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GeV emission from the Cygnus Loop

Abstract: We report the detection of the 10 kyr shell type SNR Cygnus Loop by the Fermi GST. We discuss the physical implications of the detection and discuss perspectives with Fermi.

The Cygnus Loop

•The Fermi/LAT detector has recently opened a new window on the particle acceleration process which takes place in the shock waves driven by a supernova event in the surrounding medium. After several thousands years, high-energy and very high-energy Gamma-rays are produced by relativistic ions via the decay of π mesons produced in inelastic collisions with the thermal gas, or electrons via the inverse-Compton or bremsstrahlung radiation. While tentative association with SNRs were proposed for EGRET unidenfied sources, Fermi/LAT has recently established W51C as the first SNR at GeV energies (*Abdo et al. 2009*).

•The Cygnus Loop is a well-known middle-aged (~10 kyr) Supernova Remnant observed at radio, IR/optical, and X-ray wavelenghts. Thanks to its proximity (d < 576 ± 61 pc, *Blair et al. 2009*), it is bright and very extended (2.5 deg x 3.5 deg, *Levenson et al. 1997*), allowing to resolve the ejecta structure and to study the surrounding material. Despite its almost circular shell-like morphology, the radio HI, optical Hα and X-ray observations point out a non-homogeneus environment: the blast wave deceleration is affected by encounters with dense, extended clumps distributed inhomogeneously in the pre-shocked gas (*Levenson et al. 1997, 1998*). This is confirmed by the study of the X-ray temperature, brightness, and emission measure of the thermal gas across the limbs and the inner remnant (*Uchida et al. 2009*), which also suggests that the cavity-wall density is higher in the northeast than that in the southwest, where an extended protrusion (the so-called "blowout") lies. This special environment can be understood if the supernova generating the Cygnus Loop is exploded into the cavity generated by the progenitor star of ~15Mo (*Levenson et al. 1998*).

•Hence, the Loop should result from a core-collapse supernova. The clumpy material around the Cygnus Loop provides an ideal target for the hadronic interaction. On the other hand, the cosmic-ray pressure has been found to be much smaller than the thermal pressure (*Salvesenet al., 2009*), suggesting that the Loop is not an efficient particle accelerator.

•Here we report the Fermi/LAT detection of the Cygnus Loop and discuss implications.

GeV flux & morphology

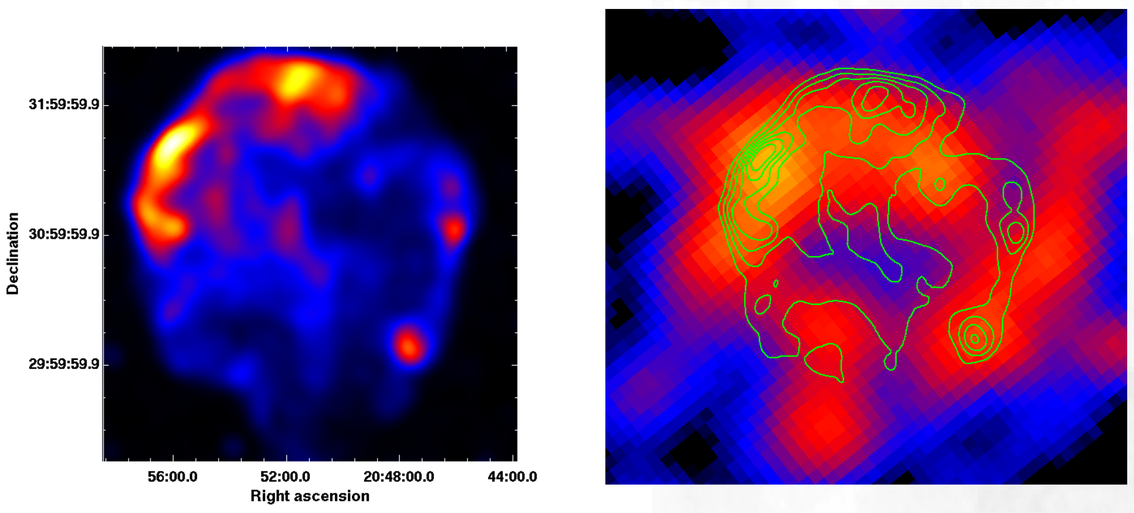
•The correlation with X-ray shell is good. (correlation with radio confused by second shell SNR not present in Fermi data)

•A tentative likelihood fit using ROSAT map as template does not improve the fit result. This is most likely due to the hot ejecta thermal emission pervading the SNR that is still present in ROSAT data. Work is in progress to find a better template for the GeV emission.

