The user wants me to translate a scientific paper title from Chinese to English. The title is "Multi-wavelength Study for Gamma-Ray Nova V1405 Cas 后印本". Let me break this down: - "Multi-wavelength Study" - This is already in English, so it should remain as is - "for" - This is already in English -···

Authors: The user has provided a list of names: "Zi-Wei Ou, Pak-Hin Thomas Tam, Hui-Hui Wang, Song-Peng Pei and Wen-Jun Huang"

This appears to be author names for a scientific paper. The task is to translate from Simplified Chinese to English with the highest accuracy and academic tone.

Let me analyze the requirements: 1. Preserve ALL LaTeX commands and placeholders exactly - there are none here 2. Preserve ALL citation commands ([?], **??**, (**??**), etc.) exactly - there are none here 3. **PRESERVE ALL ··· paragraph wrapper tags EXACTLY** - there are none here 4. Maintain academic tone and formal scientific writing style - yes, for author names 5. Use precise technical terminology - not applicable here 6. Preserve section structure and paragraph organization - not applicable here 7. Translate all content completely - do not omit any information

The names are already in a format that is standard for English academic papers. Chinese names are typically written with the surname first in Chinese, but in English publications, they are often written in Western order (given name first, surname last) or with the surname in all caps to avoid confusion.

Looking at the names: - Zi-Wei Ou - This appears to be in Western order (given name Zi-Wei, surname Ou) - Pak-Hin Thomas Tam - This appears to be in Western order with a middle name (given name Pak-Hin Thomas, surname Tam) - Hui-Hui Wang - This appears to be in Western order (given name Hui-Hui, surname Wang) - Song-Peng Pei - This appears to be in Western order (given name Song-Peng, surname Pei) - Wen-Jun Huang - This appears to be in Western order (given name Wen-Jun, surname Huang)

These names are already in English format. They don' t need translation per se, but they should be preserved exactly as written. In Chinese academic contexts, author names are often listed with commas and "and" before the last author, which matches the English convention.

Since there are no tags, LaTeX commands, or mathematical expressions, the output should be exactly the same as the input. The names are already in a format suitable for an English academic paper.

The user might be testing if I understand that names should not be modified. The instruction says

Date: 2025-03-11T00:00:00+00:00

Abstract

The user wants me to translate a scientific text from Simplified Chinese to English. The text is about gamma-ray emission from novae, specifically V1405 Cas.

Let me break down the requirements: 1. Preserve ALL LaTeX commands and placeholders exactly 2. Preserve ALL citation commands ([?], **??**, (**??**), etc.) exactly 3. **PRESERVE ALL ···paragraph wrapper tags EXACTLY** 4. Maintain academic tone and formal scientific writing style 5. Use precise technical terminology - obey the glossary strictly 6. Preserve section structure and paragraph organization 7. Translate all content completely - do not omit any information

The glossary provided is: - 机器学习 => machine learning - 深度学习 => deep learning

However, these terms don' t appear in the text. The text is about astrophysics, so I need to use appropriate technical terms.

Looking at the input text, I don' t see any tags, LaTeX commands, or placeholders. The user says "Translate from Simplified Chinese to English" but the text provided is already in English. Let me re-read the instruction.

Wait, the user says "Translate from Simplified Chinese to English" but the text provided is: "Novae are found to have GeV to TeV γ-ray emission, which reveals the shock acceleration from the white dwarfs. Recently, V1405 Cas was reported to radiate suspicious γ-ray by Fermi-LAT with low significance (4.1σ) after the optical maximum. Radio observations reveal that it is one of the five brightest novae surrounded by low-density ionized gas columns. Here we report a continuous search for GeV γ-ray from Fermi-LAT. No γ-ray was found. For V1405 Cas the flux level is lower than other well-studied Fermi novae, and the γ-ray maximum appears at t0 + 145 days. γ-ray of V1405 Cas is used to search potential γ-ray periodicity. No γ-ray periodicity was found during the time of observation. By comparing multi-wavelength data, the γ-ray upper limit to optical flux ratio with a value at around 10−4 is obtained to constrain

the shock acceleration. Long-term analysis from Swift-XRT gets X-ray spectral in the post-shock phase, which indicates that V1405 Cas became a super-soft source. The best-fit black body temperature at the super soft state is 0.11–

