Bispectrum analysis of the Unresolved Gamma-Ray Background

The origin of the UGRB is an open question in astrophysics. Recent studies have placed constraints on the contribution from various astrophysical sources such as blazars through the measurement of anisotropies using the angular power spectrum.

In this work, efforts have made made to extend the measurement of anisotropies to higher order statistics of the UGRB through use of the angular bispectrum.

The formalism and analysis pipeline developed by the Fermi-LAT collaboration [1] for the analysis of the angular power spectrum has been extended to the angular bispectrum. Measuring diagonal components of the angular bispectrum allows this analysis pipeline to be applied in a similar fashion.

Point source amplitudes

For a population of unresolved point sources, the expected angular power spectrum and bispectrum are expected to be independent of multipoles and can therefore be characterized by a single amplitude. For a source population characterized by a source count distribution *dN/dS*, these amplitudes are given by

$$C_P = \int_0^{S_t} dS \, \frac{dN}{dS} S^2$$

$$b_P = \int_0^{S_t} dS \, \frac{dN}{dS} S^3$$

where *S* is the flux, and S_t is the threshold flux above which sources can be individually resolved.

Fermi-LAT data

Data used in the analysis of the UGRB is the P8R3_ULTRACLEANVETO event class in the range 700 MeV to 1 TeV binned in 10 logarithmic bins.

Known sources in the 4FGL [2] and 3FHL catalogues have been masked in addition to a generous cut of the Galactic plane. Regions where the flux from the Galactic diffuse emission exceed five times the flux from the isotropic component are

Angular power spectrum

The angular power spectrum is the two-point correlator of the harmonic coefficients a_{lm}. It is a decomposition of the variance into angular scales *l*.

$$C_l = \frac{1}{2l+1} \sum_{m=-l}^{m=l} |a_{lm}|^2$$

Due to the instrument PSF, masking of the galactic foreground emission and the finite exposure time, the measured angular power spectrum is given by

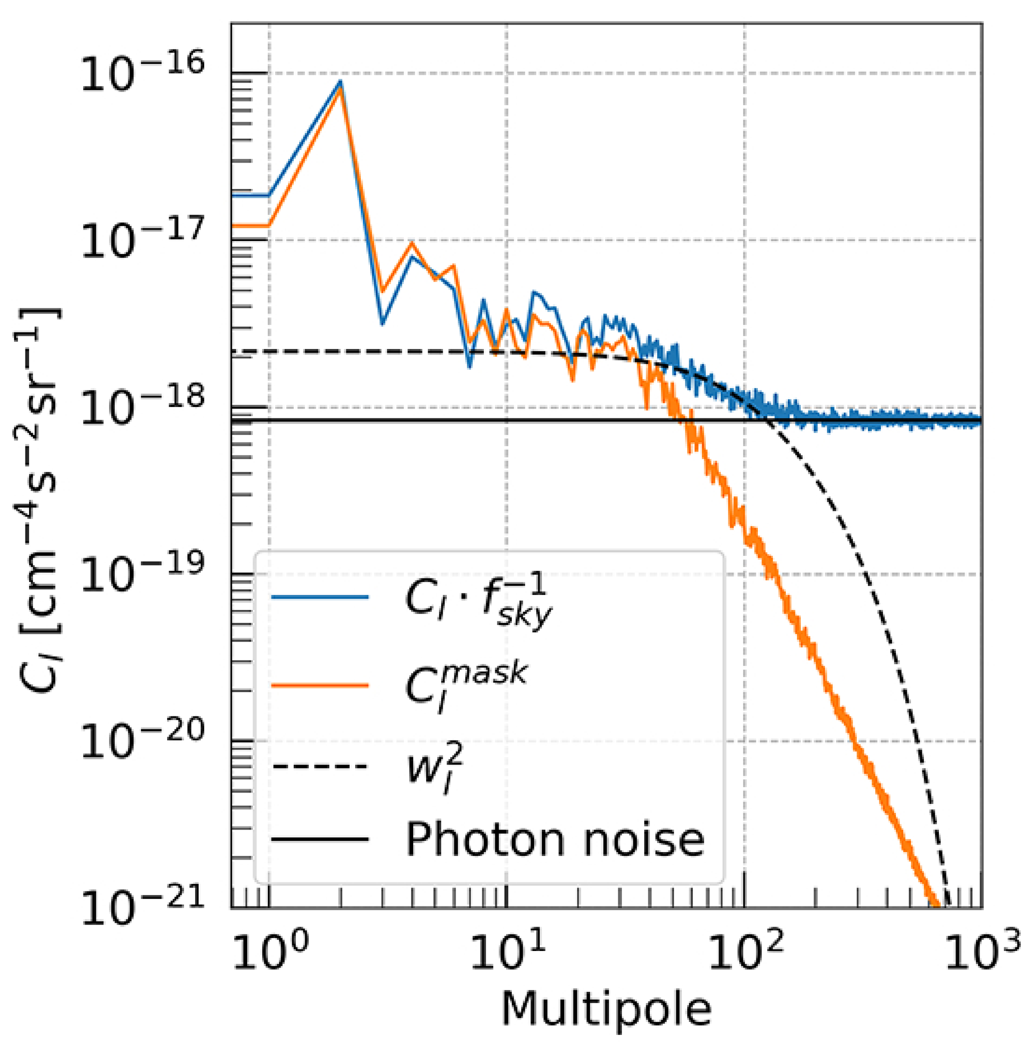
$$C_l^{\mathrm{raw}} = (C_l^{\mathrm{signal}} w_l^2 + C_N) f_{\mathrm{sky}}$$

