A Plasma Torus Around a Young Low-Mass Star

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Approximately one percent of red dwarfs younger than 100 million years show structured, periodic optical light curves suggestive of transiting clumps of opaque circumstellar material that corotate with the star [1–4]. The composition, origin, and even the existence of this material are uncertain. The main alternative hypothesis is that these stars are explained by complex distributions of dark starspots or bright faculae distributed across their surfaces [5]. Here, we present time-series spectroscopy and photometry of a 40 million year old complex periodic variable (CPV), TIC 141146667. The spectra show coherent sinusoidal Balmer emission at up to four times the star's equatorial velocity, demonstrating the presence of extended clumps of circumstellar plasma — a plasma torus. These data rule out "starspot-only" and "dust-only" origin scenarios for CPVs, instead supporting either a purely stellar origin for the phenomenon or extrinsic scenarios involving long-lived disks or outgassing rocky bodies capable of supplying sufficient gas. Given that long-lived condensations of cool (10^4 K) plasma can persist in the hot (10^6 K) coronae of stars with a wide range of masses [6–11], these data support the idea that such condensations can become optically thick around the lowest-mass stars, although the exact source of opacity remains unclear.

1 Main

Introduction Lorem ipsum whatever...

Results

Discussion

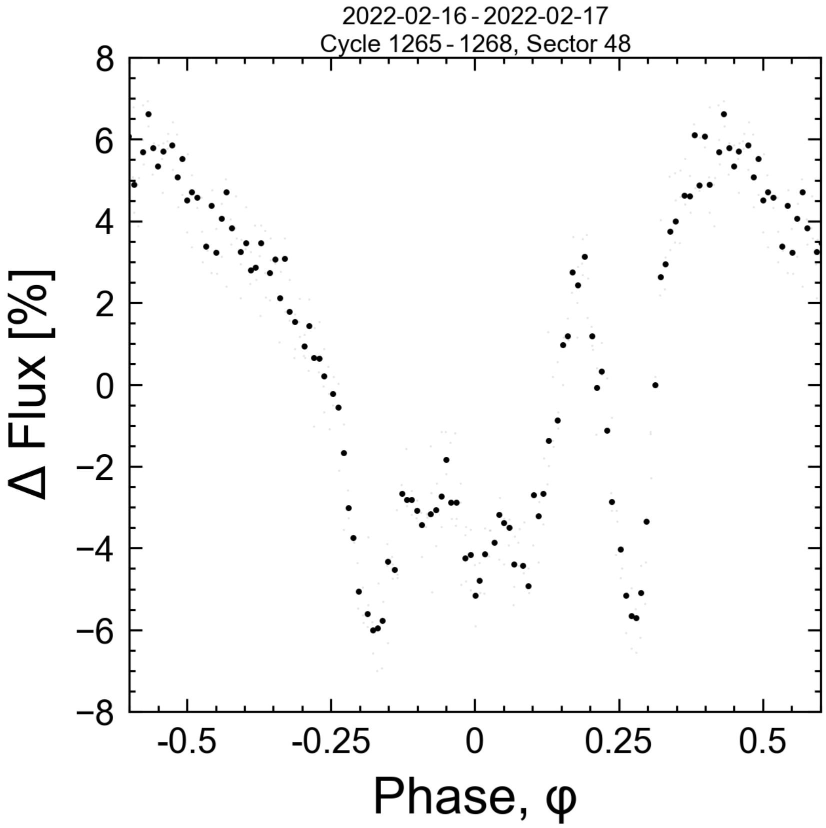

Figure 1: **Figure 1 (Movie): TIC 141146667 is a complex periodic variable (CPV).** For the best experience, please view the online movie available here, which spans a baseline of 5,784 cycles irregularly sampled over three years. The TESS light curve is phased to the 3.930 hour period in groups of a few cycles per frame. Raw data acquired with two minute sampling are in gray; black is their average. Similar to other members of this class, the sharp photometric features persist for tens to thousands of rotational cycles.