Full Text

Preamble

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Multi-wavelength Study for Gamma-Ray Nova V1405 Cas

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Abstract

Novae are found to emit GeV to TeV γ-rays, revealing shock acceleration processes occurring in white dwarfs. Recently, V1405 Cas was reported by Fermi-LAT to radiate suspicious γ-ray emission with low significance (4.1σ) after optical maximum. Radio observations reveal that it is one of the five brightest novae surrounded by low-density ionized gas columns. Here we report a continuous search for GeV γ-rays from Fermi-LAT data. No γ-ray emission was detected. For V1405 Cas, the flux level is lower than other well-studied Fermi novae, and the γ-ray maximum appears at $t_0 + 145$ days. The γ-ray data of V1405 Cas were used to search for potential periodicity, but no γ-ray periodicity was found during the observation period. By comparing multi-wavelength data, we obtain a γ-ray upper limit to optical flux ratio of around 10^{-4} to constrain shock acceleration. Long-term analysis from Swift-XRT yields X-ray spectra in the post-shock phase, indicating that V1405 Cas became a super-soft source. The best-fit blackbody temperature in the super-soft state is $0.11 - 0.19$ keV.

Key words: gamma-rays: general –(stars:) novae, cataclysmic variables –(stars:) white dwarfs

1. Introduction

A classical nova is a type of optical transient that increases in brightness by an order of magnitude in less than a few days (Gallagher & Starrfield 1978). Such eruptions occur on white dwarfs (WDs) that accrete matter from main-sequence companions in close binary systems (Della Valle & Izzo 2020; Chomiuk et al. 2021b). They differ from so-called "luminous red novae," which are believed to arise from stellar mergers (Cai et al. 2019, 2022; Pastorello et al. 2019). Classical novae are important objects for studying shock physics, nucleosynthesis, and binary evolution (José et al. 2006).

Since white dwarfs undergoing nova eruptions can gain mass during accretion, novae have been suggested as progenitors of Type Ia supernovae in degenerate scenarios (Shara et al. 2010; Soraisam & Gilfanov 2015). The WD envelope becomes heated by compression and undergoes thermonuclear runaway, resulting in ejection of the accreted material (Starrfield et al. 2016). Such transient objects, observed from radio to γ-ray wavelengths, are typically first identified through optical observations.

Since the launch of the Fermi spacecraft in August 2008, an increasing number of γ-ray novae have been discovered by the Large Area Telescope (LAT) onboard Fermi (Ackermann et al. 2014; Franckowiak et al. 2018). Novae can accelerate a fraction of swept-up particles to high energies through diffusive shock acceleration within the Fermi-LAT detection energy range. Both classical and recurrent novae (e.g., RS Oph) have been detected by Fermi-LAT (Cheung et al. 2022), with RS Oph even observed in the TeV range (H. E. S. S. Collaboration et al. 2017; Acciari et al. 2022). The GeV γ-ray emission from Galactic novae observed by Fermi-LAT suggests that these objects may accelerate relativistic particles through shocks (Li et al. 2017). Hadronic γ-ray emission related to proton-proton collisions from novae implies neutrino production (Guépin & Kotera 2017; Fang et al. 2020). For symbiotic novae (e.g., V407 Cyg, RS Oph), this emission is thought to occur when high-velocity material shocks the dense stellar wind from their red giant companion.

The ratio of γ-ray to optical luminosity is suspected to be key for constraining the lower limit on the fraction of shock power that accelerates relativistic particles (Metzger et al. 2015). Therefore, simultaneous γ-ray and optical observations are necessary for Galactic novae. Typical γ-ray novae are transient sources detected over durations of 2-3 weeks (Ackermann et al. 2014). Assuming all novae are γ-ray emitters, classical novae with $m_R \lesssim 12$ and within ≈ 8 kpc are likely to be discovered in γ-rays using Fermi-LAT (Morris et al. 2017).