Correcting for these effects, the signal angular power spectrum is therefore

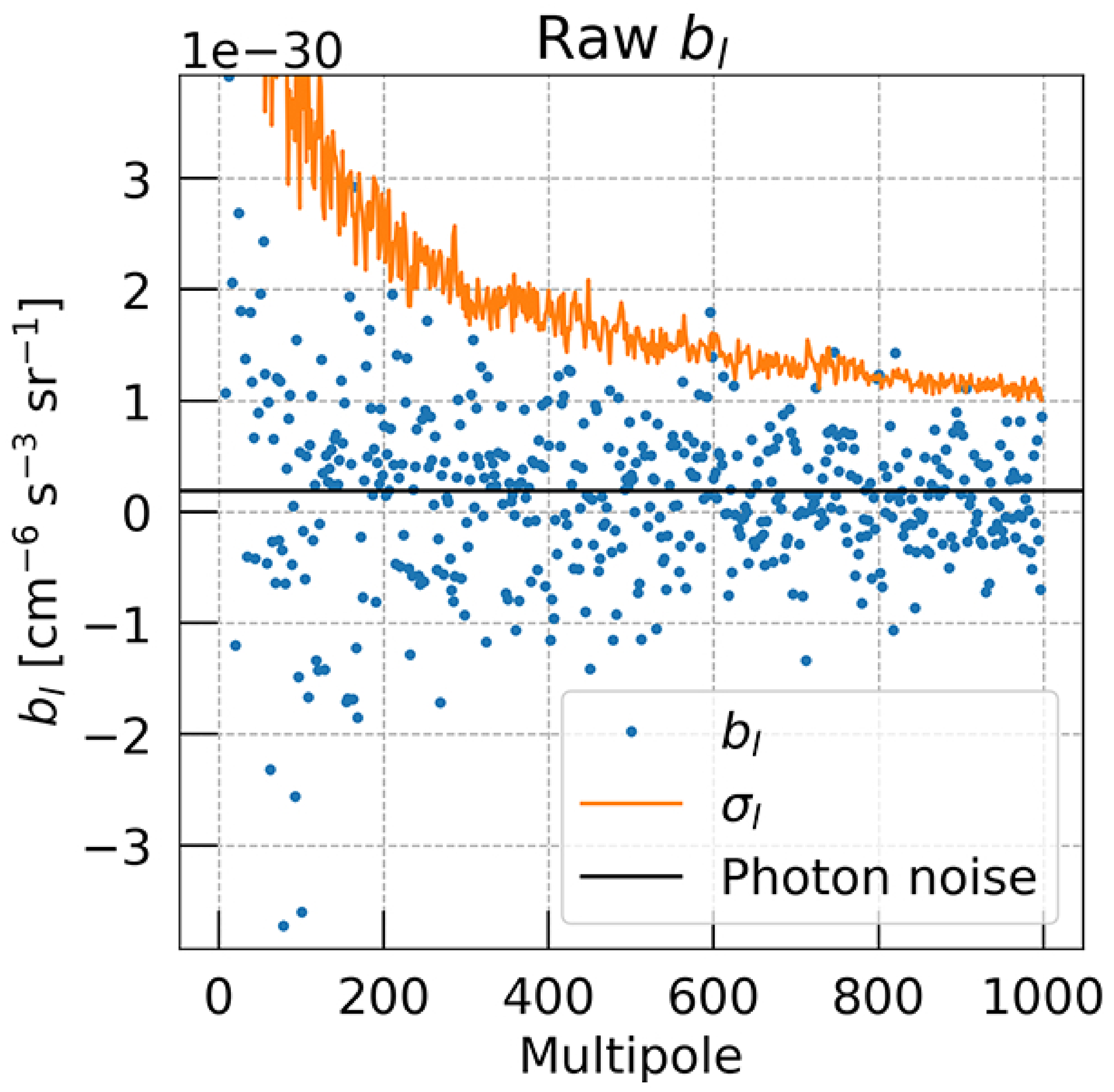
$$C_l^{\mathrm{signal}} = \frac{C_l^{\mathrm{raw}}/f_{\mathrm{sky}} - C_N}{w_l^2}$$

