Multiwavelength properties of the a new Geminga-like pulsar: PSR J2021+4026

(based on Trepl, L. et al., 2010, MNRAS, 405, 1339)

seit 1558

L. Trepl[1], C. Y. Hui[2,3], K. S. Cheng[3], J. Takata[3], Y. Wang[3], Z. Y. Liu[4], N. Wang[4]

[1] Astrophysikalisches Institut und Universitäts-Sternwarte Jena, Schillergäßchen 2-3, 07745 Jena, Germany; ludwig.trepl@uni-jena.de
[2] Department of Astronomy and Space Science, Chungnam National University, Daejeon 305-764, South Korea
[3] Department of Physics, University of Hong Kong, Pokfulam Road, Hong Kong
[4] Urumqi Astronomical Observatory, NAO-CAS, 40 South Bejing Road, Urumqi 83001, China

Abstract

We report on a detailed investigation of the multiwavelength properties of a newly detected γ-ray pulsar, PSR J2021+4026, in both observational and theoretical aspects. We firstly identify an X-ray source in the XMM-Newton serendipitous source catalogue, 2XMM J202131.0+402645, located within the 95% confidence circle of PSR J2021+4026. With an archival Chandra observation, this identification provides an X-ray position with arcsecond accuracy which is helpful in facilitating further investigations. Searching for the pulsed radio emission at the position of 2XMM J202131.0+402645 with a 25-m telescope at Urumqi Astronomical Observatory resulted in null detection and places an upper-limit of 0.1 mJy for any pulsed signal at 18 cm. Together with the emission properties in X-ray and γ-ray, the radio quietness suggests PSR J2021+4026 to be another member of Geminga-like pulsars. In the radio sky survey data, extended emission features have been identified in the γ-ray error circle of PSR J2021+4026. We have also re-analyzed the γ-ray data collected by FERMI's Large Area Telescope. We found that the X-ray position of 2XMM J202131.0+402645 is consistent with that of the optimal γ-ray timing solution. We have further modeled the results in the context of outer gap model which provides us with constraints for the pulsar emission geometry such as magnetic inclination angle and the viewing angle. We have also discussed the possibility of whether PSR J2021+4026 has any physical association with the supernova remnant G78.2+2.1 (γ-Cygni).

Introduction

The γ-ray detection of PSR J2021+4026 was firstly reported in the FERMI bright source list with a signal-to-noise ratio >10 σ (Abdo et al. 2009d). The nominal γ-ray position of PSR J2021+4026 is located at the edge of the supernova remnant G78.2+2.1 (Abdo et al. 2009d; Green 2009). Using the first 6 months of the LAT data, the timing ephemerides of the pulsar were recently reported by Abdo et al. (2009c). It has a spin period of P=265 ms and a spin-down rate of $P_{dot}=5.48 \cdot 10^{-14}$ s s^{-1}. These spin parameters imply a characteristic age of τ_{sd} ~77 kyr, a surface magnetic field of ~ $4 \cdot 10^{12}$ G and a spin-down luminosity of E_{dot} ~ 10^{35} erg s^{-1}.