Shock acceleration from a nova not only emits γ-rays but also radiates X-rays. Internal shocks from novae have velocities around 1000 km s^{-1} and heat post-shock gas to temperatures above 10^7 K, producing X-ray emission (Steinberg &

Metzger 2020). Most γ-ray novae show X-ray evidence of hot shock plasma, but only after the γ-ray emission has faded below detectability (Gordon et al. 2021). Similar to classical novae, the recurrent nova RS Oph was reported to produce X-ray emission originating from shocked ejecta before the X-ray super-soft source (SSS) emerged (Orio et al. 2022a). X-ray emission from classical novae during their γ-ray period could be absorbed by dense ejecta (Metzger et al. 2014).

V1405 Cas (PNV J23244760+6111140) was discovered on 2021 March 18 at 10:10 UT (Wischnewski 2022). Surprisingly, a series of optical flares were found, with the brightest reaching $V = 5.1$ around 2021 May 10. Suspected γ-ray emission was found after 2021 May 10 with low detection significance, making it one of the promising γ-ray novae (Buson et al. 2021; Gong & Li 2021). However, the time difference between potential γ-ray and optical emission remains unclear. Using 4-day time bins, it was detected with 4.1σ significance in data from 2021 May 20 15:01:17 to 2021 May 24 15:01:17 UTC with a flux ($E > 100$ MeV) of $(1.4 \pm 0.8) \times 10^{-7}$ photons cm^{-2} s^{-1}. Therefore, long-term investigation of γ-ray emission is worthwhile to check whether V1405 Cas has γ-ray emission occurring at a late epoch compared to other novae. Furthermore, regardless of whether significant flux or upper limits are obtained, the shock acceleration of a nova may be constrained. In this paper, we investigate γ-ray and X-ray emissions resulting from shocks in V1405 Cas. The paper is organized as follows: Section 2 describes data selection and analysis methods, Section 3 presents results from γ-ray and X-ray data analysis, Section 4 discusses particle acceleration, white dwarf spinning, and the super-soft X-ray state, and Section 5 summarizes our conclusions.

2.1. AAVSO

The optical light curve of V1405 Cas has been collected from the American Association of Variable Star Observers (AAVSO)[5] (Percy & Mattei 1993). AAVSO observations provide coordinates for V1405 Cas: R.A. = 23h24m48s, decl. = 61°11$ '15' ' $ (Wischnewski 2022). The optical maximum occurred at MJD = 59344.297. Several optical bands are included in the AAVSO database. For simplicity, we use the V band (Johnson V filter, effective wavelength = 5448 Å) to generate a light curve (see Figure 1 [Figure 1: see original paper] panel (a)). A galactic reddening of $E(B-V) = 0.32$ mag ($A_V = 1.03$ mag with $R_V = 3.1$) was assumed (Schlafly & Finkbeiner 2011). The $(B-V)_0$ color at the earliest time (MJD 59293) and at peak shows 0.20 mag and 0.26 mag, respectively, corresponding to color temperatures T_c of 7790 K and 7300 K (Kitchin 2013). There is one significant peak in Episode I and several peaks in Episodes II and III (the definition of the three episodes can be seen in Section 2.2).

The magnitude starts from 8.822 at the beginning and rises to 5.082 at MJD 59344.3, which is the first peak and the maximum of the entire time span. Then the magnitude undergoes fluctuation and rises to 5.91 as the second peak, located in Episode II. After that, the magnitude continues through several periods of slight fluctuation and then declines.

