PULSAR ANALYSIS WITHIN C O M P A S S

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Abstract

The COMPASS system is a large software package, involving several subsystems, whose development has been 'shared' by the four institutes of the COMPTEL Collaboration.
A principle goal of the COMPTEL mission is the observation of point sources whose emission, in gamma or in other energy bands, is pulsed. In order to search for periodicity in the gamma-ray emission from these sources and from the new COMPTEL-detected sources, the COMPASS subsystem PUL (for "PULsar analysis") has been designed. In this paper a description of the PUL performance, with the adopted analysis methods, is given.

Data Analysis in Astronomy IV, Edited by V. Di Gesù *et al.*
Plenum Press, New York, 1992

Introduction

The **COMP**tel **A**nalysis **S**oftware **S**ystem COMPASS[1] has been designed and developed to pre-process, select and analyze the 1-30 MeV events collected by the Compton Telescope COMPTEL[2], on the NASA spacecraft GRO[3], the Gamma Ray Observatory. Elsewhere, in these proceedings, a detailed description of this system is given.
Within COMPASS, PUL is the software subsystem devoted to the "Pulsar Analysis" (periodicity searches, light-curve analysis and modelling, etc...). More specifically, PUL v.1 (March 1991) includes the following major tasks:

1) analysis of signal from already "known" pulsars
2) analysis of signal from newly discovered COMPTEL-sources
3) multiple observation analysis
4) global analysis

Then, the architectural design of PUL involves four "analysis functions":

1) **PULIND** which performs the analysis of single observations of the known pulsars, e.g.:

- search for periodicity in a "small" period range around the value extrapolated at the COMPTEL observation epoch and
- analysis of the pulsar light curve in the case of positive detection or
- evaluation of the upper-limit for the source flux in the case of no detection.

The need for pulsar parameter extrapolation is minimized because of simultaneous radio observations[4],[5]

2) **PULCOM** which performs a "large band" search for periodicity in case of new gamma-ray sources detected by COMPTEL (e.g. whose parameters are not known). Once again, in case of positive detection, a specific analysis of the "new-pulsar" light-curve will be performed.

3) **PULMLA** which performs analysis of several observations of the same source (so improving the statistics in the case of

"weak" pulsars, whose pulsation features could be undetectable in a single observation).

4) **PULGLA** for the "global analysis" of a sample of pulsars, which single observations have given a null detection. In this case, the combination of the significances of the single observations can supply information about the behaviour of the entire source sample.

PUL data-flow

PUL subsystem requires "external" inputs; these external interfaces and some intermediate steps (before the actual analysis procedure) are shown in Fig.1.

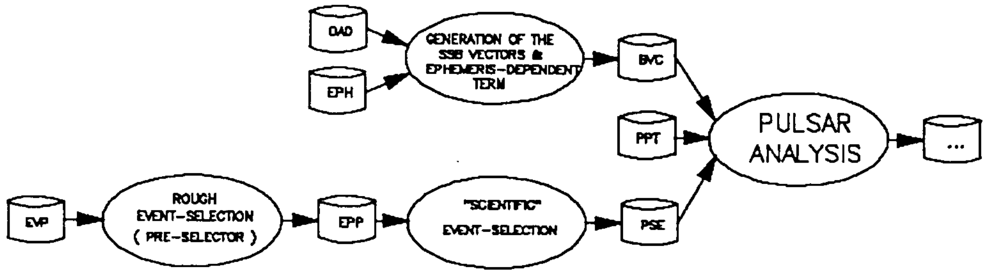
The Event Message dataset (EVP) contains the information (arrival time at the spacecraft, direction, energy released) for each of the events in one observation day. The first step performed by PUL is the "rough" pre-selection of events: this step reduces the data volume by:

- selection of the "good" time intervals (by removing those parts of the observations which are affected by South Atlantic Anomaly (SAA), Earth in the field of view, ...;
- selection of the global energy range of interest;
- selection of the events by photon arrival direction.

The output EPP dataset reproduces the same structure of the EVP dataset (all information are kept for all events), but only for the potentially "good" events.

Subsequently, the actual "scientific" selection discriminates between events in terms of more scientific criteria (e.g. a restricted energy range, by taking into account the Point-Spread Function). Eventually, only the list of arrival times for the selected events will be used for the analysis (PSE dataset).