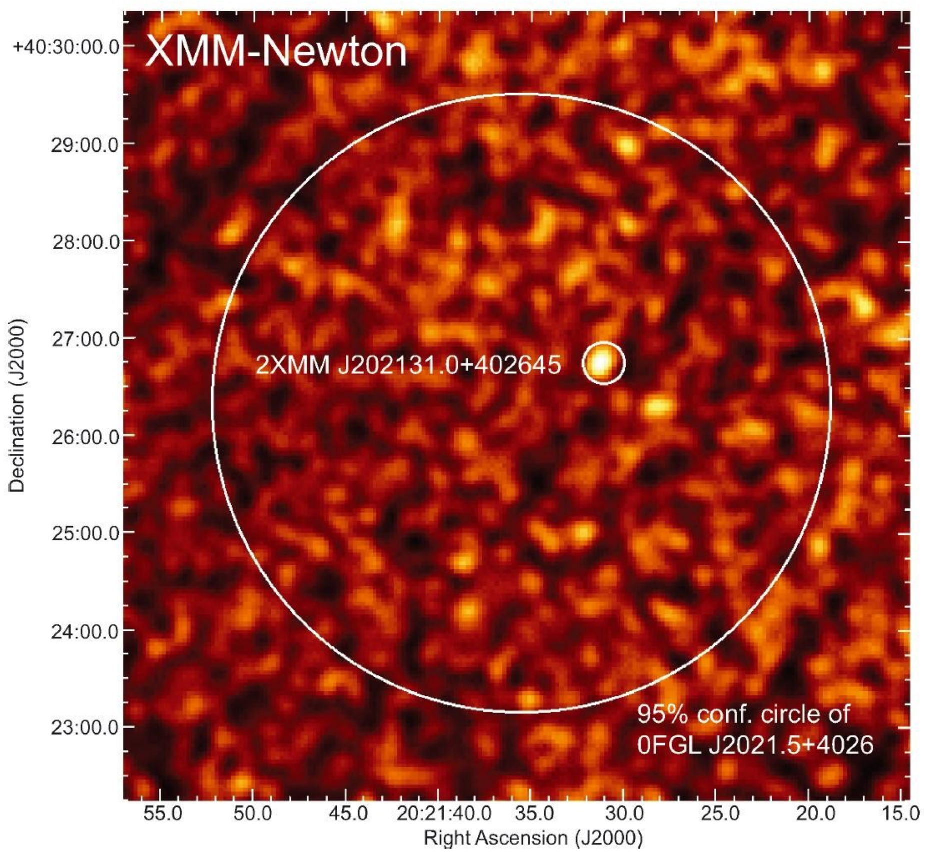


Fig. 1: The 8 X 8 $arcmin^2$ XMM-Newton image in the energy range 0.3-10 keV on 1 December 2003 with the MOS1/2 and PN data merged. The 95% confidence circle of the γ-ray sources PSR J2021+4026 (0FGL J2021.5+4026) is illustrated as white circle. The small white circle indicates the position of 2XMM J202131.0+402645.

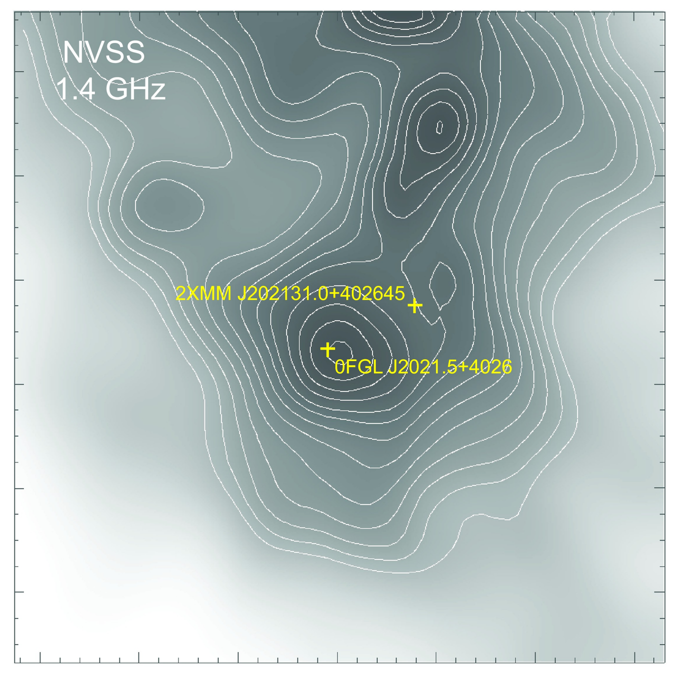
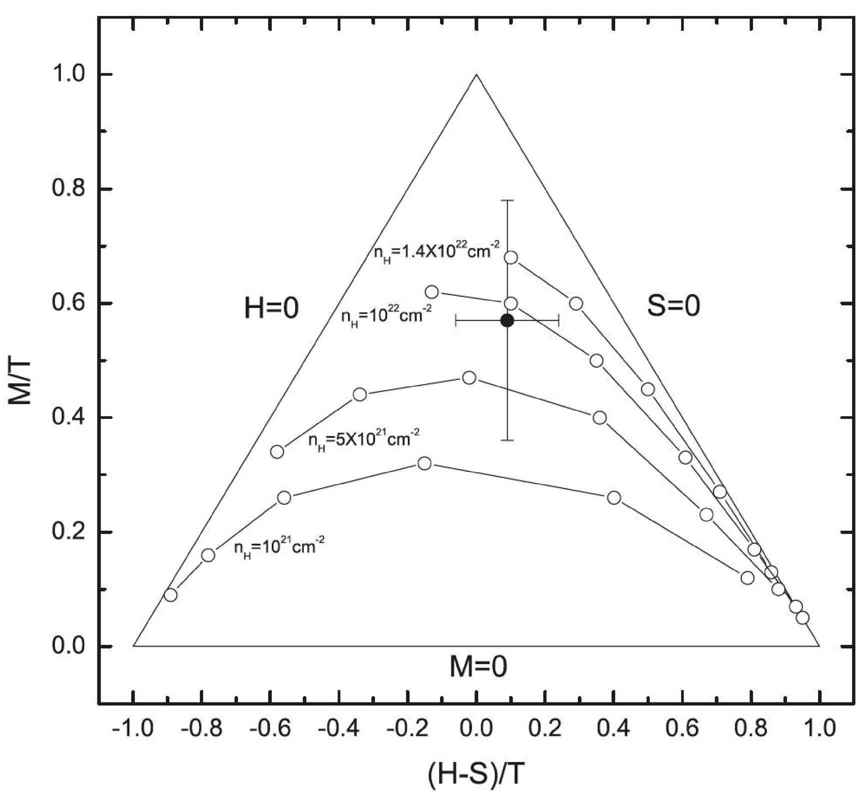


