A model independent method for the stacking analysis of multiple gamma-ray sources for Dark Matter searches

Francesco de Palma[1,2], Francesco Loparco[1,2] and M. Nicola Mazziotta[2]
[1] Università di Bari
[2] INFN Bari
on behalf of the Fermi Large Area Telescope Collaboration

Abstract

We have developed a new technique based on the unfolding spectral analysis tools, that allows to perform a stacking analysis of a set of multiple point-like sources. Our technique yields the average energy spectrum of the sources, eventually allowing to set upper limits on the fluxes in case of faint sources. Such analysis turns out to be very useful when a set of sources, with similar spectral features have to be studied. As an example, we have applied the stacking analysis to a set of dwarf spheroidal galaxies and to the Milky Way. The results of the analysis will be shown and their implications in terms of dark matter annihilation cross sections will be discussed.

1. Introduction

At a given energy *E* the gamma-ray flux from WIMP annihilation in a Dark Matter (DM) source can be factorized in two terms [1]:

$$\phi_{WIMP}(E,\psi) = J(\psi) \times \Phi^{PP}(E) \qquad (1)$$

where

$$\Phi^{PP}(E) = \frac{1}{2}\frac{\langle\sigma v\rangle}{4\pi m_{WIMP}^2}\sum_f \frac{dN_f}{dE}B_f \qquad (2)$$

is the *particle physics factor* while J(ψ) is the *astrophysical factor* that is determined by the DM density distribution along the line of sight from the source to the detector, and depends only on the angular distance ψ of the source. In Eq. (2) <σv> is the relative velocity of the two annihilating particles times the WIMP annihilation cross section; B_f and dN_f/dE are respectively the branching ratio and the photon spectrum of each pair annihilation final state (f).

The analysis of **dwarfs Spheroidal galaxies** (dSph) is really promising for DM studies for several reasons. In fact, their mass-to-light ratio can be of the order of 10^2-10^3[1], implying that they are largely DM dominated. Moreover negligible gamma-ray emission of astrophysical origin is expected.

New measurement and multiwavelength observations of dSph have made new data available for the estimation of J. In this analysis J is evaluated assuming a Navarro-Frenk-White (NFW) [2] DM density profile as in [3]. The values of J for each dSph used in this analysis are listed in Table 1.

The **Milky Way** is another good candidate for DM studies. Since it hosts many bright astrophysical gamma ray sources, to study DM emission from the Milky Way we have chosen a set of different positions in the sky far away from the known sources reported in the 1FGL catalog [4] (clean sky regions). For each location the J factor for the galactic DM is evaluated along the line of sight [5] assuming a NFW profile with ρ_0=0.3 GeV/cm^3.

2. Method description

We have developed a new method to perform DM searches and to evaluate ULs without any best fit procedure and without assuming any background model.

Given a sky direction, corresponding to a candidate DM source, the total number of photons (signal + background) coming from a cone centered on the source position (Region of Interest, RoI) is recorded. To evaluate the background, the photons in an external annulus to the RoI (with an inner radius larger than the instrument PSF value at the lowest energy used in the analysis) are considered. All the known sources (from the 1FGL catalog) within the annulus are masked in order to better evaluate the diffuse background components. In this case the background annulus is divided into a set of HEALPIX pixels [7] and those pixels at an angular distance less of a preset value (2°) from any of the sources in the 1FGL catalog are masked. Once the total and the background events as function of energy are evaluated, ULs on the signal events have been calculated with respect to the null hypothesis of no signal detection. A Bayesian approach that assumes Poisson Probability Density Functions (PDFs) for the counts in the RoI and in the annulus and uniform priors for both signal and background, and takes into account the solid angle and live time ratios between the RoI and the annulus has been used [6]. The ULs on the signal counts distributions are finally converted into ULs on the flux by means of the unfolding tools [8] developed for the spectral analysis of the Fermi LAT data.

The expected gamma-ray flux from DM annihilation is then evaluated as a function of <σv> using the DMFIT package [9] implemented in the LAT Science Tools [10] and taking into account the source J factor. The ULs on <σv> are therefore evaluated imposing that the predicted photon flux from DM does not exceed the measured flux ULs.

