Localizing Stellar Activity on Low-Mass Stars with the Transiting Exoplanet Survey Satellite

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Credit: NASA/ESA/G. Bacon (STScI)

1. Stellar Activity

- Low-mass stars often have high flaring rates
- Caused by a sudden magnetic reconnection
- Usually associated with star spots [Ikuta et al. 2023]
- Spot modulation is caused by a decrease in optical flux from an increase in star spot coverage.
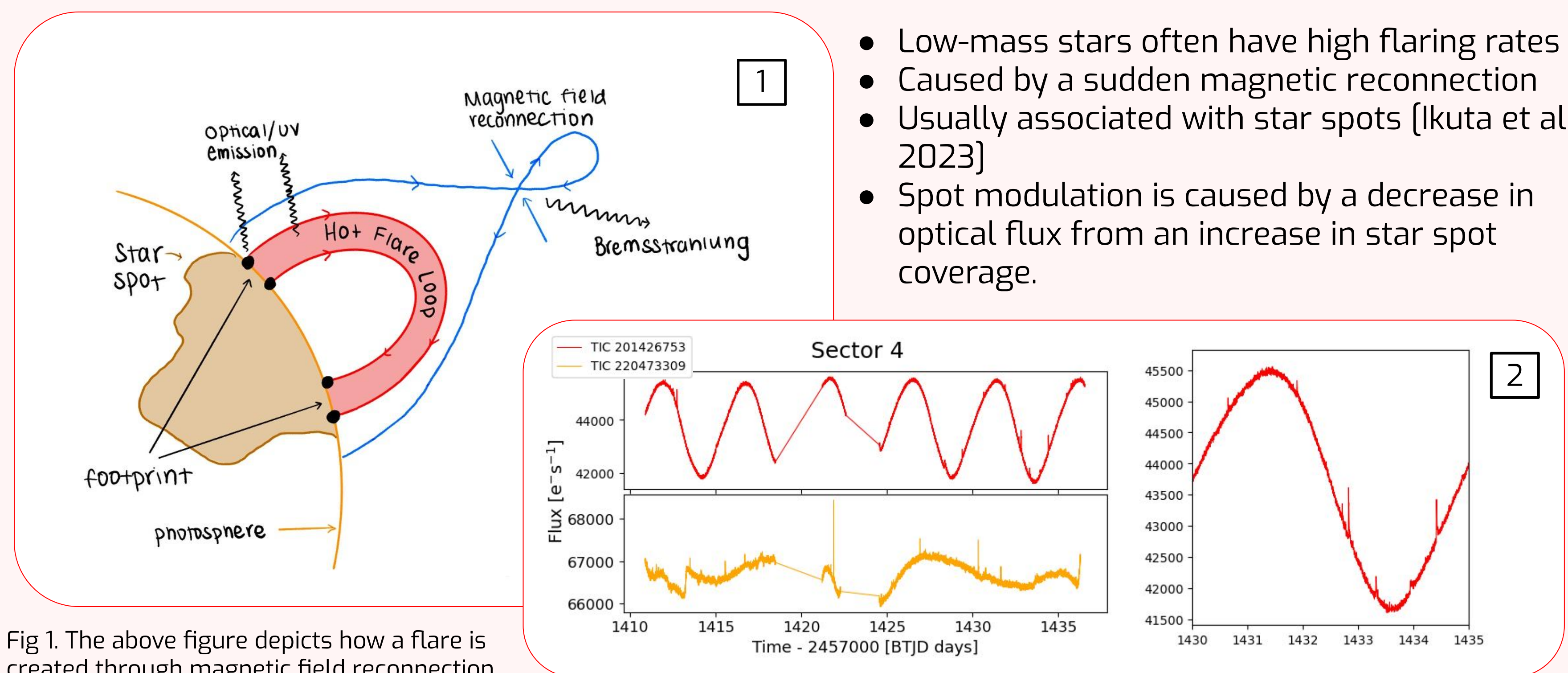

Fig 1. The above figure depicts how a flare is created through magnetic field reconnection.