PSE contains the time values, as measured at the spacecraft, which are to be corrected, during the analysis, by referring them to the Solar System Barycentre. This correction (dependent from the source coordinates which are supplied, as



EVP : Event Messages
EPP : Pre-selected Event Messages
PSE : Selected Event Arrival Times

OAD : Orbit/Aspect Data
EPH : Ephemeris JPL DE200
BVC : Barycentric Vector Components

PPT : Pulsar Parameters

Fig. 1

Tab. I

INPUTS:	1.	UTC arrival time
	2.	$\mathbf{GRO}_{geo}$ vector components
	3.	source direction
	4.	JPL DE200 Ephemeris[6]
DATA PROCESSING:	-	Time units transformation from UTC to ephemeris time
	-	Evaluation of the components of the $\mathbf{GRO}_{SSB}$ vector using the information on the Solar System Barycentre position supplied by the Ephemeris
	-	Evaluation of light travel time to the Solar System Barycentre
	-	Computation of relativistic delay due to gravitational field of the Sun
ANALYSIS METHOD:		The term to be added to UTC time to get the "corrected" SSB time is computed by adding the above defined terms[7]

well as the other pulsar parameters, by the Pulsar Parameter Table) uses the JPL Ephemeris at epoch 2000.0 and the geocentric spacecraft position which is supplied elsewhere by COMPASS.

The "source" and "off-source" event time lists, PSE, and the list of parameters required for the barycentric correction, BVC, together with PPT information, are the inputs to the PUL functions for the analysis of the signal from the source.

Steps of Pulsar Analysis by PUL

The main purpose of PUL is to search for periodicity in the gamma-ray emission of point-sources: the two main analysis methods available in PUL are described in detail.
The other analysis procedures directly follow and depend upon the results previously obtained. The barycentric correction is always required at the beginning of the analysis, before starting the search for periodicities in the COMPTEL detected gamma-ray signal.

Barycentric correction of the photon arrival times is required in order to eliminate the effect of the "clock motion" (due to the orbiting observatory) affecting the time measurements at GRO. Each time value is corrected by referring it to the Solar System Barycentre. This reference-frame transformation requires the spacecraft coordinates, the source coordinates, and the Solar System Ephemeris: PUL, as well as the other GRO systems for timing analysis, adopts JPL DE200 Ephemeris. The routine to properly read and handle the ephemeris information was kindly supplied by L.Rawley. In Tab.I a schematic description of the procedure is given.

Search for periodicity methods are employed to detect the presence of pulsed signal in the gamma emission of the sources observed by COMPTEL. Different approaches are to be followed in the two cases: "already known pulsars" and "new sources".

For the already known pulsars (see Tab.II), PUL is required to verify the presence of a pulsation at the expected frequency in the signal from a "pulsar" source. In this case, the first step is the extrapolation of the pulsar parameters to the COMPTEL observation epoch and then the evaluation of the scanning steps required to span the period range. The pulsar parameter reference time should be close to the COMPTEL observation, or the accuracy in the parameter values very high, to avoid scanning in period and period derivative which would reduce the sensitivity of the method.

If a positive detection is obtained, a check against system frequencies has to be performed: in order to state "positive detection", analysis of arrival times from an "off-source" event list, at the same period value where the positive detection from the source signal has been obtained, must give a negative result.

Large-band scanning is required to detect the presence of a pulsed component in the gamma-ray emission of a new COMPTEL source (see Tab.III): PUL includes the facility to perform this large-band search by FFT analysis.

For each COMPTEL observation (14 days) the events are grouped in time blocks (whose length is defined by user) and the FFT procedure over each data block generates the corresponding power spectrum. The resulting overall power spectrum (obtained by adding the single spectra), has to be properly "normalized" to estimate the significance of any power peak. This procedure has to be iterated for each of the scanning steps in Right Ascension (RA) and Declination (D) that are required to span the uncertainty in the source location. The "significance" of each power peak is verified in terms of comparison with a chosen threshold value. Also, a check to discriminate against "system frequencies" has been foreseen: if a 'significant' peak has been detected, a search for periodicity at this frequency value is also performed in an "off-source" list of events to verify the presence of the same signal.

Light-curve analysis and **modelling** procedures can be performed in case of 'positive detection'.

