

Probing Magnetic Reconnection as a Mechanism for Recurrent GeV γ -Ray Emission in the Intermediate Polar V1674 Her

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V1674 Hercules - Nova Herculis 2021

- Nova eruption: June 2021
- One of the fastest novae known
- Optical decline timescale

$$t_2 \simeq 1.1 \text{ d}$$

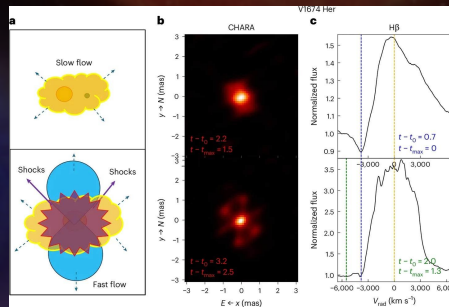
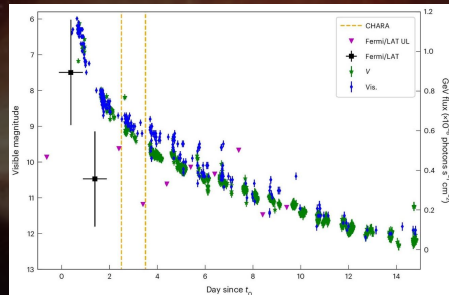
- **Structured ejecta**

- Fast bipolar outflows
- Interaction with slower material

- **Multiwavelength emission**

IR $\rightarrow$ Radio $\rightarrow$ Optical $\rightarrow$ X-ray $\rightarrow$ γ -ray

- X-ray shocks and radio synchrotron indicate **non-thermal particle acceleration**



The Fermi-LAT detection of GeV Emission

Early, transient GeV emission

- Detected ~ 6 h after eruption
- Energy range: 0.1–300 GeV
- Duration: ~ 18 h
- $L_\gamma \sim 10^{36} \text{ erg s}^{-1}$

$$E_\gamma \simeq 6.61 \times 10^{40} \text{ erg}$$

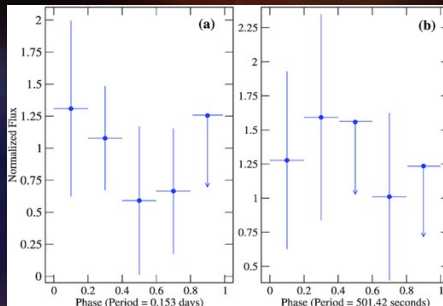
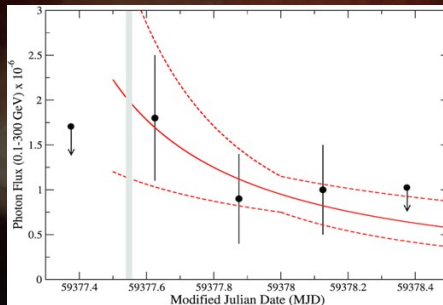
Proposed origin

- Shock acceleration

Our proposed pathway

- Differential rotation extracts rotational energy
- Magnetic reconnection and particle acceleration

Can the disk–magnetosphere interaction power the observed GeV emission?



Classification of V1674 Herculis

System classification

- Classical nova following the 2021 thermonuclear eruption
- Magnetic white dwarf
- Accreting binary system
- Accretion disk present
- Rapid WD spin:

$$P_{\text{spin}} = 501.5 \text{ s}$$

Classification

Intermediate Polar (IP)

Magnetic WD–disk configuration

$$M_{\text{WD}} = 1.09 M_{\odot}$$

$$R_{\text{WD}} = 5.0 \times 10^8 \text{ cm}$$

$$B_{\text{WD}} = 21.3 \text{ MG}$$

$$P_{\text{orb}} = 3.67 \text{ h}$$

$$P_{\text{spin}} = 501.5 \text{ s}$$

The magnetic field truncates the disk at

$$R_m = 1.68 \times 10^9 \text{ cm.}$$

The corotation radius is

$$R_{\text{co}} = 9.73 \times 10^9 \text{ cm.}$$

Therefore, $R_m < R_{\text{co}}$

Thus, the system is in the accreting regime and the magnetosphere can couple to the disk.

Search for Recurrent Gamma-ray Activity

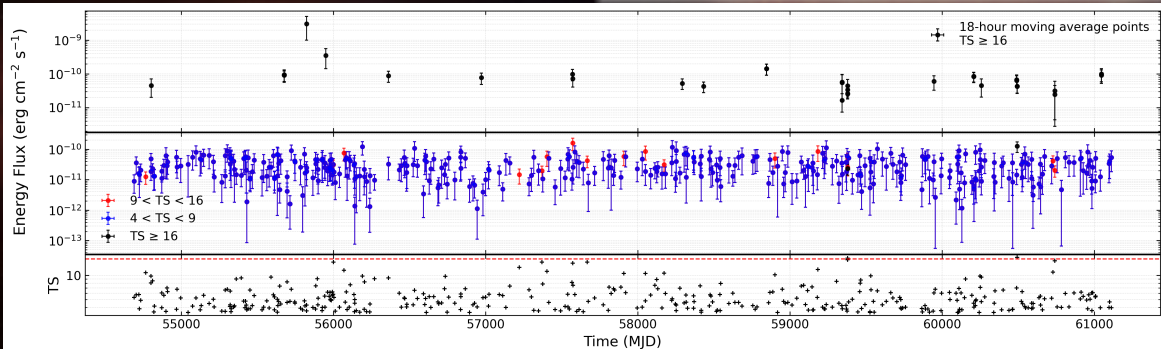
- Is the 2021 gamma-ray episode isolated?
- Search for additional gamma-ray enhancements before and after the known 18-hour episode
- Six-hour binned Fermi-LAT light curve
- Three-bin moving average probes the ~ 18 -hour timescale of the known episode
- Moving-average points retained at $\sim 4\sigma$