The contribution due to unresolved sources is determined by minimizing

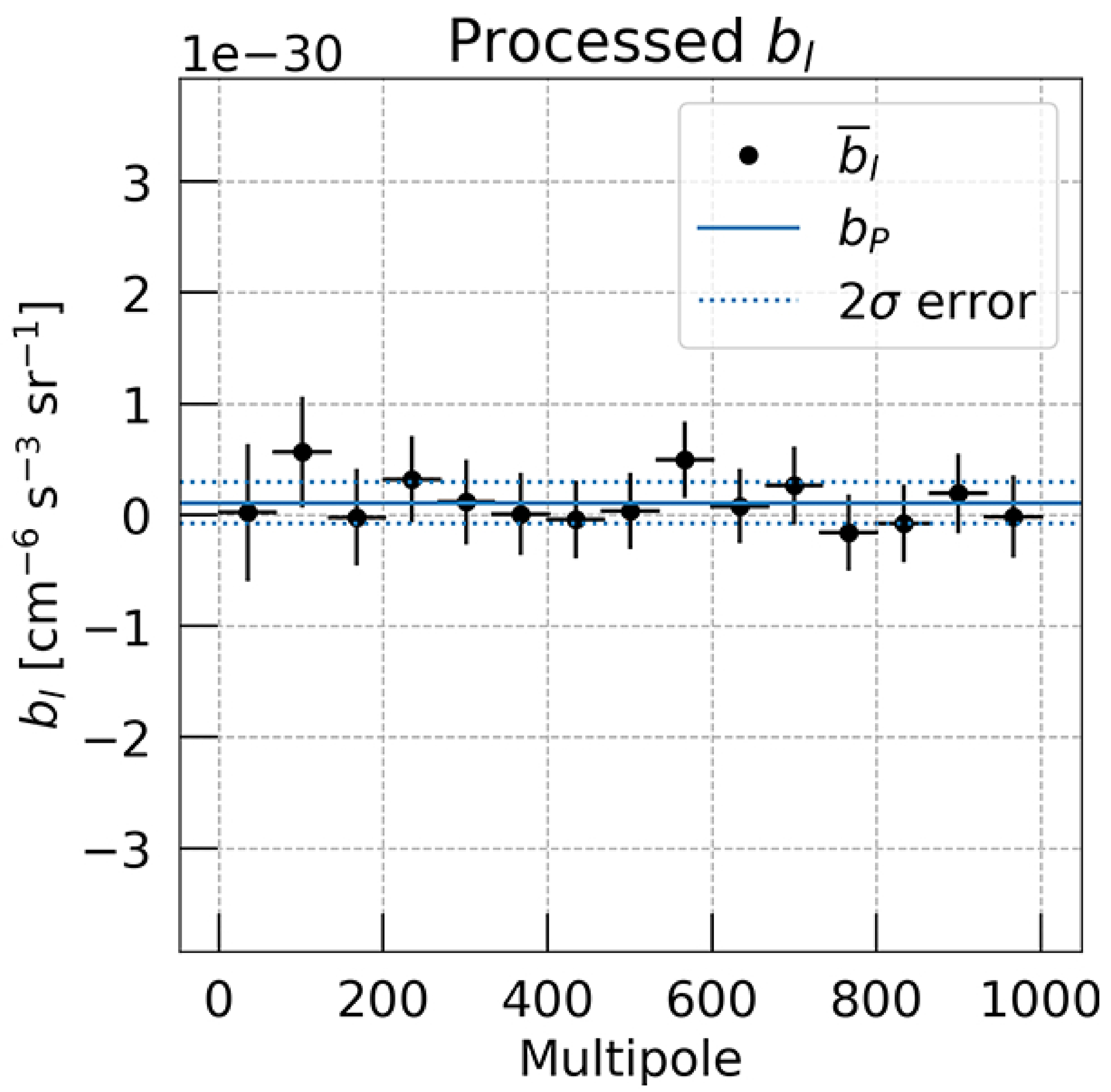
$$\chi^2 = \sum_l \frac{(C_l - C_P)^2}{\sigma_l^2}$$



