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Centrifugal Breakout around a Young M Dwarf

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Overview

- Our M3.5 target star, TIC 234284556, hints at the possibility of **uniting concepts** mainly discussed in the massive star community (like centrifugal breakout and magnetospheric clouds), with phenomena associated with low-mass stars (such as slingshot prominences).
- At ~ 45-million-years-old, TIC 234284556 is older than its potential analogs, so it may give us insight into how centrifugal breakout, magnetospheric clouds, and related phenomena work at **different evolutionary stages**.
- We have three TESS sectors over a **two-year baseline**, critical to understanding the system's evolution over time.
- Our target star, TIC 234284556, is **brighter** (I-mag: 11.68) than its potential analogs (PTFO 8-8695 and the stars described by Stauffer et al. (2017)), making it well-suited for follow-up photometry and a useful guide for understanding this mysterious class of stars.
- **X-Ray observations** scheduled for 2021 will help us better understand the nature and origin of the dips.

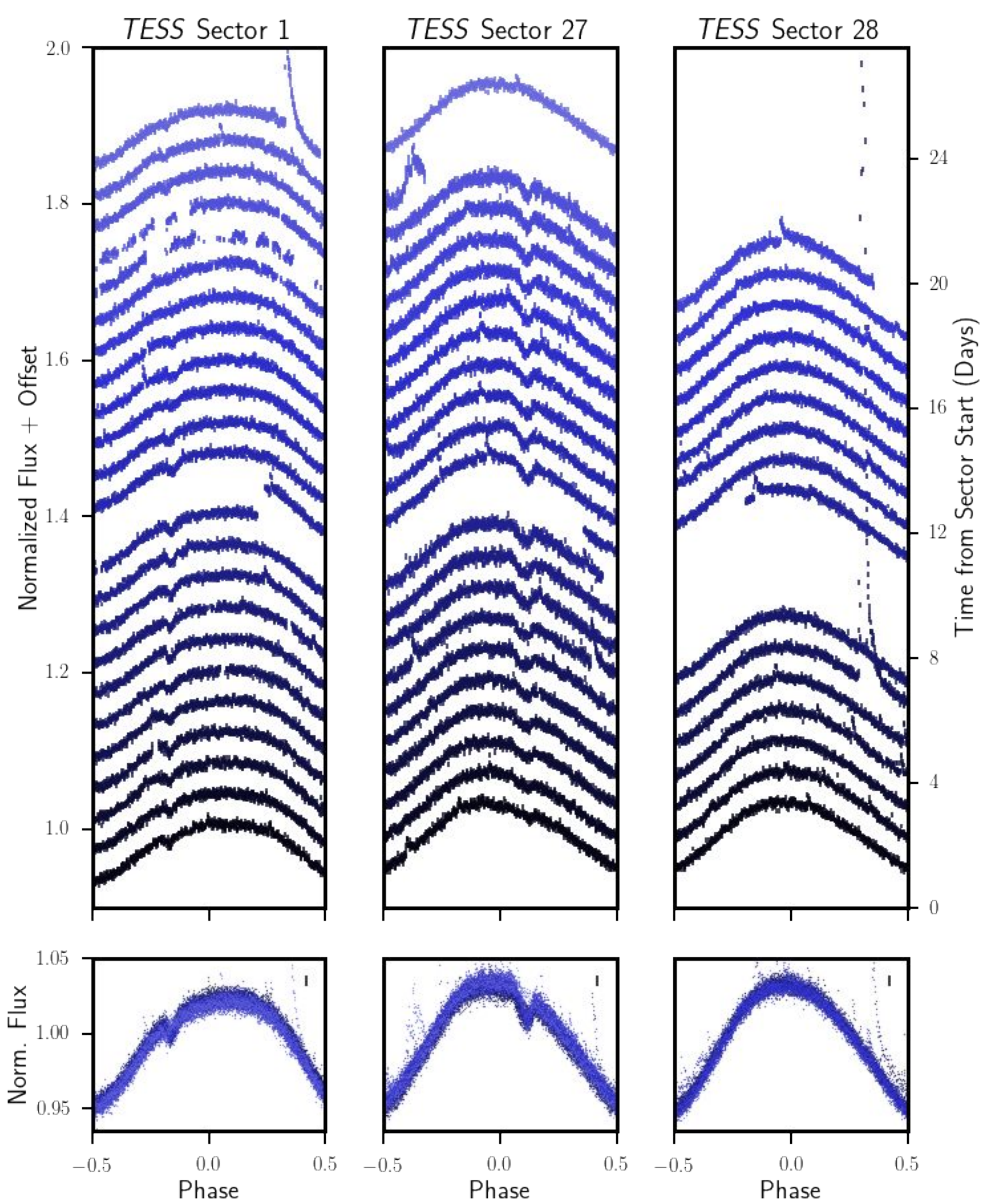

Figure 2. Visualizing the changes in dip morphology, depth, and duration during three sectors of *TESS* observations. Notice that the dip suddenly disappears between the end of Sector 27 and start of Sector 28 — our potential breakout event — and that there is a > 120% flare soon after.

Introduction

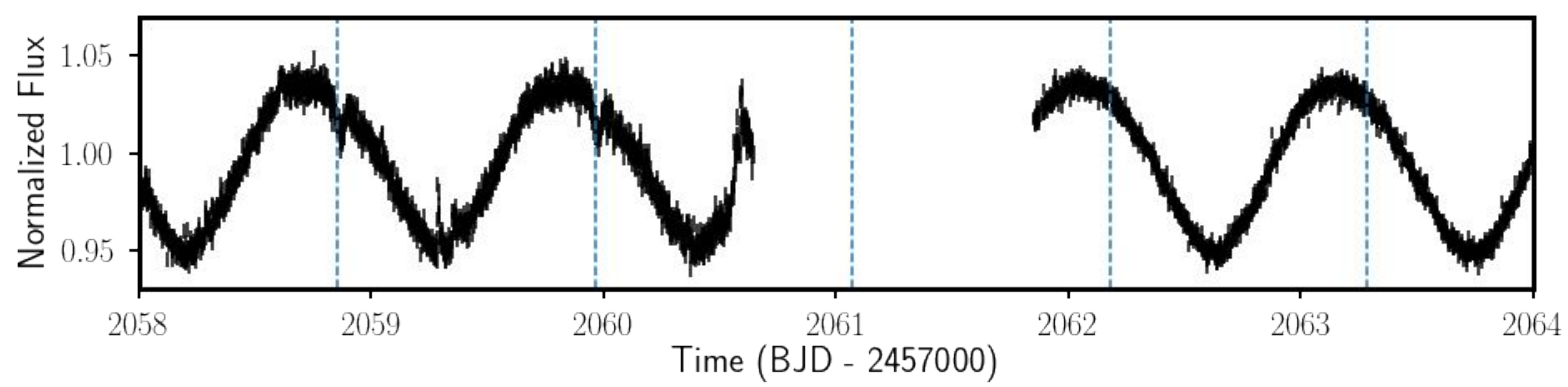

Figure 1. The potential breakout event coincides with the dip's disappearance between day 2060 and 2062. Note also the anomalous brightening event that occurs immediately before the gap in the data.

- **Young star systems** — because they tend to be rapidly evolving and magnetically active, and because their protoplanetary disks may not yet have dissipated — are known for having light curves with complex morphology.
- Some young stars, like RIK-210 and the stars described by Stauffer et al. (2017), have depth-varying periodic signals that have been attributed to **magnetospheric clouds**, plasma that accumulates in dense clumps at the corotation radius of stars with particularly stable rotational periods and strong magnetic fields (Figure 3).
- Stellar theory first developed by Townsend and Owocki (2005) predicts that plasma from stellar winds will continue to accumulate in the magnetosphere until the trapped plasma is massive enough that the magnetic loops snap, suddenly freeing the material in a so-called **centrifugal breakout** event.
- However, the physical mass-loss mechanisms and the timescales associated magnetospheric clouds are **still debated** in the astronomical community, largely because of a **lack of data**. In particular, Townsend et al. (2013)'s non-detection of centrifugal breakout signatures in data from the B2 star σ Ori E led to a debate about alternatives to centrifugal breakout.

Here we present TIC 234284556, a candidate for a direct detection of centrifugal breakout.