Fig 2. Spot modulation is seen in light curves as the dips in flux. For young stars, other sources of variability can cause aperiodic brightness changes and lead to complex, non-sinusoidal morphologies. The zoom in shows the morphology of a flare and the spot modulation.

2. Sample Demographics

We selected our sample to include young stars.
- BANYAN Moving Group Stars [Gagné et al. 2018]
  - Stars from β Pictoris Moving Group (βPMG), AB Doradus Moving Group (ABDMG), Tucana-Horologium Association (THA), Columba Association (COL), Carina Moving Group (CAR)
- Sample optimization removed the field stars as they do not have detectable spot modulation.
- We used **Lightkurve** [Lightkurve Collaboration 2018] to examine the light curves for possible contamination.

Fig 3. The outer donut chart depicts the percentage of light curves used from each moving group. The inner donut chart depicts the number of sources used from each moving group. The color blocks are different shapes as some stars had multiple sectors of observation. The sectors were treated individually to maintain observation integrity.
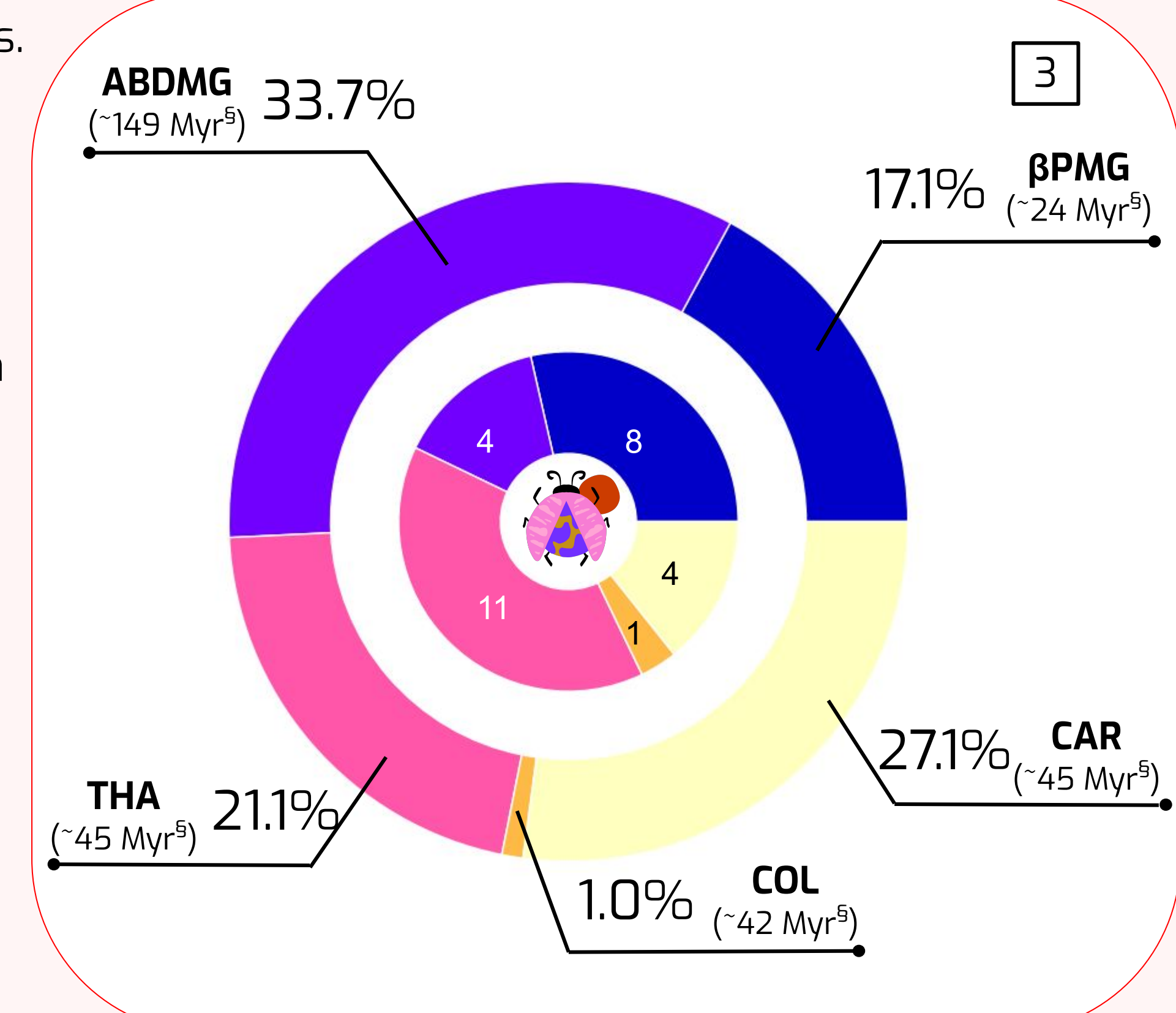
3. Data Analysis
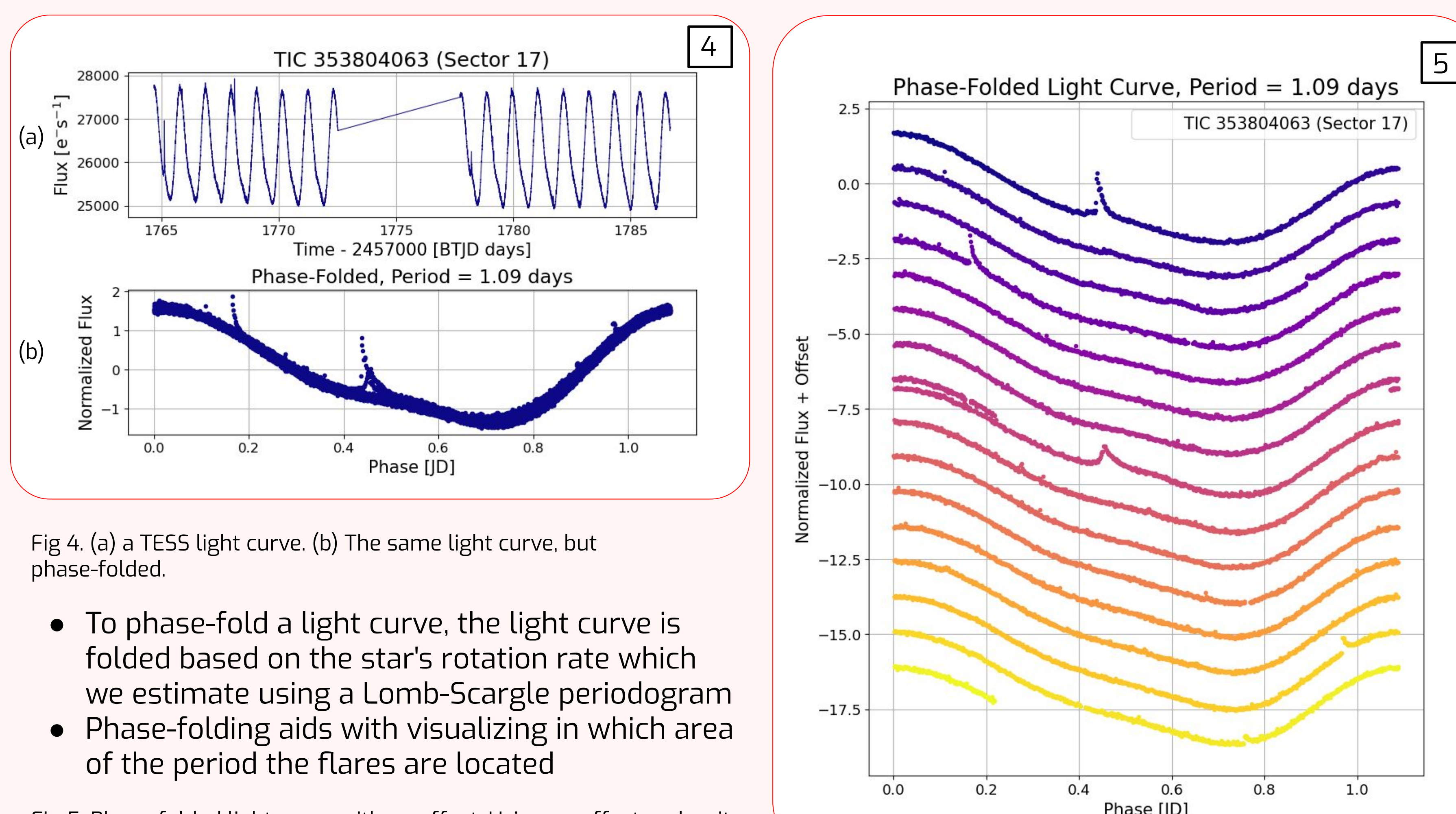
Phase Folding the Light Curves