•The exposure is $\varepsilon \sim 3.4 10^{10}$ cm^2.s at the Cygnus Loop position. With the estimated counts from the source this yields ~ 10^{-8} ph cm^{-2} s^{-1} , therefore a preliminary estimate of the energy flux of the SNR above 500 MeV is 10^{-11} erg.cm^{-2}s^{-1}

•Radio emission is flat with α = -0.5 *(Uyaniker et al, 2004)* with a flux of 143 Jy at 1.4 Ghz. Assuming GeV photons are produced by IC of 20 GeV electrons in optical field of 1 cm$^{-3.}$ The magnetic field should be somewhat low ~ 5-10 μG. Given densities inferred from X-ray measurements, bremstrahlung emission should be the dominant energy loss factor for electrons.

•Conversely, $L_\gamma \sim 2\ 10^{32}$ erg/s can easily be accounted for with π^0 decay in a 1 cm^{-3} medium



(left) ROSAT flux image in the hard band *(right)* 0.5-10 GeV Cygnus Loop excess map (smoothed with 0.4° radius gaussian). The shell structure of the residuals is clear and the correlation with the thermal X-ray emission traced by ROSAT is good.

Discussion and conclusions

•Fermi detects emission above 500 MeV from the direction of the Cygnus Loop SNR at the 8 σ level with a correlation radius of 1.5°.

•With the available statistics, a clear shell like morphology is visible in the Fermi data

•The preliminary estimated flux of the SNR above 500 MeV is ~ 10^{-11} erg.cm^{-2}s^{-1} Precise spectral extraction is underway.

•Origin of the GeV emission is unclear: bremsstrahlung of GeV electrons in the shell or hadronic interactions?

•Fermi should be able to detect other large scale evolved SNR

Fermi observations & data reduction

•To search for possible high energy emission from Cygnus Loop, we have used the first year dataset with "diffuse" event quality selection applied. Because of the large extent of the SNR we used a large region of interest (ROI) radius of 15°. To avoid confusion effects due to the large PSF at low energies we restricted ourselves to energies above 500 MeV. Analyses were performed using Science Tools v9r15p2.

•We first determined a source list candidates from the count maps and used the tasks *gtlike* to fit their spectra with unbinned likelihood technique and *gtfindsrc* to improve their source localization. The list of fitted positions and spectra is given in table 1.

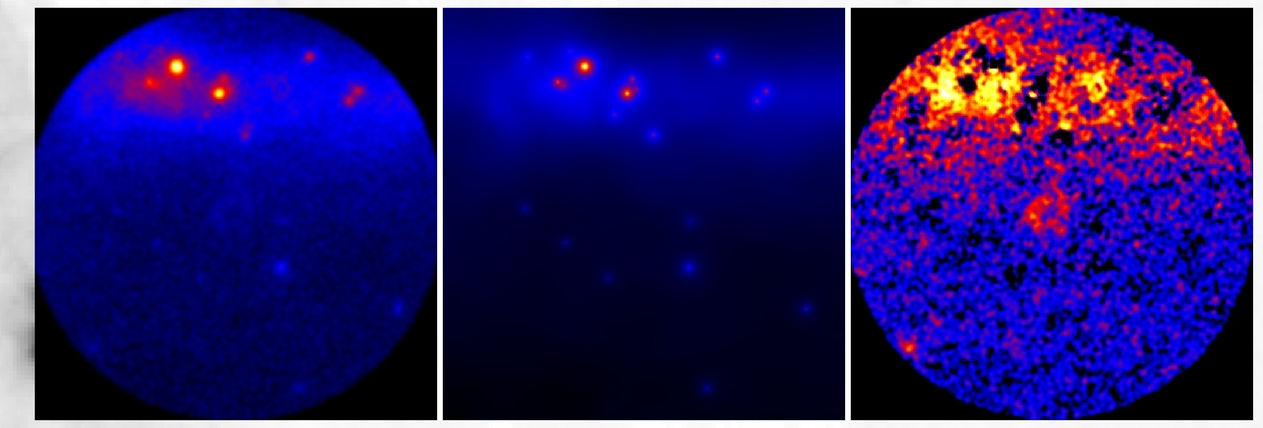
•We then get a complete model of the region with point sources and Galactic and extragalactic diffuse emission.

