Fermi-LAT observations of the Gamma Cygni complex

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Abstract: The Cygnus region is one of the most complex and interesting in the γ-ray sky, containing pulsars, supernova remnants, and massive-star associations. In particular the Gamma Cygni complex contains the γ-ray selected pulsar PSR J2021+4026, the supernova remnant G78.2+2.1, and the very high-energy source VER J2019+407. Understanding γ-ray emission from this region is challenging, because sources are piled up along the line of sight and the Galactic interstellar emission is bright and highly structured. We present an analysis of *Fermi* Large Area Telescope (LAT) observations of the Gamma Cygni complex, including a new timing solution for PSR J2021+4026, the characterization of its emission spectrum, and the study of the morphological and spectral properties of the extended emission associated with the supernova remnant. The results will offer new clues on the origin of γ-ray emission from sources in the region and their interrelations.

Keywords: gamma rays, pulsar: J2021+4026, supernova remnant: G78.2+2.1, *Fermi*.

1 The Gamma Cygni region in γ rays

A γ-ray source in the direction of Gamma Cygni was discovered by the COS-B satellite (2CG 078+01, [14]). It was confirmed as an unidentified γ-ray source by EGRET (3EG J2020+4017, [6]). The Large Area Telescope (LAT) aboard the *Fermi Gamma-Ray Space Telescope* [5] identified two different γ-ray sources in the Gamma Cygni complex: pulsar PSR J2021+4026, and the supernova remnant (SNR) G78.2+2.1.

PSR J2021+4026 was discovered using LAT data in a blind frequency search [1]. The spin period of 265 ms and the period derivative of 5.5×10^{-14} s s^{-1} characterize it as a young (characteristic age τ_c=77 kyr) and energetic (spin-down power 10^{35} erg s^{-1}) pulsar. Deep searches with *Chandra* and *XMM-Newton* have been conducted to identify a firm X-ray counterpart, leading to the tentative association with the source labeled as S21 by [19]. The discovery of X-ray pulsations from this source was recently reported by [9] using deeper *XMM-Newton* observations. Searches in radio and optical did not return any plausible counterparts [15].

SNR G78.2+2.1 is a well known shell-type SNR detected in radio, e.g. [7]. Optical observations indicate that the remnant is adiabatically expanding with a speed of ~ 750 km s^{-1} in a medium with a low density of ~ 0.3 cm^{-3} [10, 11], which sets the supernova explosion at approximately 7000 years ago. The observed diameter of 1° and the plasma temperature inferred from X-ray data consistently imply a shock velocity of ~ 800 km s^{-1} and an age of 6600 years at a distance of 1.5 kpc with an uncertainty of a few hundred pc [16], hence they locate it at a distance comparable to those of the clusters in the Cygnus X massive-star forming region [13]. LAT observations revealed spatially extended γ-ray emission associated with the SNR at energies above 10 GeV [8].

The tentative identification of PSR J2021+4026 with the neutron star generated from the core collapse of the progenitor of SNR G78.2+2.1 [1] is challenged by the facts that assuming a distance of 1.5 kpc for the pulsar implies an efficiency of spin-down power conversion into γ-rays larger than 100% if the beaming factor is ~ 1 [2], and that the characteristic age of the pulsar is a factor of ten larger than the estimated age of the SNR. However, outer gap emission models predict beaming factors ~ 0.1 for geometries that reproduce the observed pulse profile [17], suggesting a more realistic efficiency. There are also well known cases of pulsars with characteristic ages larger than the ages of the associated SNRs, e.g. [12].

In the mean time, the VERITAS survey of the Cygnus region revealed the small extended source VER J2019+407 with a diameter of $\sim 0.2°$ above 300 GeV on the rim of the SNR [18]. The very high-energy γ-ray emission from VER J2019+407 may be due to particles accelerated by the shockwave of SNR G78.2+2.1 interacting with the surrounding interstellar material or radiation fields, but the association remains unclear. SNR G78.2+2.1 may also be the source of freshly-accelerated cosmic rays in the nearby Cygnus X region detected using *Fermi* data [3]. This would require, however, an advection-dominated transport of the energetic particles while there is no evidence that the SNR shell breaks free into the interstellar cavities of Cygnus X.

2 Analysis outline

Using *Fermi*-LAT observations from 100 MeV to > 300 GeV, we aim to simultaneously characterize the properties of γ-ray sources in the Gamma Cygni complex. It is important to study those sources together because the limited angular resolution of the LAT (68% containment of the point spread function going from a few degrees below 1 GeV to $\sim 0.2°$ at 10 GeV and higher energies) makes it challenging to disentangle the different contributions, and, moreover, we would like to investigate their interrelations.

We take advantage of the recent progresses made in the understanding of interstellar emission from the Cygnus complex [3, 4]. We will present a new timing solution for PSR J2021+4026, the characterization of its emission spectrum, and the study of the morphological and spectral properties of the extended emission associated with the supernova remnant, as well as the search for γ-ray emission in the LAT energy band associated with VER J2019+407.

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