1D, 2D, 3D wavelets methods for gamma-ray point source analysis

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Abstract
Wavelet transforms are commonly used to translate a 1D signal or a 2D/3D field into both space and scale/frequency, showing the information in a more useful shape. 1D wavelet transforms allow to characterize the variability behavior, which represents an useful piece of information in the astrophysical identification of gamma-ray sources. On the other hand the 2D/3D wavelet technique has turned out to be a valid alternative/partner of the classical (model-dependent) Likelihood analysis, permitting a rapid, efficient and blind detection of bright sources. Here are reported few examples of the application to EGRET observations and simulated data of GLAST.

Introduction
Wavelet transforms (WT) are commonly used to translate a 1D signal and 2D/3D array into both space and scale/frequency, showing the information in a more useful shape. WT make use of space-localized and oscillatory functions called wavelets, that are dilated and contracted before convolving them in each part of the signal, providing a scale decomposition and analysis of local variations of power, and allowing an efficient deconvolution and cleaning. Here are presented few examples of the application of the WT to light curves and gamma-ray maps from EGRET observations and full-instrument simulations of GLAST. The large effective area (8500 cm² at 1 GeV) and wide field of view (2.4 sr) of the LAT instrument of GLAST (passband 30 MeV - 300 GeV), provide means a rather continuous monitoring of variable sources on a wide range of time scales, and the expected detection of a few thousands of new gamma-ray point sources. Source detection, source identification, and variability analysis are therefore central problems for GLAST, and wavelets can play an useful role.

Light curve analysis with 1D wavelets
The continuous wavelet transform (CWT) can be an useful tool to analyze coherent time structures, spectral features, and localized variations of power within a light curve. Light curves form the fundamental simulations of the LAT (Data-Challenge 2, DC2, 55-days of simulated observations, and now starting on Service Challenge, SC, 1-year simulations) are extracted using python scripts and the standard method of aperture photometry (DC2 only). These are then analyzed using the 1D WT with a Morlet mother wavelet (plane wave modulated by a Gaussian envelope).

Detection of gamma-ray sources with 2D wavelets
Source detection at gamma-ray energy bands is a tricky problem owed to the few photon counts collected. Statistics is intimately poor (Poissonian regime) and the S/N ratio of a typical source is low. Moreover high energy detectors show a large variation of the Point Spread Function (PSF) in energy, and a quite bad resolution compared with other lower frequencies (giving spreading, source overlap and harder source detection). On the other hand bright and extended sources (diffuse emission, some bright AGN or SNR) obscures the closest and faint point-like sources, making harder their detection and characterization. The 2D wavelet called Mexican Hat (or Marr, i.e. the Laplacian of a Gaussian function) has the best features for the point-like source detection. Our 2D WT algorithm (named PGWAVE) does not require “a priori” model of the source and could be profitably useful together with the standard, parametric, Likelihood techniques. This 2D tool was applied on the LAT DC2 simulated maps, dividing the gamma-ray sky in 34 areas, each one with a 30deg side and with a 0.25deg resolution. The final result is a catalogue with more than 800 sources (Sigma confidence). This result is satisfactory, compared with the DC2 official released catalogue. The method can generate additional information and files (like maps produced by the Gaussian, median, adaptive and wavelet filters, the threshold/over-threshold and significance maps).

Summary
- 1D WT method can be useful to analyze and characterize variability of the gamma-ray sources, and it thus represents also an useful tool in the identification process of new detected sources.
- 2D WT algorithm allows a fast, efficient and blind source detection without any complex model or parameterization of sources. It can be useful for a first quick look of transients, flares and bright signals, and produced already a significant detection. At higher energies the method identify easily the sources, and shed light on different energy spectra (some sources present at lower energies can disappear at higher energies, while other sources become brighter). Such method might also define the position of the detected sources with a finer precision, respect to the 2D version in some cases (as the PSF improves in spatial resolution at higher energies).

Detection of gamma-ray sources with 3D wavelets
The 2D WT can be extended adding the energy or time as third dimension, to obtain “cubes” holding, respectively, the spectral energy development or count/intensity temporal behavior of a sky region. The 3D WT algorithm, was applied as a first test in the DC2 LAT area around 3C 279, working with the energy (logarithmic binning), the third dimension. At lowest energy (below 100MeV) the background noise is very strong and prevents any significant detection. At higher energies the method identify easily the sources, and shed light on different energy spectra (some sources present at lower energies can disappear at higher energies, while other sources become brighter). Such method might also define the position of the detected sources with a finer precision, respect to the 2D version in some cases (as the PSF improves in spatial resolution at higher energies).

3D wavelet source detection in the field of 3C 279 (detail). Each image represents a map extracted in a defined energy band. Energy in the panels rises from 100MeV (panel a) to 200 GeV (panel h).