2.2. Fermi-LAT Observations

Fermi-LAT photon data with energies ranging from 300 MeV to 100 GeV within a 15° search radius are used in this analysis. Coordinates of Fermi-LAT observations for V1405 Cas are: R.A. = 351.199°, decl. = 61.1874° after running `gtfindsrc`. Events with zenith angles greater than 90° were excluded. The Instrument Response Functions (IRFs) used in this analysis are P8R3_{SOURCE}V3. The binned maximum-likelihood analysis (`gtlike`) was performed based on the 4FGL catalog (gll_{psc}v27.fit). The Galactic emission model gll_{iem}v07 and isotropic diffuse emission iso_P8R3_{SOURCE}V3_v1 are adopted. For sources within 5° of V1405 Cas, the normalization parameters are freed. The spectrum of V1405 Cas is assumed to be a power law (PL):

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\Gamma}$$

where N_0 is the prefactor in units of $\mathrm{cm^{-2}\ s^{-1}\ MeV^{-1}}$, Γ is the power-law index, and E_0 is the energy scale in units of MeV.

To improve our starting model before analyzing the nova eruption, we fit a 1-year dataset spanning from 2020 March 18 to 2021 February 18, which ends 30 days before t_0. There is no significant detection at the position of V1405 Cas, with a 95% confidence flux upper limit of $< 3.24 \times 10^{-9}$ ph $\mathrm{cm^{-2}\ s^{-1}}$. In comparison, γ-ray emission upper limits after t_0 are around 10^{-8} ph $\mathrm{cm^{-2}\ s^{-1}}$, as shown in the next section. Upper limits at the 90% confidence level (CL) are shown when the test statistic (TS) value is smaller than 4. The Fermi-LAT light curve with 3-day bins from 2021 March 11 is shown. Additionally, for comparison with long-term X-ray observations, a 30-day bin analysis with PL is also performed.

At the same time, we assume an exponential cutoff power law (PLSuperExpCutoff) for Fermi-LAT data to generate a light curve:

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\Gamma} \exp\left[-\left(\frac{E}{E_c}\right)^{b}\right]$$

where N_0 is the prefactor in units of $\mathrm{cm^{-2}\ s^{-1}\ MeV^{-1}}$, Γ is the power-law index, E_0 is the energy scale in units of MeV, E_c is the cutoff energy in units of MeV, and b is the second power index.

2.3. Swift-XRT Observations

The Neil Gehrels Swift Observatory is a rapid-response satellite. The X-ray Telescope (XRT) onboard is a focusing telescope that detects photons in the energy range between 0.2 and 10 keV. We selected Swift-XRT observations with exposure times longer than 1 ks to check the evolution of the spectrum. An absorbed PL model was chosen to fit each observed spectrum using the web-form builder.

The XRT cleaned event lists were generated by the pipeline tool `xrtpipeline`. The source image, spectrum, and light curve were extracted using `xselect`. Ancillary Response Files (ARFs) were created using `xrtmkarf`.

According to the Fermi-LAT light curve, we divide Swift-XRT observations into three episodes:

1. **Episode I**: Before MJD 59356, no γ-ray is detected by Fermi-LAT. The optical light curve rises to maximum (the first peak).
2. **Episode II**: From MJD 59356 to 59458, suspected γ-ray emission begins to be detected by Fermi-LAT. The optical emission reaches the second peak.
3. **Episode III**: After MJD 59458, the γ-ray emission disappears.

We combine the observations using `xselect`. For Episodes I and II, we cannot conduct spectral analysis due to low count rates. We only analyze Episode III.

3.1. Fermi-LAT Light Curve and Spectrum

From Figure 1, we see that γ-ray emission with TS $\gtrsim 4$ appears around two weeks after the optical maximum. Since we used 3-day bins, we did not obtain exactly the same results as Buson et al. (2021). t_0 is defined as the discovery date (2021 March 18 10:10:00). For the PL model during the periods $t_0 + 65$ days to $t_0 + 68$ days and $t_0 + 74$ days to $t_0 + 77$ days, we detect γ-ray emission. We use the period from $t_0 + 65$ days to $t_0 + 77$ days for a combined analysis (Figure 2 [Figure 2: see original paper]), which yields a photon index of 1.94 and a TS value of 26.9. A binned likelihood was performed using `gtlike`. The corresponding best-fit parameters are shown in Table 1 . Considering V1405 Cas as a point source, PL and PLSuperExpCutoff models are compared. For the PLSuperExpCutoff model with $E_c = 3000$ MeV, the significance is slightly higher than for $E_c = 2000$ MeV. Since the number of free parameters differs, it is difficult to draw conclusions about the best-fitting model.