A stacking analysis is also implemented. In this case the counts from the RoIs and the annuli corresponding to each source are added, and the ULs on the signal are evaluated following the same procedure as for individual sources. The different exposures of the sources are taken into account when evaluating the smearing matrix [8], and the ULs on <σv> are evaluated in the same way as for individual sources.

The stacking analysis has been applied to study sets of dSphs with similar J factors and similar background contamination and to study of the Milky Way.

3. Data Selection

For this analysis we used the data collected by the LAT during its first 30 months of operation. The analysis was performed using the P7V6 Instrument Response Functions (IRFs) [11]. All photons detected by the LAT (i.e. events converting in either the front or back part of the instrument) were used, with energies from 562 MeV to 562 GeV. A standard set of event selection cuts for the rejection of albedo photons around 10° from the sky direction to be analyzed were applied.

The **dSph analysis** was performed selecting *SOURCE class* photons within a 0.5° angular radius RoI around each source, while the background events were evaluated in an annulus from 5° to 6°.

The **Milky way** analysis was performed choosing a set of 89 positions in the sky, each one at least 6° far away from the known sources of the 1FGL Catalog and at least 10° far away from the galactic plane. For this analysis *CLEAN class* photons within a 2° RoI centered on each sky position were selected and no background subtraction was performed.

References

1. Baltz, E. A. et al., JCAP07 013, 2008
2. Navarro, J. F. et al., ApJ 490, 1997
3. Abdo A. A. et al., ApJ 712, 2010
4. Abdo A. A. et al., ApJS 188, 2010
5. Fornengo N. et al., Phys. Rev. D70 2004
6. Loparco F. and Mazziotta M. N., submitted to NIMA
7. K. M. Górski et al. Astrophys. J.622, 759 (2005); http://healpix.jpl.nasa.gov)
8. Mazziotta M. N., contribution to 31st ICRC, arXiv 0912:1236; Loparco F., Mazziotta M. N., Contribution to the II Fermi Symposium, arXiv 0912:3695
9. Jeltema, T. E. and Profumo S., JCAP11 003, 2008
10. http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone
11. Charles, E., Rando R., Validation and Calibtation of the Fermi LAT Instrument Performance, talk in this Symposium

4. Dwarfs Spheroidal Galaxies analysis results

Name	L	B	J_{NFW} (10^{19}Gev^{2}cm^{-5})
Segue I	220.48	50.42	2.0
Draco	86.37	34.72	1.2
Fornax	237.1	-65.7	0.06
Carina	260.11	-22.2	0.06
Sextans	243.4	42.2	0.06

Table 1: List of the dSph galaxies used in this analysis. The J factor values are evaluated in a cone of 0.5° radius (solid angle 2.4x10^{-4}sr) centered on each dSph, and are taken from [3]. The two dSphs with highest J factor are highlighted in yellow; the three dSphs with lowest J factors are highlighted in light blue.