Evidence For Breakout

- The dip **disappears on a one-day timescale** (Figure 1).
- The dip's **depth variation** in Sectors 1 and 27 (Figure 2) can be explained with magnetospheric clouds.
- The signal's phase change between Sector 1 and 27 (Figure 2) is indirect evidence for **another breakout event**.
- A **~120% triple flare** (Figure 3) that occurs days after the breakout event is evidence for increased magnetic activity — not surprising because the star's magnetic field lines snap and then reconnect during breakout.

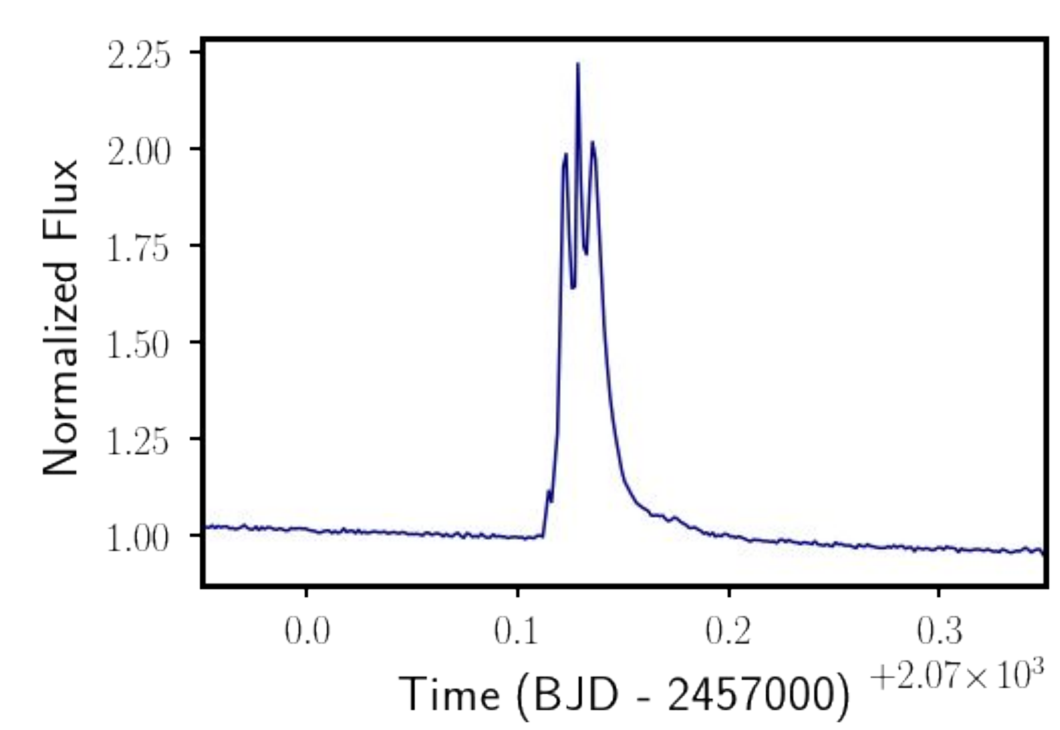

Figure 3. An enormous triple flare, over 120% in the TESS bandpass — potential evidence for increased magnetic activity following magnetic reconnection.