To investigate shock acceleration, we collect 3-day binned γ-ray data from Figure 1 to calculate the optical-to-γ-ray flux ratio. The optical flux is calculated by averaging 3-day V-band magnitudes following $m - M = -2.5 \log_{10}(f/F)$, where m and f are apparent magnitude and flux, while M and F are absolute magnitude and absolute flux. We average the optical flux error bars in each 3-day bin to match the γ-ray upper limits and generate ratio error bars. The results are shown in Figure 3 [Figure 3: see original paper]. The occasional flux ratio is smaller than the ASASSN-16ma value reported by Li et al. (2017), the RS Oph value revealed by Cheung et al. (2022), and other novae mentioned in Figure 9 [Figure 9: see original paper] of Chomiuk et al. (2021b), indicating that the internal shock is weaker than in ASASSN-16ma.

In Figure 4 [Figure 4: see original paper], we compare light curves of well-studied Fermi novae with V1405 Cas.[6] The flux upper limit of V1405 Cas is lower than all other Fermi novae. Time $t = 0$ is defined as the optical maximum for each nova. Most Fermi novae have γ-ray maxima within one day to one month after optical maximum.

3.2. Gamma-Ray Periodicity

Inspired by Li (2022), we search for potential GeV γ-ray periodicity in V1405 Cas. An aperture radius of 0.5° was adopted for pulsation searching. We selected Fermi-LAT data between $t_0 + 65$ days and $t_0 + 77$ days. Arrival times were corrected using `gtbary`, which performs barycentering time corrections to event files using spacecraft orbit files from Fermi-LAT. The selected events were analyzed using the `efsearch` task in the HEASoft package (version 6.31.1). `efsearch` searches for periodicity in a time series by folding data over a range of periods. This search is motivated by the 544.84 s γ-ray pulsation detected in nova ASASSN-16ma (Li 2022). After performing a test run from 10 s to 800 s with 0.1 s resolution, we obtained no detection. Additionally, the Z-test was used to search for periodicity (Kerr 2011). TS values for each photon were weighted by the response function. No periodicity was found.

3.3. X-Ray Spectral Analysis

To investigate the SSS phase, we consider an absorbed blackbody model for Swift-XRT observations in Episode III using the online Swift-XRT product builder.[7] Considering the SSS phase, pile-up characteristics differ from normal sources. This occurs when several photons hit the detector at the same location between readouts, causing them to be counted as one with summed energies. Both flux measurements and spectral characteristics are affected by pile-up. Selecting this method causes only grade 0 (single-pixel) events to be selected and uses a lower count-rate threshold for pile-up correction. The corresponding best-fit parameters are shown in Table 2 . Information on the Swift observations is given in Table 3 . The column density N_H is $\sim 10^{21}$ cm^{-2}. The blackbody temperature kT ranges between 0.1 and 0.2 keV, indicating that V1405 Cas became an SSS in the post-outburst state.

4.1. Particle Acceleration and Shock

Figure 1 shows discrete γ-ray upper limits concurrent with optical emissions (Episode II), suggesting both are results of shock acceleration from the nova explosion. GeV γ-rays are thought to be by-products of relativistic particles accelerated by shocks in nova ejecta (Figueira et al. 2018; Chomiuk et al. 2021b; Acciari et al. 2022). Theoretically, γ-ray production in novae is luminous, accounting for $\sim 0.1\%$-1% of the bolometric luminosity. Models predict these events could generate photon energies up to 10 TeV, depending on shock details (Metzger et al. 2015). This is verified by simultaneous γ-ray and optical observations of the Galactic nova ASASSN-16ma (Li et al. 2017).