Fig. 2: The 1.4 Ghz NVSS image of a 6 x 6 $arcmin^2$ field centered at the nominal γ-ray position of PSR J2021+4026 = 0FGL J2021.5+4026. The field-of-view of this image corresponds to the size of the γ- ray error circle. The position of 2XMM J202131.0+402645 is also indicated. The radio contours are at the levels between 10-25 mJy/beam.

X-ray data analysis

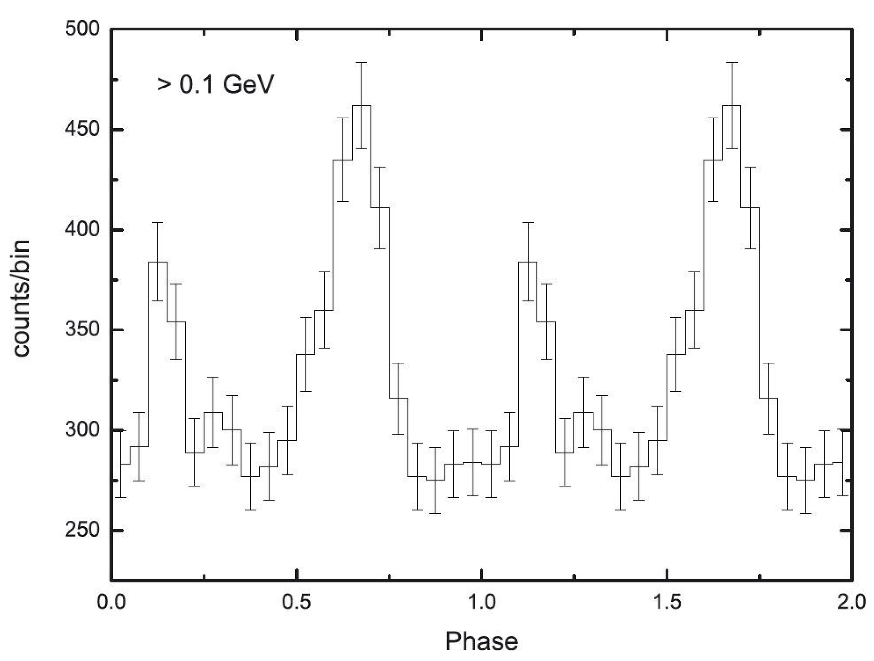


The hardness ratios of 2XMM J202131.0+402645 as shown in an X-ray color-color diagram (filled circle). The bands are S=0.5-1 keV, M=1-2 keV and H=2-8 keV. The curves within the triangular boundary are the calculated values for a power-law spectrum with the photon index varying from Γ=1 (right end) to Γ=6 (left end) for different adopted column densities. Each open circle along illustrates the position of Γ from 1 to 6 (from right to left) increments of 1.

