Study of 6 years of Fermi/LAT data on the Cygnus Loop Supernova Remnant

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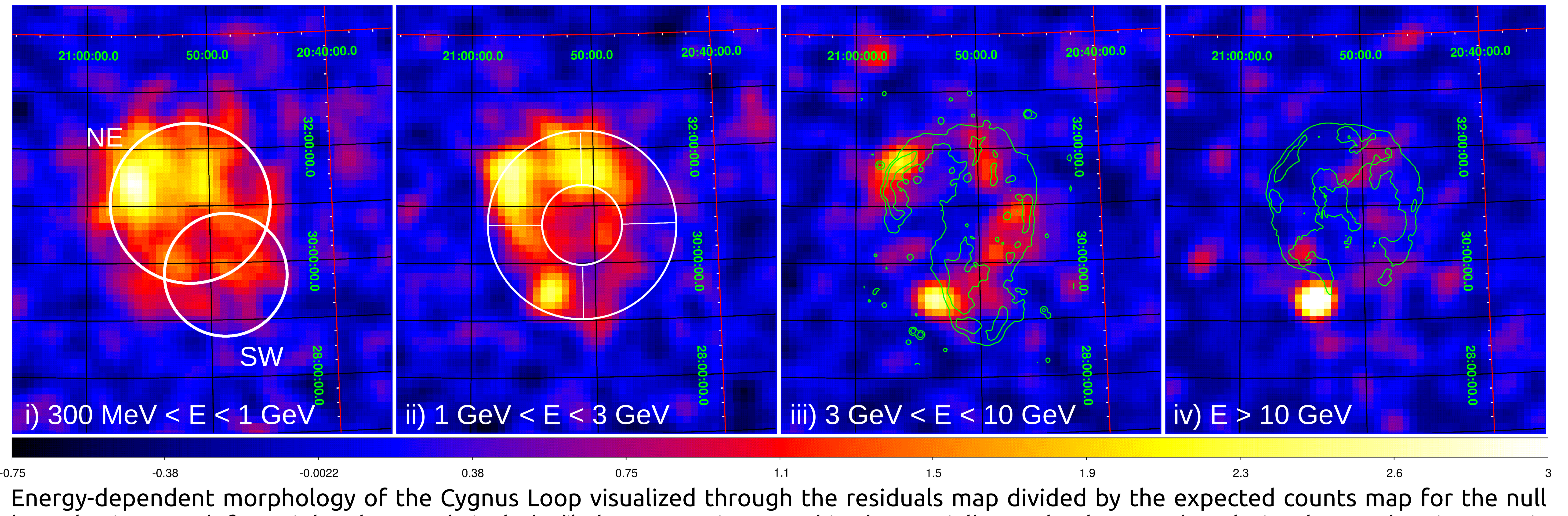
Context: The Cygnus Loop is the 10-20 kyr old remnant of a core-collapse supernova. At just 540 pc from Earth, it is 3 degrees extended, which permits spatially resolved studies with Fermi/LAT.

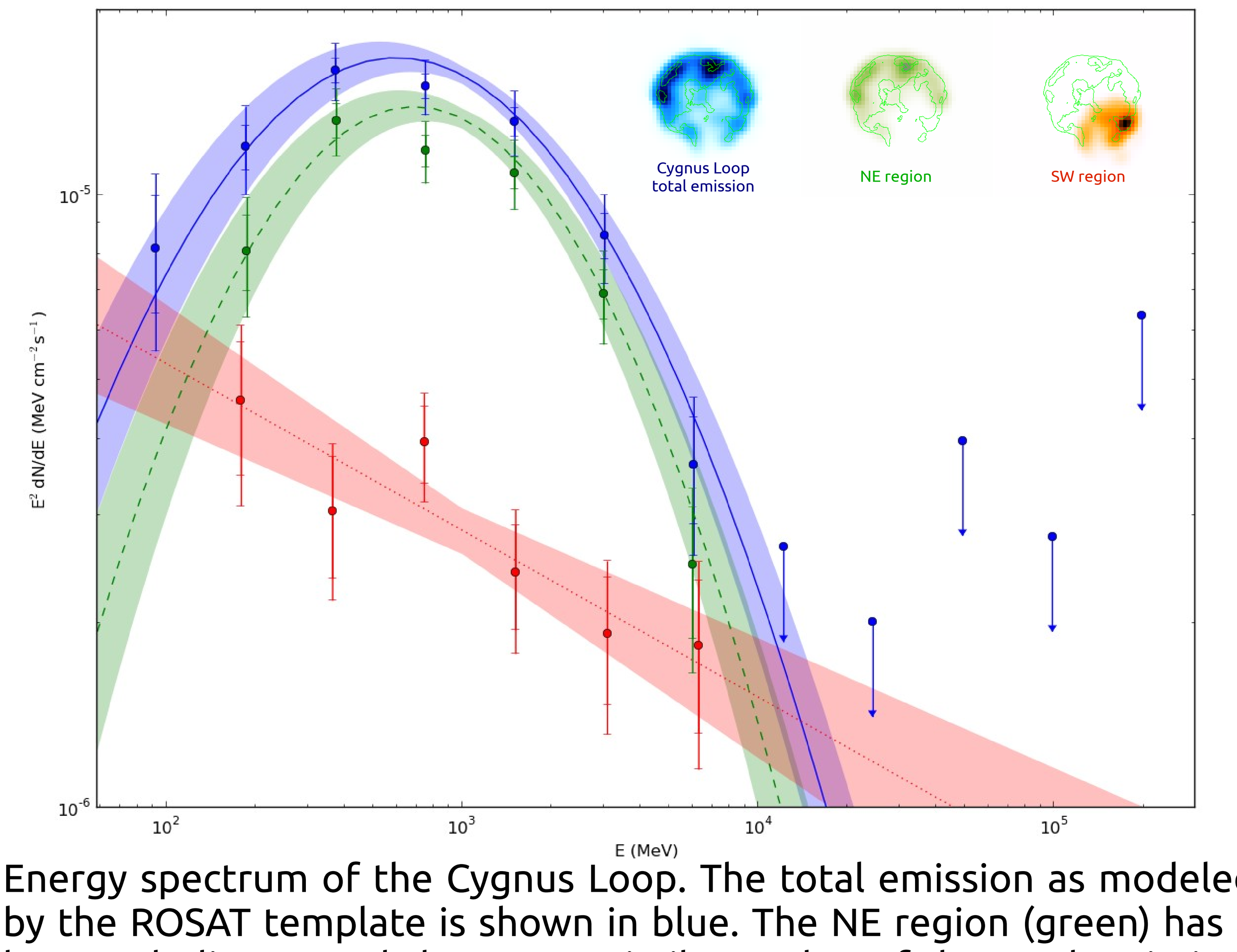
The Cygnus Loop is included in the 2nd Fermi LAT catalog as a uniform disk with an inner/outer radii of 0.7/1.6 degrees. The extension of the template exceeds that of the X-ray shell. The previous study **[1]** divided the ring in four quarters and found no spectral differences among the different regions.