Fig 4. (a) a TESS light curve. (b) The same light curve, but phase-folded.

- To phase-fold a light curve, the light curve is folded based on the star's rotation rate which we estimate using a Lomb-Scargle periodogram
- Phase-folding aids with visualizing in which area of the period the flares are located

Fig 5. Phase-folded light curve with an offset. Using an offset makes it easier to see where the flares are located in the phase-folded graph.

Identifying the Flares

We used **AltaiPony** [Ilin et al. 2021] to detect the flares on all the light curves. A flare is detected if there is enough data 3σ above the midline. The midline is found by detrending the light curve, which removes the periodic signal from the light curve.

Fig 6. The flares are highlighted in blue. This is useful for making sure that all flares are identified properly and allows for localization analysis by eye.

Localizing the Flares

- Trends in flare rates and spot modulation can provide a means to "localize" on the rotation phase where flares occur more frequently and whether they are associated with active regions (ie star spots).
- To validate our methods, we did an initial survey on 44 light curves with consistent, sinusoidal spot modulation. We plotted the start location of flares along the rotation phase. The phase-folded light curves were co-aligned in phase space using their minima.
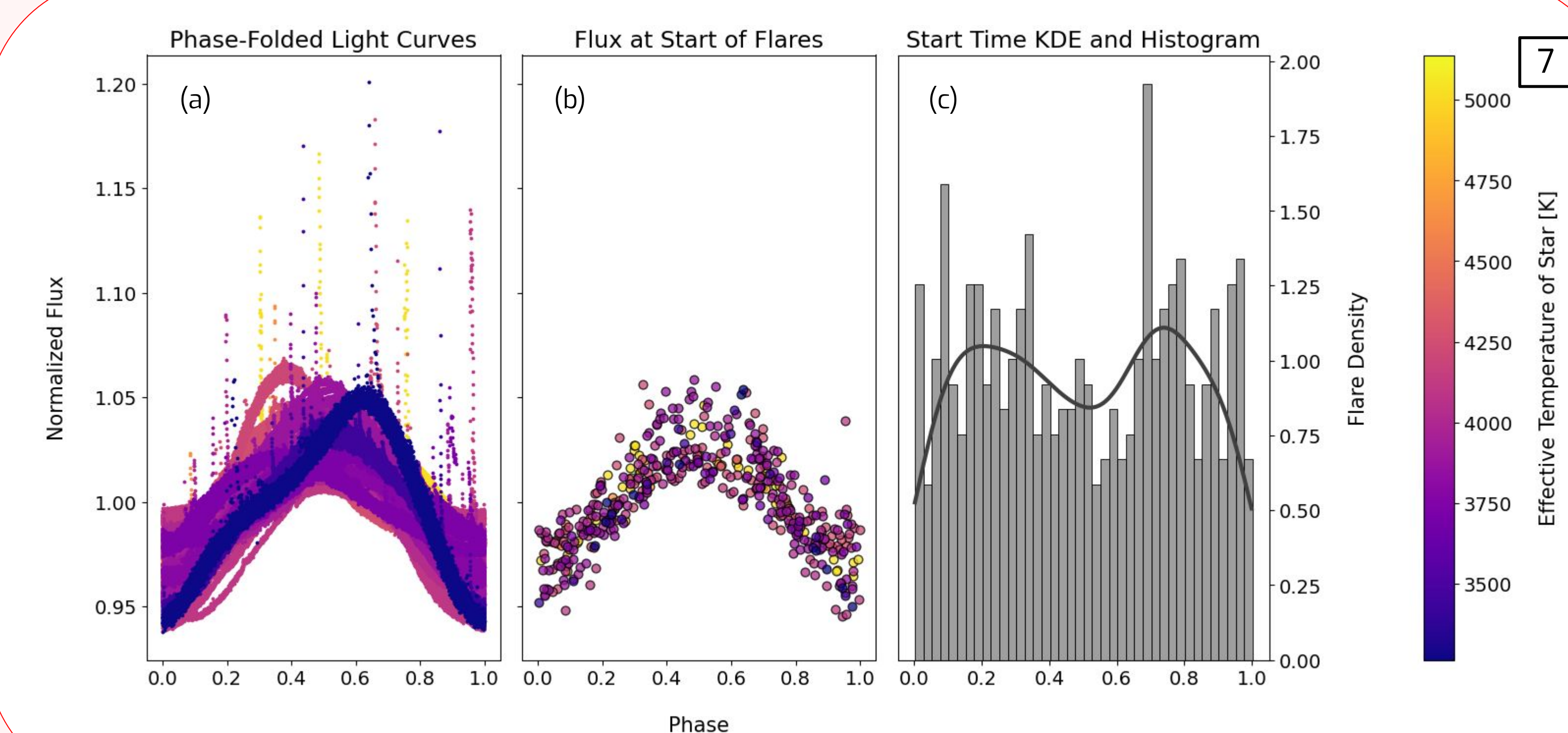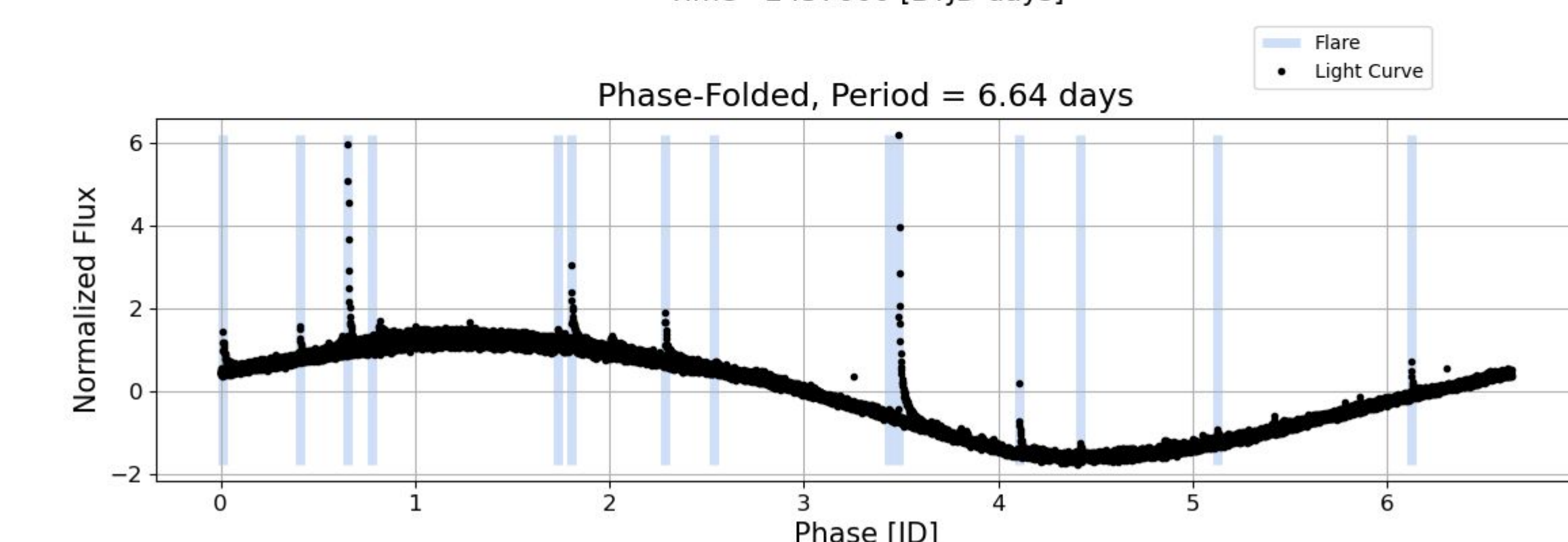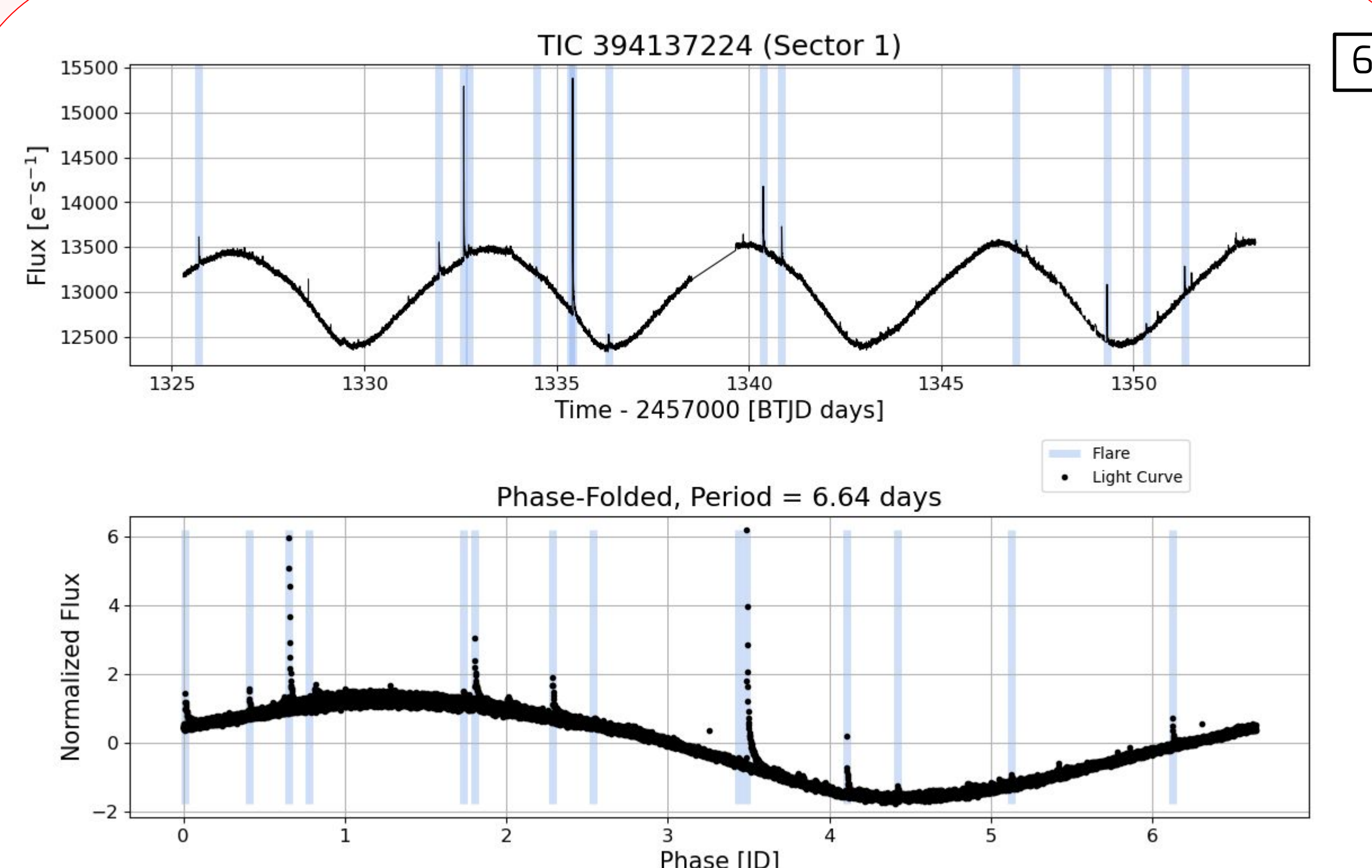