Methods

Observations

Data Reduction

Discussion

1. Rebull, L. M. *et al.* Rotation in the Pleiades with K2. II. Multiperiod Stars. Astron. J. **152**, 114 (2016).

2. Stauffer, J. *et al.* Orbiting Clouds of Material at the Keplerian Co-rotation Radius of Rapidly

Parameter	Host	Source
	Identifiers	
TIC	141146667	TESS
Gaia	todo	Gaia DR3
	Astrometry	
α	todo	Gaia DR3
δ	todo	Gaia DR3
μ_α (mas yr^{-1})	todo	Gaia DR3
μ_δ (mas yr^{-1})	todo	Gaia DR3
π (mas)	todo	Gaia DR3
	Photometry	
$TESS$ (mag)	todo	TESS
G (mag)	todo	Gaia DR3
$G_{\rm BP}$ (mag)	todo	Gaia DR3
$G_{\rm RP}$ (mag)	todo	Gaia DR3
J (mag)	todo	2MASS
H (mag)	todo	2MASS
K_s (mag)	todo	2MASS
$W1$ (mag)	todo	ALLWISE
$W2$ (mag)	todo	ALLWISE
$W3$ (mag)	todo	ALLWISE
$W4$ (mag)	todo	ALLWISE
	Kinematics and Position	
RV_{Bary} (km s^{-1})	13.35 ± 3.39	Gaia DR3
U (km s^{-1})		
V (km s^{-1})		
W (km s^{-1})		
X (pc)		
Y (pc)		
Z (pc)		
	Physical Properties	
P_{rot} (hours)	$3.930 \pm 0.XXX$	This work
$v \sin i_\star$(km s^{-1})	todo	This work
$i_\star$($^\circ$)	todo	This work
F_{bol} (erg cm^{-2} s^{-1})	todo	This work
T_{eff} (K)	todo	This work
A_V (mag)	todo	This work
$R_\star$ ($R_\odot$)	todo	This work
$L_\star$ ($L_\odot$)	todo	This work
$M_\star$ ($M_\odot$)	todo	This work
Age (Myr)	todo	This work

Extended Data Table 1: Properties of TIC 141146667.

Rotating Low-mass WTTs in Upper Sco. Astron. J. **153**, 152 (2017).

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Author Contributions ...

Data Availability ...

Competing Interests The authors declare that they have no competing financial interests.

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Code availability We provide access to a GitHub repository including all code created for the analysis of this project that is not already publicly available.