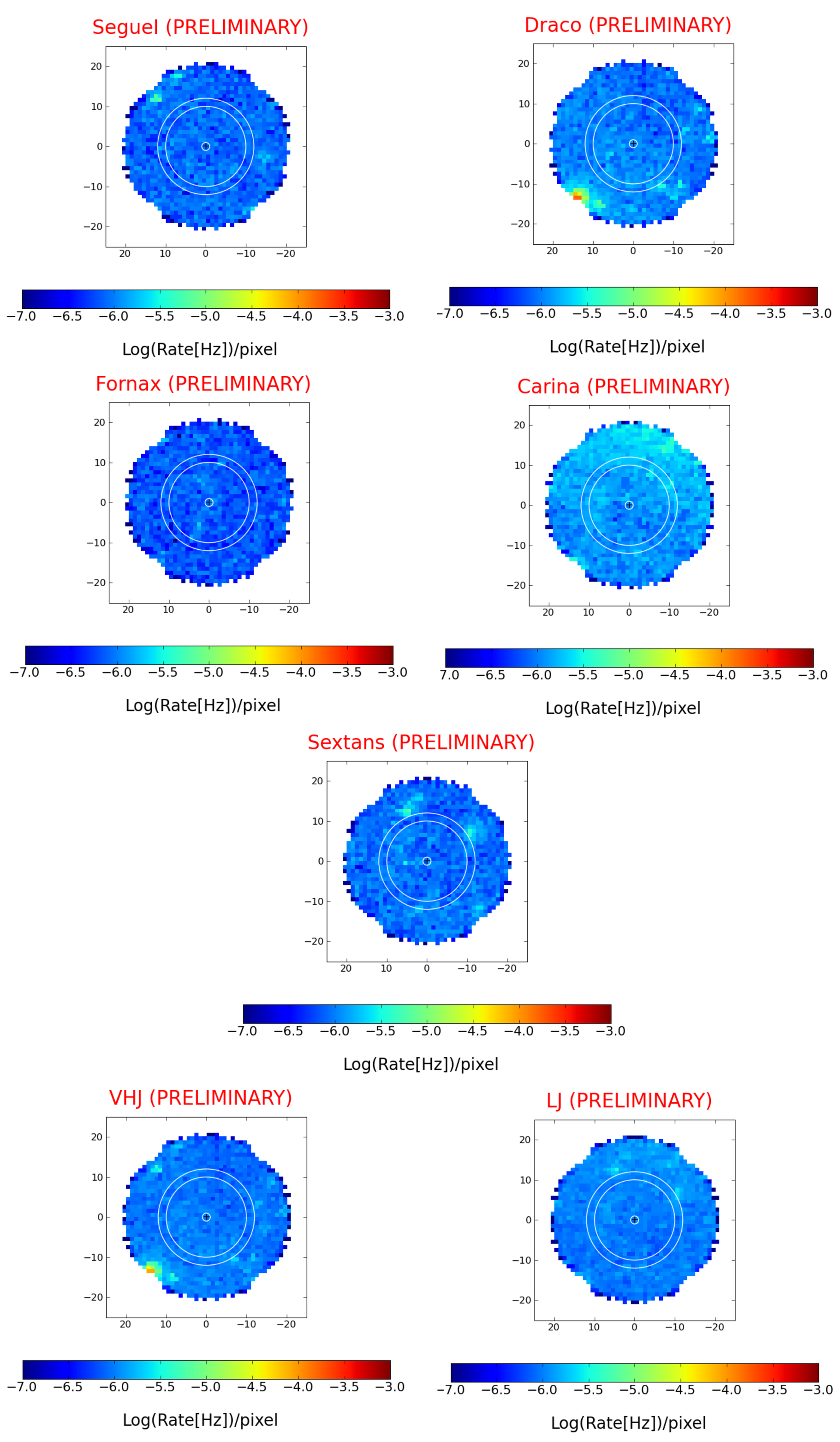
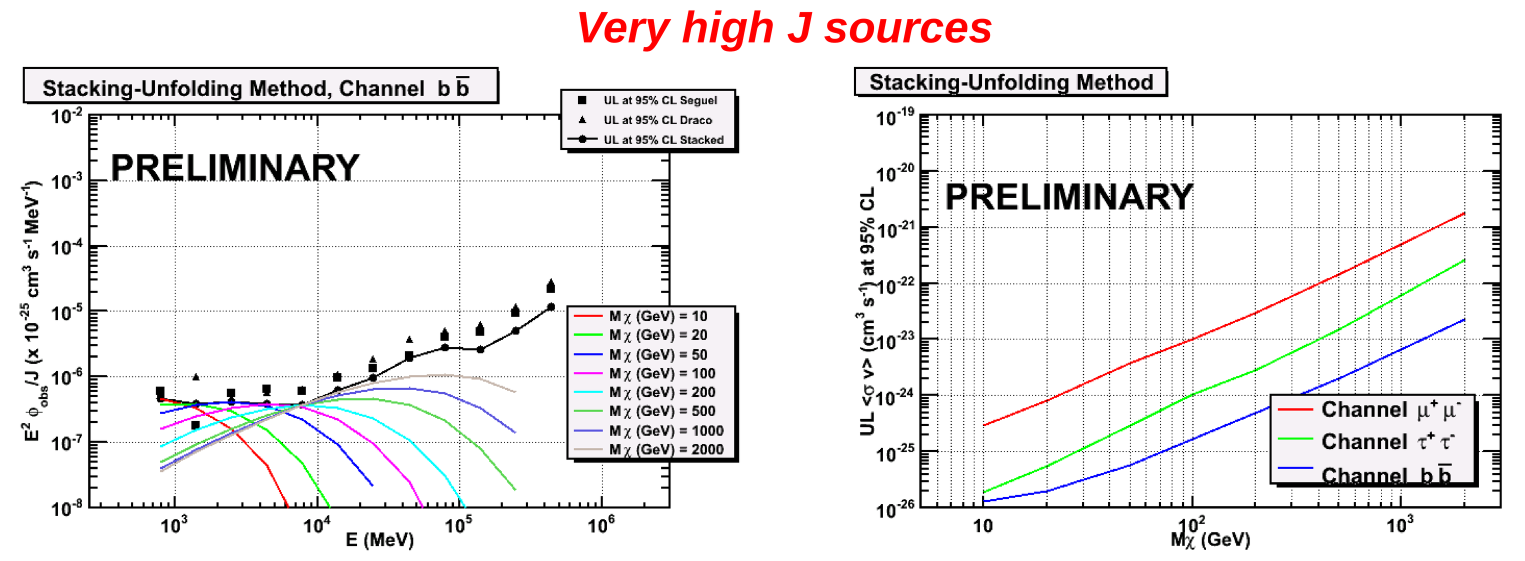