In order to search for possible X-ray counterparts of PSR J2021+4026 we first cross-correlated the XMM-Newton serendipitous source catalog (XMM SSC) with the FERMI LAT bright source list. We have identified only one X-ray object, 2XMM J202131.0+402645, in the 95 % error circle of PSR J2021+4026. This X-ray source is located less than 1 arcmin away from the reported gamma-ray position of the LAT pulsar. Utilizing a Chandra ACIS-I observation we are able to constrain the position to RA=$20^h21^m30.553^s$, Dec=+40°26'46.89" with positional errors of deltaRA=1.18" and deltaDec.=0.84".
We derived spectra for the XMM and Chandra data and fitted them simultaneously and ended up with an absorbed blackbody model as a best fit. The values for the temperature and the interstellar absorption are kT= 0.38±0.09 keV and n_H= $(2.24^{+5.40}_{-2.24}) \cdot 10^{21}$ cm^{-2}. Comparing the X-ray flux in 0.3-10 keV f_X~$0.36 \cdot 10^{-13}$ erg $cm^{-2}s^{-1}$ with the gamma-ray flux the ratio (f_X/f_γ~$2 \cdot 10^{-5}$) is consistent with the typical values for gamma-ray pulsars. Although the blackbody model can yield a physically reasonable temperature one should note that the spectral parameters are poorly constrained and we therefore have to admit that the nature of 2XMM J202131.0+402645 cannot be determined unambiguously.