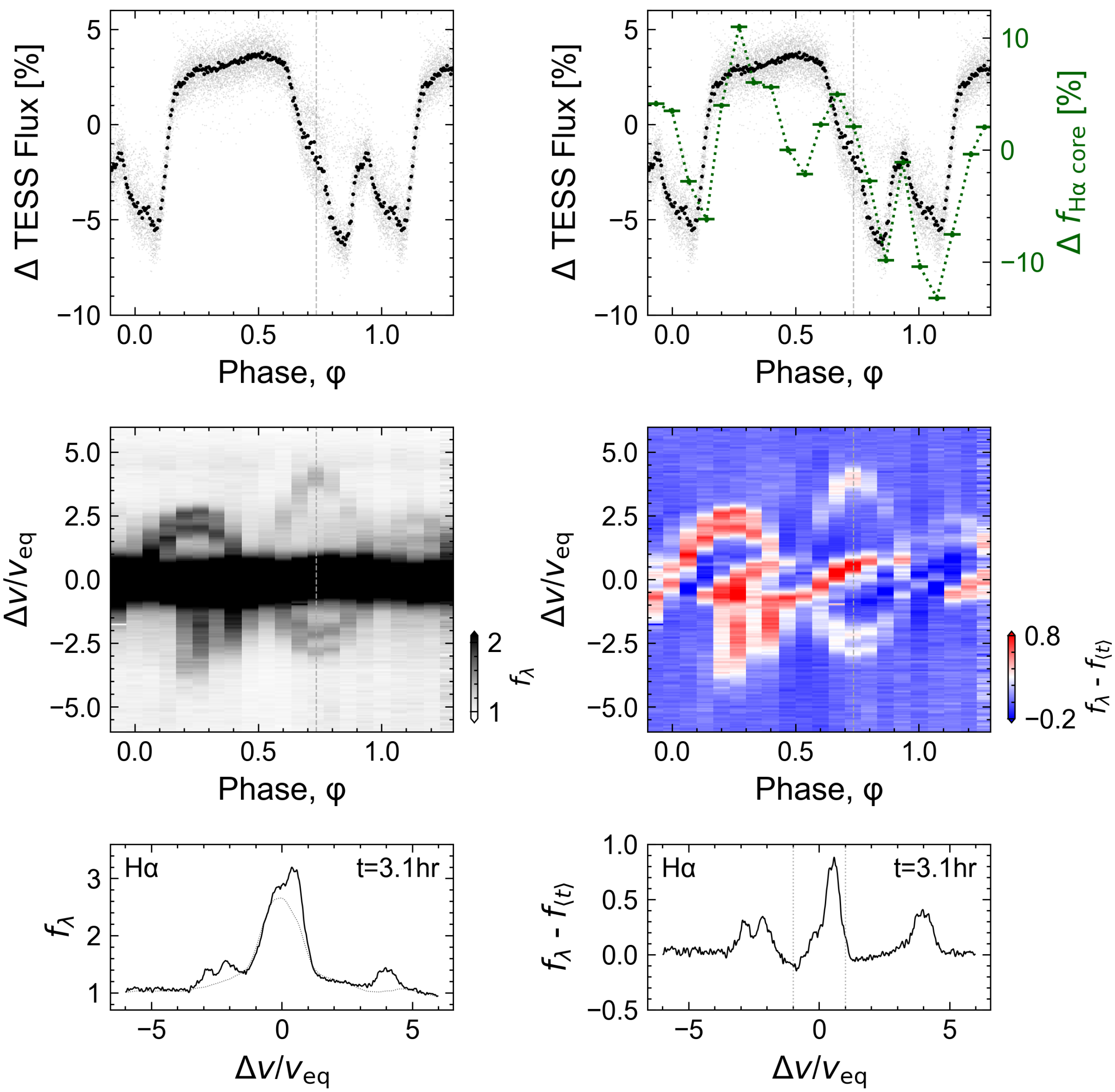

Figure 2: **Figure 2 (Movie):** Hydrogen emission from circumstellar plasma orbiting TIC 141146667. (**TODO**)For the best experience, please view the online movie available here. **Panel a:** TESS light curve from UT 2024-02-05 to UT 2024-02-26 folded on the 3.930 hour period. Black points are averaged; gray are the raw data. **Panel b:** Keck/HIRES Hα spectra acquired on UT 2024-02-17. The continuum is set at unity, and the darkest color is set at twice the continuum to accentuate emission outside the line core ($|v/v_{\mathrm{eq}}| > 1$, for v_{eq}=130 $\mathrm{km\,s^{-1}}$). While emission in the line core originates in the stellar chromosphere, the sinusoidal emission features are most readily described by a warped plasma torus. **Panel c:** Individual epochs of Panel b, visible in the online movie. The dotted line shows a time-averaged spectrum, $f_{\langle t\rangle}$. **Panel d:** As in Panel a, but overplotting the median-normalized Hα light curve at $|v/v_{\mathrm{eq}}| < 1$. **Panel e:** As in Panel b, after subtracting the time-averaged spectrum. In addition to circumstellar emission, the line core shows absorption during the plasma clump transits. The asymmetric stretch is set to match the dynamic range of the data. **Panel f:** Individual epochs of Panel e, visible in the online movie.