Source ID	RA	δ	Flux	Index	TS
J2021+4027	305.359	40.455	68.71 ± 3.17	-2.59 ± 0.02	17382
J2021+3650	305.255	36.843	36.25 ± 2.47	-2.56 ± 0.03	6905
J1953+3252	298.256	32.879	12.76 ± 1.44	-2.58 ± 0.05	2242
J2027+3334	306.941	33.574	19.75 ± 2.88	-2.85 ± 0.06	1330
J2055+2540	313.917	25.666	6.52 ± 1.11	-2.67 ± 0.07	1262
J2032+4123	308.068	41.397	10.88 ± 1.81	-2.45 ± 0.05	1215
J1954+2836	298.573	28.603	8.99 ± 1.39	-2.56 ± 0.06	880
J1958+2845	299.664	28.760	10.40 ± 1.67	-2.63 ± 0.06	864
J2015+3708	303.905	37.135	12.35 ± 2.10	-2.66 ± 0.06	755
J2043+1710	310.811	17.167	1.19 ± 0.29	-2.34 ± 0.09	469
J2030+3641	307.509	36.686	10.38 ± 2.29	-2.77 ± 0.08	433
J2032+4054	307.992	40.906	23.53 ± 7.17	-2.99 ± 0.12	316
J2121+1901	320.239	19.019	0.85 ± 0.26	-2.36 ± 0.11	266
J2030+4413	307.689	44.217	8.58 ± 2.16	-2.81 ± 0.10	252
J2017+3625	304.453	36.425	6.87 ± 1.89	-2.65 ± 0.09	206
J2019+4156	304.922	41.935	7.50 ± 2.42	-2.81 ± 0.12	160
J2116+3730	319.212	37.503	3.25 ± 1.40	-2.87 ± 0.18	150
J2116+3338	319.032	33.639	0.63 ± 0.27	-2.33 ± 0.15	145
J2115+2937	318.835	29.629	1.65 ± 0.71	-2.69 ± 0.17	134
J2043+2739	310.936	27.655	4.71 ± 2.01	-3.05 ± 0.18	130

Table 1:Characteristics of the sources used to model the gamma-ray emission from the 30° surrounding the Cygnus Loop SNR.

Precise positions were obtained using the gtfindsrc task and spectral features have been fitted on events above 500 MeV by gtlike assuming simple power laws for all the sources.

•To search for extended diffuse emission, we convolve the residual image with a filter function similar to that used in the so-called *ring background* technique of VHE astronomy, to remove large scale emission not modeled by Galactic diffuse maps.

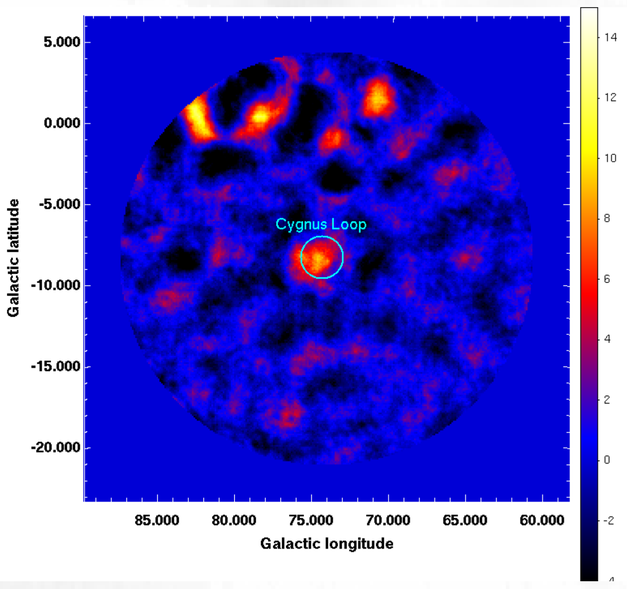


(left) 0.5-10 GeV count map of the region (smoothed with 0.3° radius gaussian). (middle) Resulting model image including pint sources and Galactic and extragalactic emission. (right) Residual image smoothed with 0.3° radius gaussian. The Cygnus region is not well modeled but a clear shell like residual emission is visible at the position of Cygnus Loop

•N_{ex} = 369 excess events for N_{mod} = 1240 expected events (associated error: σ~44)

•The resulting significance is ~ 8σ

•Some significant structures are also present in the Cygnus region in the Galactic plane showing that the model (source and diffuse) is not correct in this part of the sky.



Significance map of the residuals

•Residual data are correlated with a 1.5° radius disk and background is estimated using a 2° radius ring

•Significance of the residuals is computed with the correlation of the model and the square of the filter function *(see Terrier et al., 2001)*

•An excess of more than 8 σ significance is found compatible with the position of the Cygnus Loop SNR

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