Figure 1: Rate maps for single dwarfs with unmasked 1FGL sources. The bottom plots represent the stacked counts map of the two dSphs with the highest J factors (Segue I and Draco) and of the three dSphs with the lowest J factors (Fornax, Carina, Sextans). On each plot are shown the 0.5° contours of the analysis RoI and the 5° and 6° contours of the annulus used to evaluate the background.

Very high J sources



Low J sources

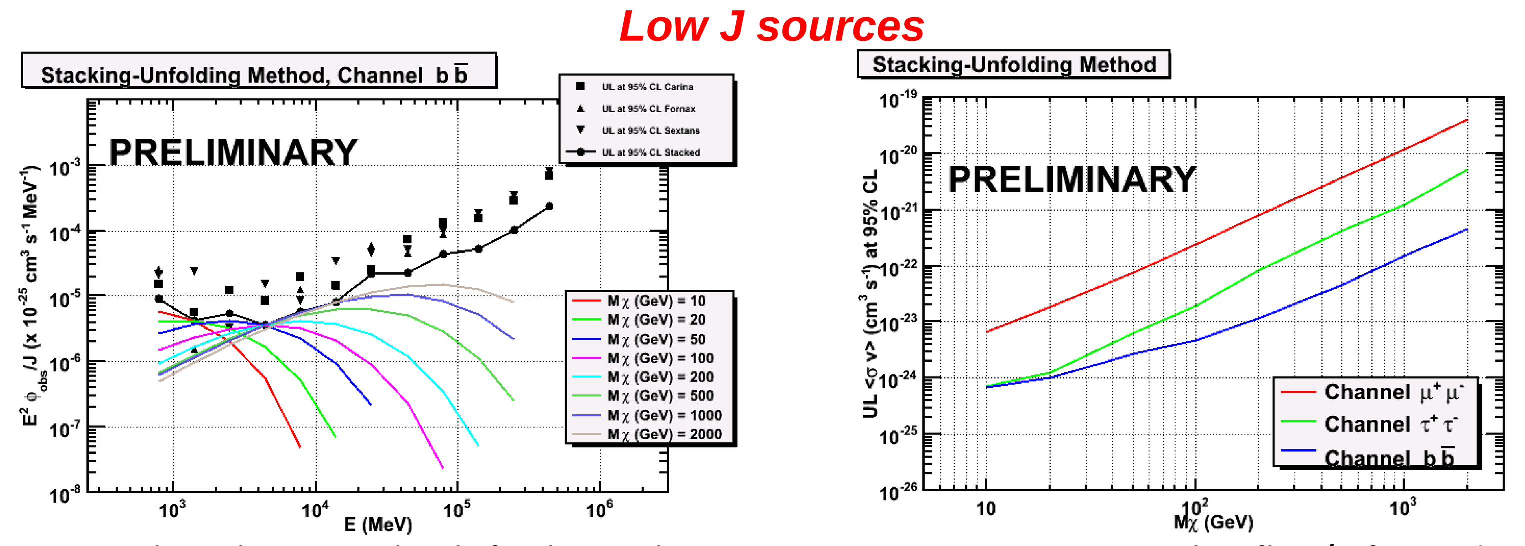


Figure 2: The plots on the left show the 95% CL Bayesian ULs on the flux/J for individual dSphs (symbols) and for the stacked sources (solid lines). The colored curves indicate the maximum photon flux from WIMP annihilation in the bb̄ channel allowed by the stacking analysis results. The plots on the right show the 95% CL Bayesian ULs on <σv> for different annihilation channels as a function of the WIMP mass.