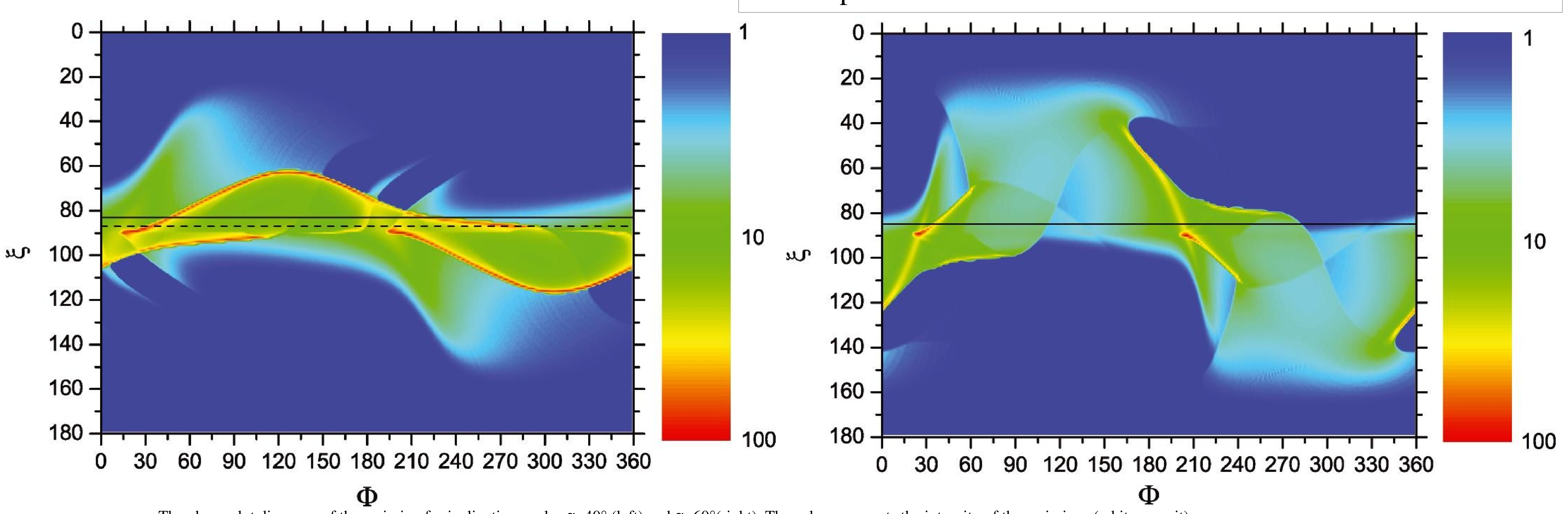
γ-ray analysis

We have carried out a detailed spectro-timing analysis of PSR J2021+4026 centered at the accurate X-ray position derived by analyzing Chandra data. We extracted events from a circle of 2.5° radius around 2XMM J202131.0+402645 in the energy range 0.1-10 GeV for the spectral analysis. The gamma-ray spectrum can be well described by an exponentially cut-off model with a best-fitting photon index of $\Gamma_\gamma=1.85^{+0.03}_{-0.04}$ and a cut-off energy $E_C=3.86^{+0.58}_{-0.48}$ GeV. The γ-ray flux is found to be $f_\gamma=(1.45^{+2.30}_{-0.88}) \cdot 10^{-9}$ erg $cm^{-2}s^{-1}$ (0.1-10 GeV).
We as well performed a pulsation search on the gamma-ray data of PSR J2021+4026 in the energy range 0.1-300 GeV. The precise position of 2XMM J202131.0+402645 was used for the barycentric correction. Frequencies in the range 3.768 858 246 397 21 to 3.769 299 993 731 75 Hz with f_{dot} = $-7.78 \cdot 10^{-13}$ Hz s^{-1} have been searched. The most probable frequency is 3.769 083 89(3) Hz with χ^2=328.0 and Z_2^2=309.7. The γ-ray phase folded light curve shows a double peaked structure with a pulsed fraction of 54%. We further divided the data into segments of equal time-span and analyzed those independently. The inferred spin-down rate is found to be steady and consistent with the aforementioned value. Therefore we conclude that there is no evidence for any unusual spin-down behavior of PSR J2021+4026 in the period 2008 Aug. - 2009 Sept.



Discussion and Summary

PSR J2021+4026 is a very bright newly uncovered γ-ray pulsar. The non-detection of any radio pulsed signal and its high-energy emission properties suggest the pulsar to be another example of Geminga-like pulsars. Together with the X-ray source 2XMM J202131.0+402645 it can be observed at the vicinity of the edge of SNR G78.2+2.1. In fact we expect that SNR G78.2+2.1 and PSR J2021+4026 are associated as follows. First, adopting the distance d~1 kpc to PSR J2021+4026 the efficiency $\eta=(L_\gamma/L_{SD})$ is ~$0.1\delta\Omega(d/kpc)^2$, where δΩ is the solid angle. This large efficiency with the distance is consistent with the typical value for a middle spin-down age pulsar like Geminga, which has η~0.07δΩ. Therefore the distance to SNR G78.2+2.1 provides a consistent efficiency with the spin-down age (77 kyr).
PSR J2021+4026 is located ~7.8 arcmin off-axis from the geometrical center of G78.2+2.1. This results in a space velocity v_p~340(d/1kpc) km s^{-1} assuming that the off-axis of the location is caused by proper motion in space. This is a typical velocity of observed pulsars (Hansen & Phinney (1997); Hobbs et al. (2005)). Thus the association of PSR J2021+4026 and SNR G78.2+2.1 is more likely.
Finally we briefly take a look on the association of PSR J2021+4026 and 2XMM J202131.0+402645. First, it is the only persistent and relatively bright X-ray source in the 95% γ-ray error circle of PSR J2021+4026. Second the nominal X-ray flux in 2-10 keV provides an X-ray luminosity of L_X~10^{30} f_Ω erg s^{-1}, where f_Ω is the solid angle divided by 4π. Comparing this luminosity with other pulsars we find that it is consistent with the typical values of pulsars with a spin-down luminosity similar to PSR J2021+4026. On this ground and looking at the f_X/f_γ value we suggest that 2XMM J202131.0+402645 is the plausible X-ray counterpart to PSR J2021+4026.



The phase-plot diagrams of the emission for inclination angles α=40° (left) and α=60°(right). The color represents the intensity of the emissions (arbitrary unit).
Left panel: The solid and dashed horizontal lines are corresponding to the viewing angle of ξ=83° and ξ=87° respectively. Right panel: The solid line represents a viewing angle of ξ=85°

References

- Abdo A. A. et al., 2009c, ApJS, submitted (arXiv:0910.1608)
- Abdo A. A. et al., 2009d, ApJS, 183, 46
- Green D. A., 2009, A Catalog of Galactic Supernova Remnants (2009 March version). Mullard Radio Astron. Obser., Cambridge
- Hansen B. M. S., Phinney E. S., 1997, MNRAS, 291, 569
- Hobbs G., Lorimer D. R., Lyne A. G., Kramer M., 2005, MNRAS, 360, 974