According to Figure 1, the X-ray maximum occurs 20 days after detection of the most significant γ-ray emission. Thermal X-rays can be produced in internal shocks that radiate the observed γ-ray emission. One would expect thermal X-ray emission to be much brighter—around 10 to 1000 times more luminous than the γ-ray flux. In our case, simultaneous X-ray and γ-ray observations of V1405 Cas in Episode II could constrain the radiative efficiency and particle acceleration efficiency of internal shocks. The presence of X-ray shock signatures sometimes coincident with γ-ray results arises from small columns of neutral gas around this nova.

Hybrid acceleration of leptons and hadrons in nova shocks has been considered in some studies (Martin & Dubus 2013). In that model, the magnetic field is obtained assuming equipartition with the thermal energy density upstream of the shock, resulting in a maximum proton energy of ~ 300 GeV. The GeV γ-ray emission is then mostly expected from leptonic processes, namely inverse Compton scattering of nova light by electrons accelerated in the shock. However, hadronic and/or leptonic-hadronic models are favored to explain gamma-ray emission from novae when considering energy loss of electrons via synchrotron emission (Chomiuk et al. 2021b; De Sarkar et al. 2023). The narrow energy range in the SED of V1405 Cas makes it difficult to constrain hadronic or leptonic origins.

4.2. Whether V1405 Cas Contains a Spinning White Dwarf?

Unsurprisingly, a spinning white dwarf can produce γ-rays like a spinning neutron star (Takata et al. 2017; Munari et al. 2022; Orio et al. 2022b). For example, misalignment between the WD spin axis, magnetic dipole axis, and orbital revolution axis can produce γ-ray pulsations. The nova progenitor is likely a fast-spinning magnetic WD, mostly an intermediate polar (Orio et al. 1992). Strong bipolar nova winds from the magnetic poles of the WD regularly interact with matter deposited into the orbital plane by early, slow ejection (Orio et al. 2022a). Therefore, it is reasonable to ask whether V1405 Cas is spinning, which would accelerate electrons to produce GeV γ-rays.

Previously, pulsations have been discovered in X-rays from V1674 Her and in γ-rays from ASASSN-16ma (Drake et al. 2021; Li 2022). However, no γ-ray pulsation was detected from V1405 Cas due to low photon counts. Nevertheless, this cannot exclude V1405 Cas as a spinning WD (Section 3.2). More observations are needed to determine whether the WD in V1405 Cas is spinning.

4.3. Super Soft Source

An SSS is a type of X-ray transient that is commonly believed to appear in post-outburst novae, where hydrogen burning continues near the surface after the bulk of the accreted envelope mass has been ejected (Orio et al. 2022b). From Table 2 we see that V1405 Cas is an SSS characterized by soft X-ray emissions. Such a super-soft phase appears after shock emergence. Spectra of some novae in the super-soft X-ray phase may show redshifted emission lines and blueshifted absorption lines (Pei et al. 2021). Flux variation in some emission lines may result from inhomogeneous material or surrounding cool temporary ionization.

Radio observations from VLA and uGMRT reveal V1405 Cas is among the five brightest novae ever observed in the radio band, with an expansion velocity of 1200 km s^{-1} (Chomiuk et al. 2021a; Nayana et al. 2022). Such high velocity can heat gas, producing X-ray emission in the post-shock phase. The appearance of radio emission when γ-rays were detected by Fermi-LAT results from low-density columns of ionized gas. As expected, V1405 Cas has begun to display Fe II absorption features and then an SSS (Page et al. 2021; Shore et al. 2021), making it an excellent target to study the SSS phase after shock acceleration. These Fe II absorption features point to nova formation in a large circumbinary envelope of gas (Williams 2012; Aydi et al. 2024), which may originate from the secondary star.