This analysis: We analyze 6 years of PASS7REPO Fermi/LAT events between 58.5 MeV and 300 GeV recorded between 2008-08-04 and 2014-09-07. As a first step, the analysis from **[1]** is reproduced. We note that the SE quarter of the ring shows a particularly hard spectrum. Moreover, the global likelihood improves when this region is substituted by a point-like source with an optimized position coincident with the extragalactic source NVSS J205350+292314. Considering this point-like source as a background source, several templates for the gamma-ray emission are tested, the best of them being the one generated from the soft X-ray emission from **[2].**



Energy-dependent morphology of the Cygnus Loop visualized through the residuals map divided by the expected counts map for the null hypothesis. From left to right, the panels include (i) the two regions used in the spatially-resolved spectral analysis. The overlapping part is considered as part of the SW region only; (ii) the four regions used in [1]; (iii) the 2.7 GHz radio emission contours from [3]; and (iv) the 0.1 keV - 2.4 keV X-ray emission contours from [2]. A point-like source coincident with the extragalactic object NVSS J205350+292314 is visible at energies greater than 1 GeV, and is the only significant emission left above 10 GeV.

Radio analysis: A reanalysis of the 11 cm radio emission observed by the Effelsberg 100 m telescope allows us to redefine the SW region of the SNR, where distinct, intense polarized radio emission was detected **[3]**. The template used for the gamma-ray emission is divided according to this definition.



Energy spectrum of the Cygnus Loop. The total emission as modeled by the ROSAT template is shown in blue. The NE region (green) has a log-parabolic spectral shape very similar to that of the total emission, while the SW region (red) is well described by a power law. The statistical uncertainty range of the best model is shown as a shaded area. Spectral points include statistical uncertainties (solid bars) and systematic uncertainties (shaded bars).

$\frac{dN}{dE}=N_0\left(\frac{E}{1\mathrm{GeV}}\right)^{-\alpha-\beta\ln\left(\frac{E}{1\mathrm{GeV}}\right)}$	α	β	Flux>58.5MeV (10^{-8} ph cm^{-2}s^{-1})	TS
Cygnus Loop	2.26 ± 0.03	0.25 ± 0.03	13.5 ± 0.9	1761
NE	2.24 ± 0.04	0.32 ± 0.04	9.0 ± 0.9	1255
SW	2.27 ± 0.06	0	7.2 ± 1.1	160

The point-like source J2053+2923

This likely AGN has measurable flux (TS>10) between 1 GeV and 72 GeV, with a spectrum best modeled by a power law with exponential cutoff:

$\frac{dN}{dE}=N_0\left(\frac{E}{1\mathrm{GeV}}\right)^{-\Gamma}\exp\left(\frac{E}{E_{cutoff}}\right)$	Γ	E_{cutoff} (GeV)	Flux>58.5MeV (10^{-9} ph cm^{-2}s^{-1})	TS
J2053+2923	1.46 ± 0.18	22 ± 10	5.2 ± 2.1	214

The source seems variable, as an unbinned likelihood analysis yields TS>10 in 13 out of 37 60-day periods.

Conclusions:

The gamma-ray emission from the Cygnus Loop follows closely the thermal X-ray emission from shocked matter in the NE of the shell, and has a peaked energy spectrum with a maximum around 0.6 GeV, as would be expected for an energy spectrum resulting from hadronic interactions. However, the SW of shell (which is brighter in radio and fainter in X-rays), has a clearly different gamma-ray spectrum, following a simple power law. The explanation for the different gamma-ray properties, and the related radiative processes of the two regions is under investigation.

TS stands for Test Statistic:
TS = -2 (log ℓ / log ℓ$_0$)
Where ℓ (ℓ$_0$) is the maximum likelihood of a model with (without) the source that is tested.

References:
[1] Katagiri et al. 2011, ApJ 741 44
[2] Aschenbach & Leahy 1999, A&A 341 602-609
[3] Uyaniker et al. 2002, A&A 389 L61-L64