Measured angular power spectrum in 0.86-1.02 GeV energy bin (blue). Also shown is the power spectrum of the mask (orange) normalized to the data spectrum. Dotted line shows beam window function and black line shows estimate of the photon noise.



Diagonal bispectrum coefficients in the 26.5 to 54.7 GeV energy range with 1-sigma error and photon noise estimates.



The diagonal coefficients after the application of binning. Blue line shows the obtained reduced bispectrum amplitude due to point sources and the 2-sigma confidence interval.

Angular bispectrum

The angular bispectrum is the three-point correlator of the harmonic coefficients.

$$\langle a_{l_1 m_1} a_{l_2 m_2} a_{l_3 m_3} \rangle = B_{l_1 l_2 l_3}^{m_1 m_2 m_3}$$

Statistical isotropy of the universe allows the use of the angle-averaged bispectrum.

$$B_{l_1 l_2 l_3} = \sum_m \begin{pmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \end{pmatrix} B_{l_1 l_2 l_3}^{m_1 m_2 m_3}$$

All physical information is encoded in the reduced bispectrum $b_{l_1 l_2 l_3}$. Other terms are geometrical.

$$B_{l_1 l_2 l_3} = \sqrt{\frac{(2l_1+1)(2l_2+1)(2l_3+1)}{4\pi}} \begin{pmatrix} l_1 & l_2 & l_3 \\ 0 & 0 & 0 \end{pmatrix} b_{l_1 l_2 l_3}$$

Since we expect a bispectrum independent of multipole, we only measure diagonal components of the redudced bispectrum.

$$b_{lll} = \frac{1}{4\pi} \begin{pmatrix} l & l & l \\ 0 & 0 & 0 \end{pmatrix}^{-2} \sqrt{\frac{4\pi}{(2l+1)^3}} \int d\Omega \, e_l^3(\Omega)$$