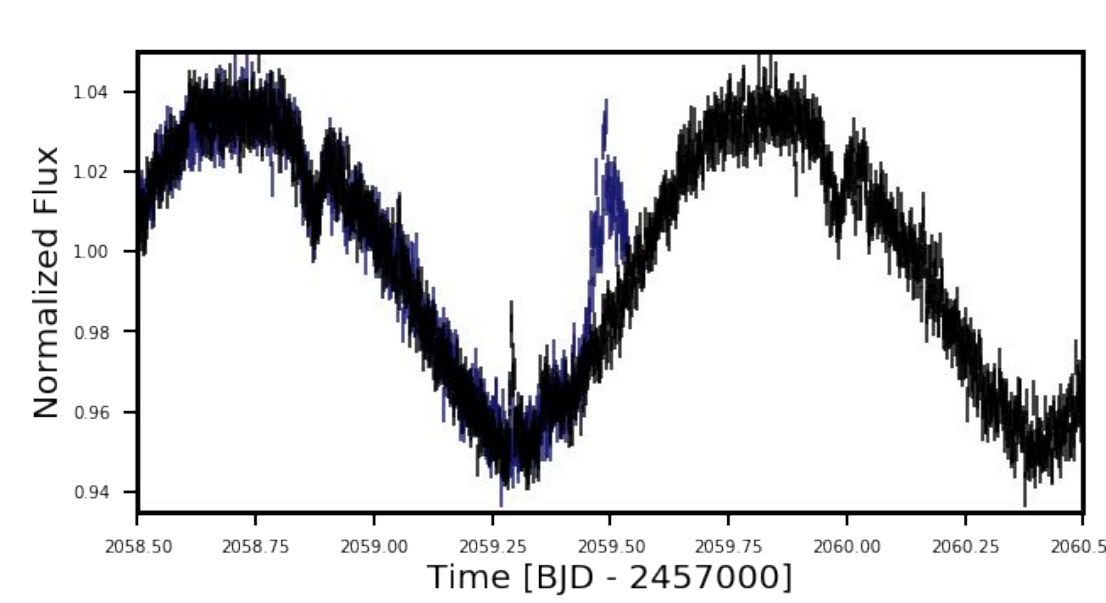

Figure 4. A flare-like event (blue), with the previous rotational period superimposed (black), which could coincide with a post-breakout magnetic reconnection event.

- We see an **anomalous brightening event** with morphology atypical for flares right around breakout (Figure 4). Stellar theory predicts that magnetic reconnection events could resemble flares, and some of Stauffer et al. (2017)'s stars had unusually symmetric flare-like events that occured at state transitions, so this could plausibly be a **post-breakout magnetic reconnection event.**

Observations

- We have three sectors of TESS data separated by two years. Sectors 1 and 27 both show a depth-varying periodic signal. **In the ~1 day gap between Sectors 27 and 28, the dip suddenly disappears**. (Figure 1)
- Follow-up photometry with LCO indicates that **the dip reappears** 107 days after our potential breakout event.
- TIC 234284556's spectral energy distribution star shows **no infrared excess**, verifying that the host star's protoplanetary disk is mostly dissipated, and indicating that the cause of our signal likely differs from the mechanism behind the so-called "dipper" stars.
- Four years of ASAS-SN data confirms that our target has a **stable rotational period** — a prerequisite for forming magnetospheric clouds, according to stellar theory.
- Spectra from Veloce and the kinematics support our target's youth.

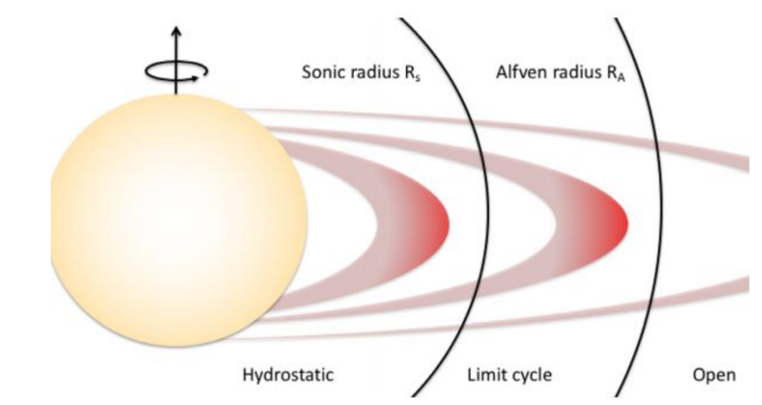

Figure 3. Visualization of plasma trapped in a star's magnetosphere. Image Credit: **Jardine and Collier Cameron (2018)**

Discussion and Future Work

- Stellar winds are the archetypal mass-accumulation mechanism for magnetospheric clouds. However, coronal mass ejections (**CMEs**) have been proposed as a possible alternative for low-mass stars.
- Future observations of TIC 234284556 may put constraints on the **mass accumulation timescale**, thereby helping us to distinguish between the CME and stellar wind scenarios.
- If successful, such observations would either help constrain the strength of stellar winds around young M dwarf stellar winds (currently uncertain to five orders of magnitude) or would provide some of the first direct evidence of extrasolar CMEs.
- X-ray observations scheduled for 2021 may give us a better understanding of our system.
- More information on TIC 234284556 is forthcoming in Palumbo et al. (in prep).

Acknowledgments

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