio ephemeris written in the "Jodrell Crab Ephemeris" format, including or not an "FDDOT" column. (see Crab.eph and PSR1951.eph)

3 Testing the package

Three differents test can be performed with this package.

3.1 Static test. baryJodrellTest.

The Jodrell Bank Observatory proposes a set of tests in order to control the barycentring procedure [1]. The testbary.ini file, read at the beginning of the execution, reproduces these datas.

The output gives the barycentric correction, the computed barycentric date, the expected one (given by Jodrell) and the difference between these two dates.

```
baryJodrellTest ini/testbary.ini
```

3.2 Computing detailed corrections. baryCorrections.

The baryCorrections test computes (and plot if the ROOT option is selected) each correction for a given observatory and source from a starting date to an ending date.

In the example:

- the observatory is Themis (French Pyrénées)

TObservatory tobs("THEMIS",1.9743,42.5025,6366.0);

(name, longitude, latitude, altitude (km from the center of the Earth))

- the source is Crab Pulsar

TSource tsource0("Crab","215854.391","053131.406",false);

(name, declination, right ascension,equinox)

(the forth arg is the equinox false = 1950 true = 2000)

- Period is a complete year from Valentine's day 2001

TCelTime tct_start("20010214","000000","000000000");

TCelTime tct_end("20020213","000000","000000000");

(yyyymmdd, hhmmss, ns).

3.3 Building the Crab Pulsar phase histogram, with a set of CELESTE Optical Data. baryOpticalCrab.

The baryOpticalCrab test is performed using crab optical data taken by CELESTE during three nights over more than one year ($\simeq 1 hour$ of data).

We have recorded in an ADC, the currents fluctuations for six of the CELESTE PMTs. After removing, identified noises (essentially the $100 Hz$ signal (Street lights) that dominates the recorded signal).

The Runxxxx.dat files contains for each event (binary)

. GPS Date (int32[2])

. ADC value (float)

. "gamma flag" (char)

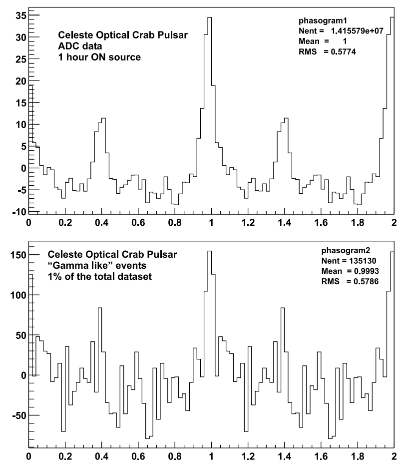

Figure 1: CELESTE Optical Crab. ROOT Phase histograms given by baryOpticalCrab

What is the “gamma flag”? As we use an ADC to record optical data, what we call “events” is a continuous set of dates. Two consecutive “events” are separated by the constant sampling period.

CELESTE gamma data have a different structure as the events are randomly distributed in time. In order to simulate such random events, we put a trigger on the ADC values. The “gamma flag” is true if the event is kept. So events with a true “gamma flag” are “Randomly distributed gamma like event”.

In the example, only 1% of ADC events are kept after the trigger.

Two phase histograms are built:

- the first one contains all events weighted with the ADC value.
- the second one contains “gamma like” events (e.g. with true “gamma flag”), randomly distributed in time and having the same weight egal to 1.

References

[1] De Naurois, Holder, et al. ApJ 566, 343-357, 2002 Feb 10

[1] A.G. Lyne, C.A. Jordan, M.E. Roberts, *Jodrell Bank Crab Pulsar Timing Results, Monthly Ephemeris,* January 21, 2002 and October 2, 2002.

[2] http://root.cern.ch