Key result

Qtn: Is the 2021 gamma-ray episode isolated, or are there any recurrent lower-level activity?

Ans: Several temporally coherent enhancements are present outside the known 2021 outburst.

- MJD 55675–55676: clearest early multi-point enhancement.
- MJD 59342 occurs ~ 35 days before the major 2021 outburst.
- MJD 58822 shows an exceptionally high reported flux, but is currently isolated.
- Additional compact clusters occur at MJD 58845, 60489 and 61046.



What Is the Gamma-Ray Spectrum?

- Fermi LAT spectrum (0.1–100 GeV) constructed from intervals with $TS > 7$ ($\sim 2.6\sigma$).
- Selected intervals are combined and analysed using a binned likelihood analysis.
- Power Law and Log Parabola models tested
- TS versus energy compares the TS-gated (black) and ungated (red) intervals.
- Higher- TS intervals show increased flux and harder emission

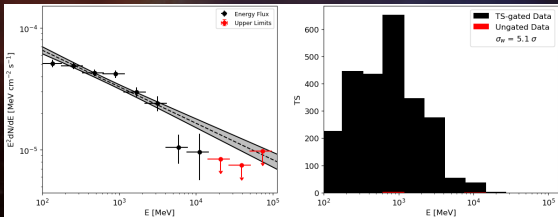


Figure: PowerLaw spectrum

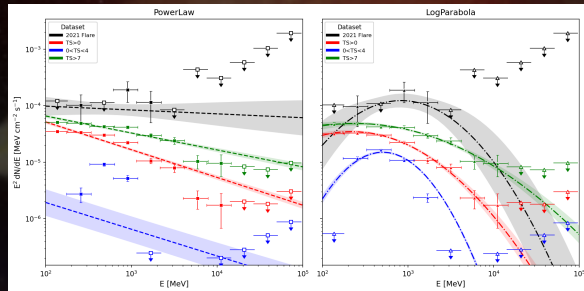


Figure: LogParabola spectrum

From Disk–Magnetosphere Shear to Reconnection

1. Differential rotation

$$\Omega_K(R_m) > \Omega_{WD}$$

$$\Delta\Omega = \Omega_K - \Omega_{WD}$$



Disk and WD rotate at different rates

Toroidal field grows $B_\phi \uparrow$

2. Field winding



3. Magnetic stress

$$T_{\phi p} = \frac{B_\phi B_p}{4\pi}$$

$$P_{\text{shear}} = N_{\text{mag}} |\Delta\Omega|$$

Rotational energy is converted into magnetic energy stored in the twisted field

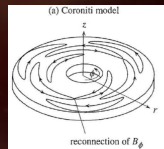


4. Reconnection



Magnetic field restructures

Stored energy is released
Relativistic particles



Is There Differential Rotation in V1674 Her?

(1) Keplerian flow reaches the coupling radius

$$\Omega_K(R_m) = \sqrt{\frac{GM_{\text{WD}}}{R_m^3}}$$

$$\Omega_K(R_m) = 1.75 \times 10^{-1} \text{ s}^{-1}$$

(2) WD spin differs from the disk

$$\Delta\Omega = \Omega_K(R_m) - \Omega_{\text{WD}} = 1.62 \times 10^{-1} \text{ s}^{-1} \neq 0$$

$$\omega_s = \frac{\Omega_{\text{WD}}}{\Omega_K(R_m)} = 0.072 \neq 1$$

The inner disk rotates faster than the WD.

(3) The shear persists long enough to wind up

$$t_{\text{build}} \gtrsim \frac{1}{|\Delta\Omega|}$$

$$\Delta\Omega t_{\text{build}} \approx 1.05 \times 10^4 \gg 1$$

The differential rotation can continuously wind the magnetic field.

Question

Is differential rotation physically established in Nova 2021

Magnetic Reconnection

(1) Strong magnetic shear

$$\frac{B_\phi}{B_p} \gtrsim 10, \quad \frac{B_\phi}{B_p} \approx 1.05 \times 10^5, \quad \frac{B_\phi}{B_p} = q_B = 20$$

The toroidal field therefore exceeds the poloidal field sufficiently to drive magnetic instability.