Fig 7. All panels are aligned in phase and colored by effective temperature of the flaring star. (a) Phase-folded light curves. Offset peaks show varied spot coverage. (b) Distribution of the flare start times. (c) Cumulative histogram of the flare density with a kernel density estimate line. We see a higher density of flares closer to the minimum.

- This histogram hints that there are more flares around the minima of the light curves, which can be interpreted as more flares are occurring when there are more spots visible.
- This result is consistent with the expectation that high spot coverage is associated with more active regions and flares, however a deeper statistical analysis is in progress to confirm the significance of this result.
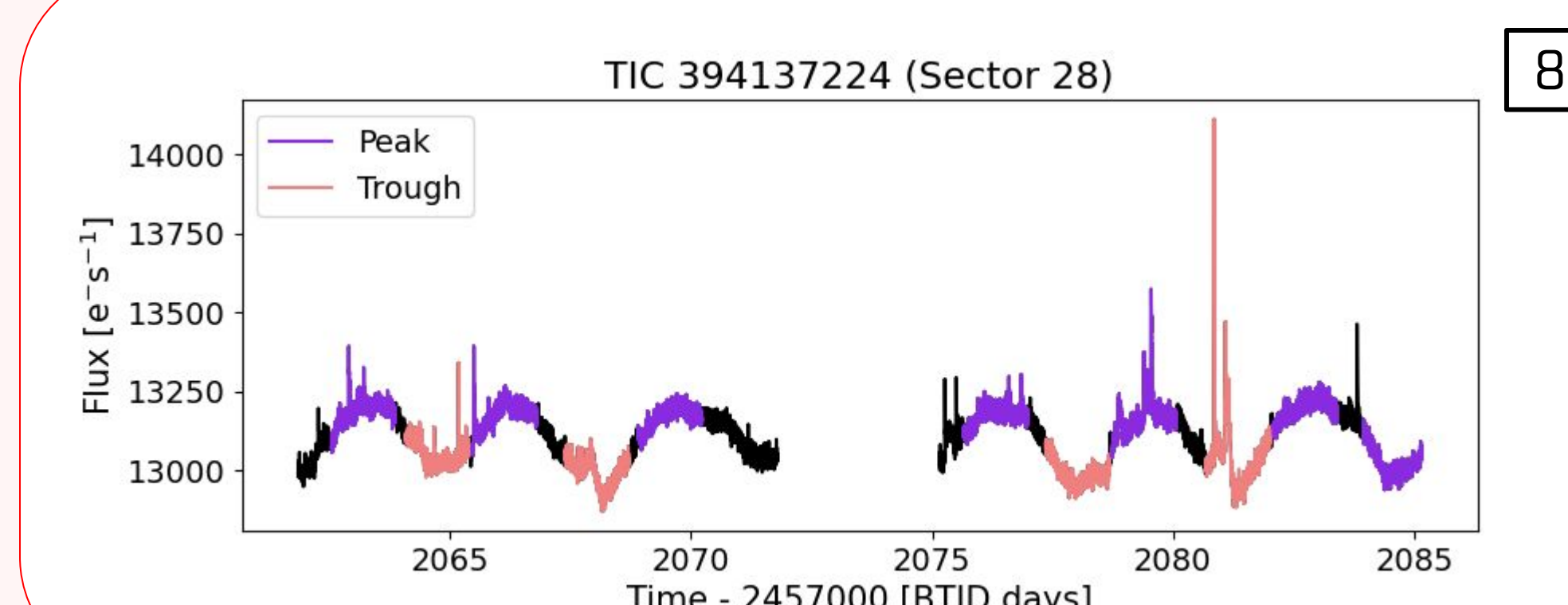
Future Work

- Inflection Point Sectioning
- Rigorous Statistics on Flare Distribution Results
- Continuum localization

Fig 8. Light curve for TIC 394137224 Sector 28. By identifying inflection points, we can isolate peaks (purple) and troughs (coral) without relying on consistent spot modulation.

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