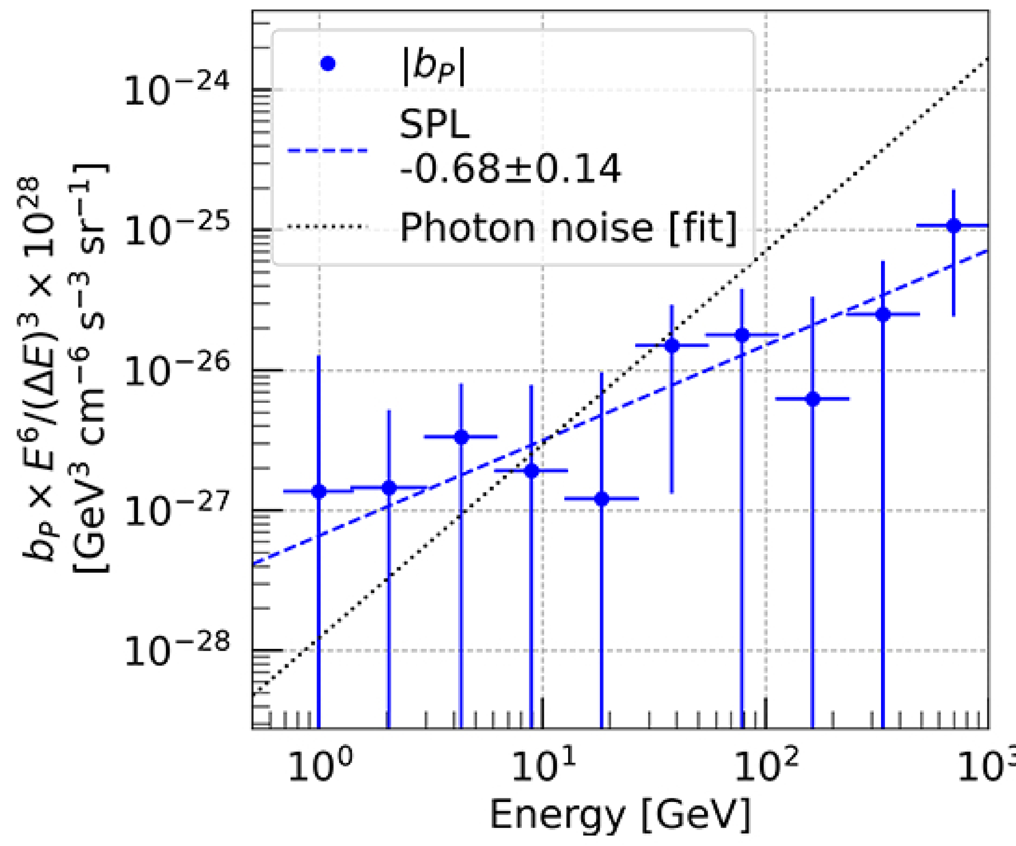
This method assumes that the formalism of the angular power spectrum can be extended to the angular bispectrum in a straightforward way

$$b_l^{\mathrm{signal}} = \frac{b_l^{\mathrm{raw}}/f_{\mathrm{sky}} - b_N}{w_l^3}$$

and that the amplitude due to unresolved point sources can be extracted in the same way as with the angular power spectrum.

$$\chi^2 = \sum_l \frac{(b_l - b_P)^2}{\sigma_l^2}$$

Fluctuations and correlation between multipoles are reduced by binning the obtained bispectrum coffiecients in 15 linearly spaced multipole bins.



Bispectrum amplitude energy spectrum showing absolute values of obtained bispectrum amplitudes and best-fit power law model.

Results

The normalized reduced bispectrum amplitudes in each of the energy bins yields a power law with index -0.68+/-0.14. This corresponds to an index of 2.32+/-0.14 for units in terms of intensity spectra. This result is inconsistent with the expected result for an unresolved population of blazars, for which an index of ~3.2-3.4 is expected.

For most of the energy bins, the obtained bispectrum is consistent with a null measurement.

Sensitivity of the analysis pipeline to photon noise and large errors on the measured bispectrum coefficients make extraction and significant detection of a non-trivial bispectrum due to unresolved point sources less straightforward than in the case of the angular power spectrum analysis.

References

[1] M. Ackermann et al., Unresolved Gamma-Ray Sky through its Angular Power Spectrum, *Physical Review Letters*, **121**, Dec. 2020

[2] S. Abdollahi et al., Fermi Large Area Telescope Fourth Source Catalogue, *The astrophysical journal supplement series*, **247(1):33**, Mar. 2020

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