(2) Low plasma beta

$$\beta_e = \frac{8\pi N_e k_B T_e}{B_\phi^2} = 2.12 \times 10^{-9} \ll 1$$

so magnetic pressure dominates the plasma pressure by a factor of $\sim 5 \times 10^8$.

(3) Super-Dreicer electric field

$$\frac{E_{\text{rec}}}{E_D} = 1.15 \times 10^{13} \gg 1$$

so electrons enter the runaway regime immediately.

Particle Acceleration and Radiation

Acceleration field

$$E_{\text{rec}} = \frac{\pi B_{\phi} V_m}{c} = 1.76 \times 10^7 \text{ statV cm}^{-1}$$

Model parameter: $\epsilon_{\text{rec}} = 0.5$

Two competing energy limits

Potential limit (diagnostic):

$$E_{\text{pot}} = e\Phi_{\text{rec}} = 8.87 \times 10^9 \text{ GeV}$$

Current-sheet limit:

$$E_w = eB_{\phi} w = 2.68 \times 10^5 \text{ GeV}$$

$$E_{\text{particle,max}} = \min(E_{\text{pot}}, E_w) = 2.68 \times 10^5 \text{ GeV}$$

Electron channel:

Radiation reaction (synchrotron dominated) caps the electron energy $P_{\text{acc}} = ecE_{\text{rec}}:-$

$$P_{\text{rad}} = \frac{4}{3} \sigma_T c \gamma_e^2 (U_B + U_{\text{rad}}) = ecE_{\text{rec}}$$

$$\gamma_{e,\text{max}} = 4.37 \times 10^4, \quad E_{e,\text{max}} = 22.3 \text{ GeV}$$

IC on nova optical field: $b_{\text{KN}} = 0.637 \rightarrow$ Thomson-KN transition

$$E_{\gamma,\text{IC}}^{\text{max}} = 22.3 \text{ GeV}$$

Proton channel:

Protons do not suffer synchrotron losses:

$$T_{p,\text{max}} = E_w = 2.68 \times 10^5 \text{ GeV}, \quad \gamma_{p,\text{max}} = 2.86 \times 10^5$$

$$E_{\gamma,\pi^0}^{\text{max}} = 4.56 \times 10^4 \text{ GeV}$$

Energy Budget and Self-Consistency

Available accretion power

$$P_{\text{acc}} \sim \frac{GM_{\text{WD}}\dot{M}}{R_{\text{WD}}} \simeq 1.51 \times 10^{37} \text{ erg s}^{-1}$$

Power extracted through differential rotation

$$P_{\text{shear}} = N_{\text{mag}}\Delta\Omega \simeq 1.40 \times 10^{37} \text{ erg s}^{-1}$$

The magnetic-stress matches the mechanical-drag and is about 14 times the observed γ -ray luminosity

Required efficiency

$$\eta_{\text{req}} = \frac{L_{\gamma}}{P_{\text{shear}}} \simeq 7.3\%$$

Only a small fraction of the extracted shear power is required to power the observed γ -ray luminosity.

Radiative channels

$$L_{\gamma} = 1.02 \times 10^{36} \text{ erg s}^{-1}$$

$$e^{\pm} \longrightarrow \text{IC } \gamma\text{-rays}$$

The leptonic channel reaches the Fermi-LAT energy range, with IC photons extending to

$$E_{\gamma,\text{IC}}^{\text{max}} \simeq 22 \text{ GeV.}$$

Conclusions

❶ **V1674 Her provides the conditions for magnetic energy extraction.**

The 501.5 s white-dwarf spin, 21.3 MG magnetic field, and rapidly rotating accretion flow produce strong disk–magnetosphere differential rotation.

❷ **Differential rotation can drive magnetic reconnection.**

The magnetic winding saturates at the adopted cap $B_\phi/B_p = 20$, exceeding the tearing-mode instability threshold $q_B > 10$ (Ghosh & Lamb 1991). The resulting magnetic stress, $T_{\text{mag}} = B_z B_\phi / 4\pi$, drives a reconnection power

$$P_{\text{recon}} \simeq P_{\text{shear}} \simeq 1.40 \times 10^{37} \text{ erg s}^{-1}.$$

❸ **The energy budget is sufficient for the observed GeV emission.** For $L_\gamma \simeq 1.02 \times 10^{36} \text{ erg s}^{-1}$, the required conversion efficiency is $\eta_{\text{req}} \simeq 7.3\%$.

Thus the reconnection-powered particle population has sufficient energy to account for the observed luminosity.

❹ **Inverse-Compton emission provides the main GeV connection.**

Relativistic electrons scattering the nova optical photon field produce IC photons in the Fermi-LAT band, extending to $\sim 20 \text{ GeV}$.

The model therefore naturally connects magnetic reconnection to the observed GeV emission.

❺ **Hadronic interactions provide a possible higher-energy extension.**

Protons accelerated in the reconnection region can undergo

$$pp \rightarrow \pi^0 \rightarrow \gamma\gamma,$$

with the current model producing characteristic photons in the TeV regime.

Thank you

Questions and comments are welcome.

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