5. Milky Way analysis

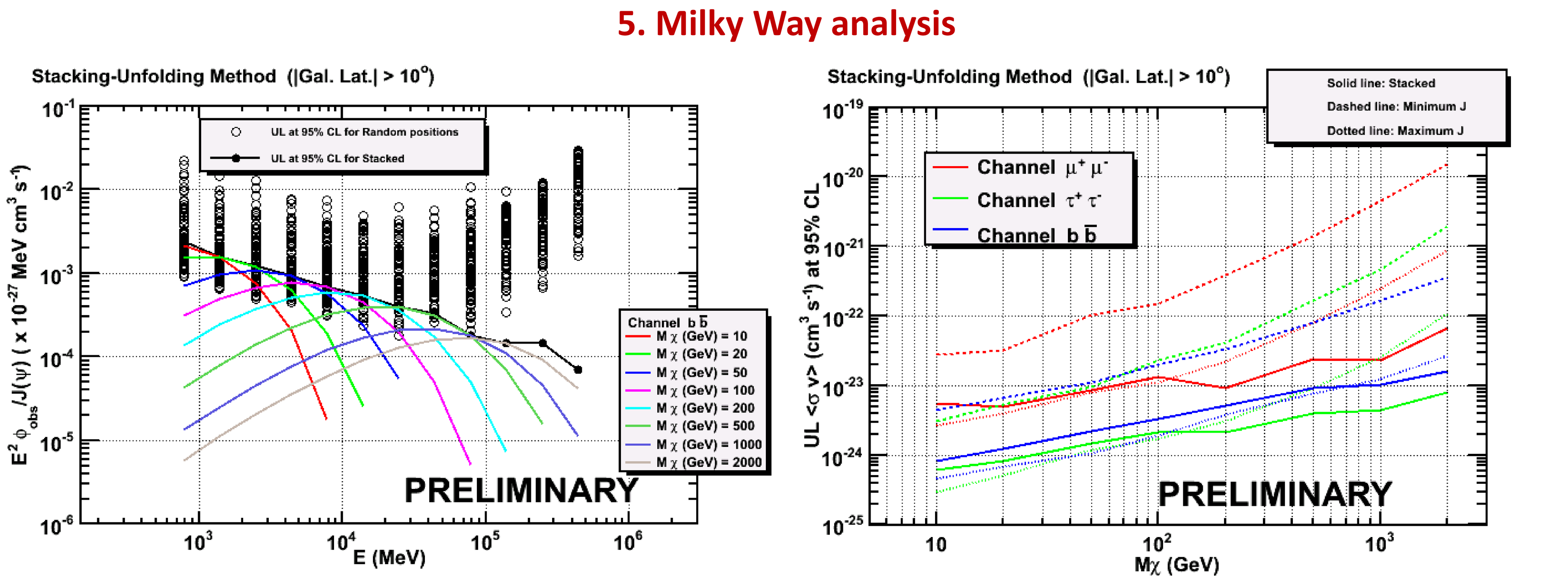


Figure 3: The plot on the left shows the 95% CL Bayesian ULs on the flux/J from individual sky positions (open symbols) and from the stacked sky positions (full circles connected by a solid line). The colored curves indicate the maximum emission allowed below the observed stacked UL for different WIMP masses in the bb̄ channel. The plots on the right show the 95% CL Bayesian ULs on <σv> for different annihilation channels as a function of the WIMP mass. The solid line corresponds to the UL obtained by stacking all the 89 sky positions, the dashed line to the UL from the sky position with the lowest J factor and the dotted line to the UL from the sky position with the highest J factor.