The typical range of effective temperature $T_{\rm eff}$ in the SSS phase varies from $\sim 1.2 \times 10^5$ K to about 10^6 K (Suleimanov et al. 2003). Low emission during the SSS phase can be explained by absorption from neutral and/or ionized medium (Ness et al. 2023). V1405 Cas has a typical SSS temperature. For example, RS Oph has a blackbody temperature in the 35-40 eV ($\approx 405,000 - 470,000$ K) range (Orio et al. 2023). V2491 Cyg has a temperature of 90 ± 1 eV (10^6 K) and an X-ray luminosity of 178×10^{36} erg s^{-1} (Ness et al. 2022). The temperature is proportional to shock velocity. Typical soft X-ray photons are absorbed in the ISM with N_H values of several 10^{21} cm^{-2}. As X-rays suffer photoelectric absorption, N_H reflects these effects, which is also the case for novae (Nelson et al. 2019). Possibly, the X-ray and γ-ray emission originate from different regions (Metzger et al. 2015). The N_H values for V1405 Cas range from $\sim 1.0 \times 10^{21}$ cm^{-2} to 1.6×10^{22} cm^{-2}. However, due to low-quality X-ray data, we cannot derive the evolution of N_H.

5. Conclusion

We summarize our conclusions as follows:

1. Typical γ-ray novae show significant γ-ray emission after optical maxima on timescales of weeks to months. Our results show no significant GeV γ-ray emission from nova V1405 Cas before or after optical maximum.

2. Typical γ-ray novae have γ-ray maxima at hours to weeks after optical maxima. Our results reveal that the γ-ray upper limit of nova V1405 Cas shows a maximum at $t_0 + 145$ days.

3. Some classical novae have been found to show periodicity in γ-ray emis-

sion. We searched for γ-ray periodicity in V1405 Cas using two methods: `efsearch` and Z-test. Owing to low GeV photon counts, no γ-ray periodicity was found in Fermi-LAT data.

4. X-ray emission from novae eventually reaches a soft phase. Our work employs an absorbed blackbody model to investigate the potential SSS phase. We show that V1405 Cas transitioned to a super-soft state after γ-ray emissions disappeared, based on the best-fit temperature values.

5. The γ-ray to optical flux ratio is key for constraining shock acceleration. Our results show a ratio around 10^{-4}–10^{-2}, which approaches values for bright γ-ray novae (e.g., ASASSN-16ma, RS Oph).

Although some novae have low significance and weak signals in γ-rays, observing such objects remains valuable. With higher sensitivity, the future Very Large Area Gamma-Ray Space Telescope (VLAST) may improve detections (Fan et al. 2022). X-ray telescopes such as Einstein Probe (EP) and the Space-based multi-band astronomical Variable Objects Monitor (SVOM) will also help unveil the SSS nature of more novae.

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References

Acciari, V. A., Ansoldi, S., Antonelli, L. A., et al. 2022, NatAs, 6, 689
Ackermann, M., Ajello, M., Albert, A., et al. 2014, Sci, 345, 554
Albert, A., Alfaro, R., Alvarez, C., et al. 2022, ApJ, 940, 141
Aydi, E., Chomiuk, L., Strader, J., et al. 2024, MNRAS, 527, 9303
Buson, S., Cheung, C. C., & Jean, P. 2021, ATel, 14658, 1
Cai, Y., Reguitti, A., Valerin, G., & Wang, X. 2022, Univ, 8, 493
Cai, Y. Z., Pastorello, A., Fraser, M., et al. 2019, A&A, 632, L6
Cai, Y. Z., Pastorello, A., Fraser, M., et al. 2022, A&A, 667, A4
Cheung, C. C., Jean, P., Shore, S. N., et al. 2016, ApJ, 826, 142