The representation of the pulsar light-curve produced by

Tab. II

INPUTS:	1.	UTC arrival time list from the source direction
	2.	UTC arrival time list from the off-source direction
	3.	List of $\mathbf{GRO}_{SSB}$ components
	4.	Pulsar parameters
DATA PROCESSING: list 1.	-	Determination of scanning steps in period P, period derivative Pdot, Right Ascension RA and Declination D, required to span the pulsar parameter uncertainty regions
	-	For each scanning step: ▸ barycentric correction of the arrival times ▸ time correction by referring it to binary focus (if the source is a binary one) ▸ computation of residual phases ▸ Evaluation of the phase distribution statistical significance
	-	Determination of the set of pulsar parameters ($\underline{P}$, $\underline{Pdot}$, $\underline{RA}$ and $\underline{D}$) which maximize the statistical variable adopted to estimate the significance of the phase distribution
list 2.	-	Barycentric correction of the arrival times
	-	Computation of the residual phases at P=$\underline{P}$ and Pdot=$\underline{Pdot}$
	-	Evaluation of the statistical significance for the phase distribution
ANALYSIS METHOD:		Significance evaluation of residual phase distribution by Z_n^2 [8] variable
ESTIMATION CRITERIA:		Comparison between results from the analysis of signals (at $\underline{P}$ and $\underline{Pdot}$) detected in the two lists 1. and 2.: a positive detection means that the signal detected in list 1 does not appear in list 2.

Tab.III

INPUTS:	1. UTC arrival time list from the pulsar direction 2. UTC arrival time list from an off-source direction 3. List of **GRO**$_{SSB}$ components
DATA PROCESSING: list 1.	- Determination of scanning steps in RA and D to span the source parameter uncertainty regions - For each of N_S scanning steps ▸ group the UTC times in blocks which time length has been chosen ▸ barycentric correction of the arrival times ▸ For each time block: - binning of the SSB - times - evaluation of power spectrum by FFT ▸ Sum of power spectra ▸ Transform the spectral densities into chi-sq. distributed variables ▸ Determination of maximum power value and relative signal frequency - Maximum power determination among the maxima found at the different scanning steps and relative values of P,RA and D - Evaluation of the probability relative to the detection of this signal after N_S trials
list 2.	- Barycentric correction of the arrival times - Evaluation of residual phases at P=P - Evaluation of the statistical significance for the residual phases distribution
ANALYSIS METHOD:	For list 1 the transformation from spectral densities to chi-sq. variable in order to evaluate the probability to get the found power peak from a poissonian distribution. For list 2 the evaluation of the significance of residual phase distribution is made by computing of Z_n^2 **[8]**
ESTIMATION CRITERIA:	Comparison between results for the two list at P=P

classical histogramming is affected by the a-priori choice of the number of bins. A "free-binning" representation of the light-curve is achieved by the Kernel Density Estimator analysis[9]: this method supplies the pulse shape after smoothing statistical fluctuations affecting its structure (at least, at the defined confidence level).
Further analysis of the pulsar light-curve may be performed by modelling the single structures (peaks): for each phase window (defined by user as "peak region") a fitting procedure may be performed to describe the peak in terms of a gaussian or sinusoidal function and a more detailed analysis of the pulse structure is possible in terms of an exponential model to fit limited regions of the peak.

The **multiple analysis** task has been included in PUL in order to fully exploit the available COMPTEL data; the analysis of several observations of the same target could make a "weak" pulsed signal detectable. This analysis can only be performed for sources whose parameters are well known (no scanning required); after a "negative" detection from single observation analysis, a binning of the residual phases is obtained and the resulting 2000 bin histogram is stored. The procedure can handle up to 10 such histograms: they are "added" and the statistical significance of the resulting "light-curve" is evaluated.

The **global analysis** task involves a sample of pulsars which have given no positive detection: sum of single significances may bring to visibility an overall signal as obtained from many small, statistically undetectable, signals. The algorithms implemented in PUL are elsewhere[10] described.

Perspectives

The present version of the PUL subsystem has no pretence to be exhaustive: it will be subject to improvement and increments in terms of possibility of analysis sophistication offered to users.
With PUL v.2 we are planning to enlarge the fields of interest covered by COMPASS: PUL should include also the

possibility to perform timing analysis of signal from binary sources. This means introducing the possibility of handling signals at higher period values ($P \approx 10 \div 100$ s.) than the typical values foreseen by the present version ($P \leq 1$ s.), or with a "quasi-periodic" behaviour; these tasks will require different analysis instruments and methodologies.
A good knowledge of the actual instrumental performances of COMPTEL, following the final validation and calibration of the software with the in-flight data, will probably suggest further improvements and corrections.

Acknowledgments

The authors acknowledge the other colleagues of the COMPTEL Collaboration. M.Busetta acknowledges the receipt of an ESA Research Fellowship.

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