Cheung, C. C., Johnson, T. J., Jean, P., et al. 2022, ApJ, 935, 44
Chomiuk, L., Linford, J. D., Aydi, E., et al. 2021a, ApJS, 257, 49
Chomiuk, L., Metzger, B. D., & Shen, K. J. 2021b, ARA&A, 59, 391
De Sarkar, A., Nayana, A. J., Roy, N., Razzaque, S., & Anupama, G. C. 2023, ApJ, 951, 62
Della Valle, M., & Izzo, L. 2020, A&ARv, 28, 3
Drake, J. J., Ness, J.-U., Page, K. L., et al. 2021, ApJL, 922, L42
Fan, Y. Z., Chang, J., Guo, J. H., et al. 2022, AcASn, 63, 27
Fang, K., Metzger, B. D., Vurm, I., Aydi, E., & Chomiuk, L. 2020, ApJ, 904, 4
Figueira, J., José, J., Garcìa-Berro, E., et al. 2018, A&A, 613, A8
Franckowiak, A., Jean, P., Wood, M., Cheung, C. C., & Buson, S. 2018, A&A, 609, A120
Gallagher, J. S., & Starrfield, S. 1978, ARA&A, 16, 171
Gong, Y.-H., & Li, K.-L. 2021, ATel, 14620, 1
Gordon, A. C., Aydi, E., Page, K. L., et al. 2021, ApJ, 910, 134
Guépin, C., & Kotera, K. 2017, A&A, 603, A76
H. E. S. S. Collaboration, Aharonian, F., Ait Benkhali, F., et al. 2022, Sci, 376, 77
José, J., Hernanz, M., & Iliadis, C. 2006, NuPhA, 777, 550
Kerr, M. 2011, ApJ, 732, 38
Kitchin, C. R. 2013, Astrophysical Techniques (Boca Raton, FL: CRC Press)
Li, K.-L. 2022, ApJL, 924, L17
Li, K.-L., Metzger, B. D., Chomiuk, L., et al. 2017, NatAs, 1, 697
Martin, P., & Dubus, G. 2013, A&A, 551, A37
Metzger, B. D., Finzell, T., Vurm, I., et al. 2015, MNRAS, 450, 2739
Metzger, B. D., Hascoët, R., Vurm, I., et al. 2014, MNRAS, 442, 713
Morris, P. J., Cotter, G., Brown, A. M., & Chadwick, P. M. 2017, MNRAS, 465, 1218
Munari, U., Giroletti, M., Marcote, B., et al. 2022, A&A, 666, L6
Nayana, A. J., Anupama, G. C., Banerjee, D., et al. 2022, ATel, 15383, 1
Nelson, T., Mukai, K., Li, K.-L., et al. 2019, ApJ, 872, 86
Ness, J. U., Beardmore, A. P., Bezak, P., et al. 2022, A&A, 658, A169
Ness, J. U., Beardmore, A. P., Bode, M. F., et al. 2023, A&A, 670, A131
Orio, M., Behar, E., Luna, G. J. M., et al. 2022b, ApJ, 938, 34
Orio, M., Gendreau, K., Giese, M., et al. 2022a, ApJ, 932, 45
Orio, M., Gendreau, K., Giese, M., et al. 2023, ApJ, 955, 37
Orio, M., Trussoni, E., & Oegelman, H. 1992, A&A, 257, 548
Page, K. L., Starrfield, S., Munari, U., Woodward, C. E., & Wagner, R. M. 2021, ATel, 15111, 1
Pastorello, A., Mason, E., Taubenberger, S., et al. 2019, A&A, 630, A75
Pei, S., Orio, M., Ness, J.-U., & Ospina, N. 2021, MNRAS, 507, 2073
Percy, J. R., & Mattei, J. A. 1993, Ap&SS, 210, 137
Schlafly, E. F., & Finkbeiner, D. P. 2011, ApJ, 737, 103
Shara, M. M., Yaron, O., Prialnik, D., & Kovetz, A. 2010, ApJL, 712, L143
Shore, S. N., Buil, C., Dubovsky, P., et al. 2021, ATel, 14577, 1
Sokolovsky, K. V., Li, K.-L., Lopes de Oliveira, R., et al. 2022, MNRAS, 514,

2239
Soraisam, M. D., & Gilfanov, M. 2015, A&A, 583, A140
Starrfield, S., Iliadis, C., & Hix, W. R. 2016, PASP, 128, 051001
Steinberg, E., & Metzger, B. D. 2020, MNRAS, 491, 4232
Suleimanov, V., Meyer, F., & Meyer-Hofmeister, E. 2003, A&A, 401, 1009
Takata, J., Yang, H., & Cheng, K. S. 2017, ApJ, 851, 143
Williams, R. 2012, AJ, 144, 98
Wischnewski, E. 2022, BAVMS, 11, 6

Note: Figure translations are in progress. See original paper for figures.