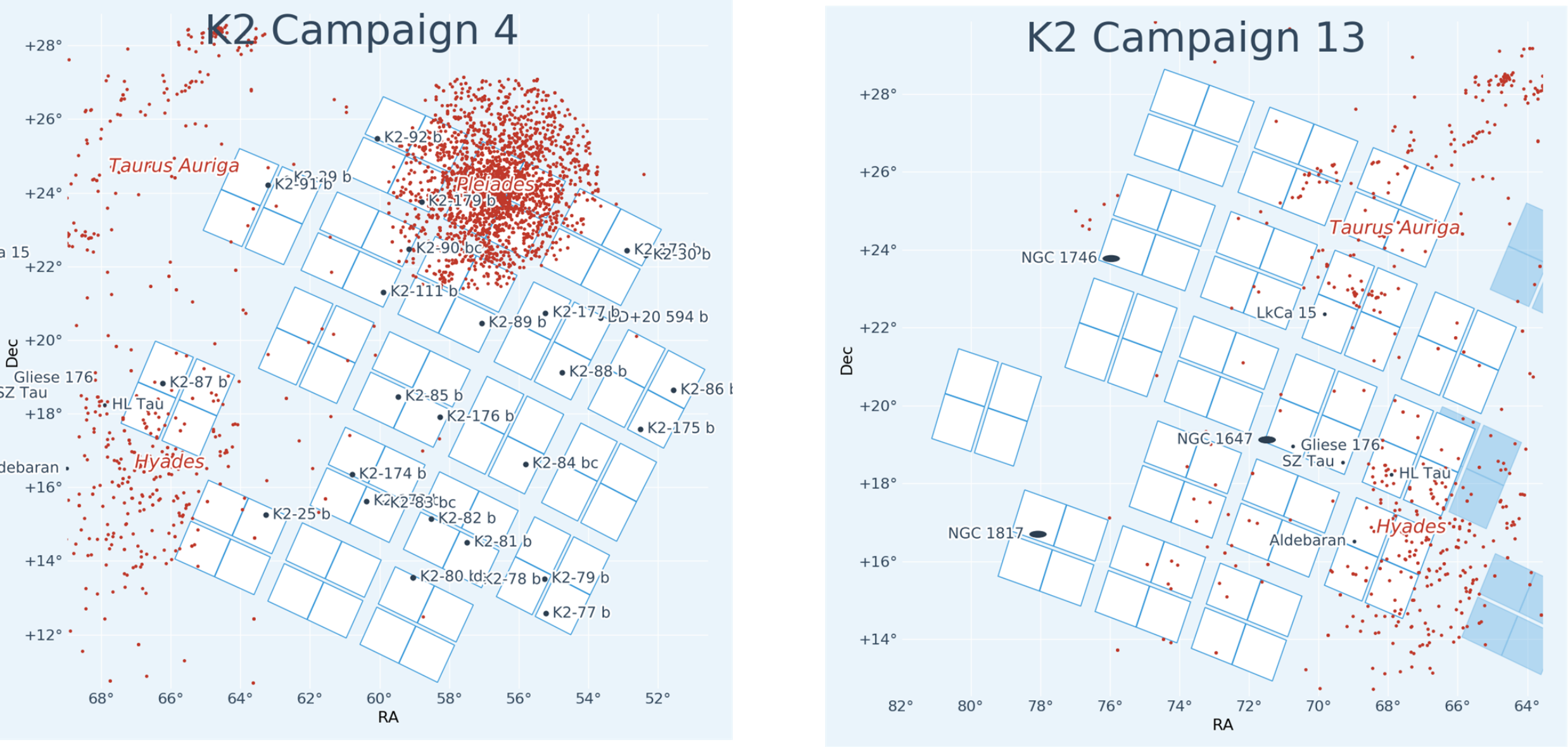


Young Stars in Taurus: The K2 View

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Summary: Young stars ("YSOs") surrounded by dust and gas disks are known to be highly variable on many timescales and at different wavelengths. Over the past decade, dedicated photometric monitoring campaigns with space telescopes have begun to show just how diverse the optical variability is in terms of light curve morphology (see, e.g., center box). We have developed a classification scheme for young, low-mass star light curves, with the aim of understanding the physical drivers. Having assessed the flux behavior of stars in NGC 2264 (Cody et al. 2014), ρ Ophiuchus, and Upper Scorpius (Cody & Hillenbrand 2018), we now extend our analysis to the Taurus association. In this region, we find a relative lack of quasi-periodic “dipper” stars.



Visualizations of the K2 fields of view (white) including Taurus members (red points on the outskirts) that are solar mass and below.

Stellar Sample:

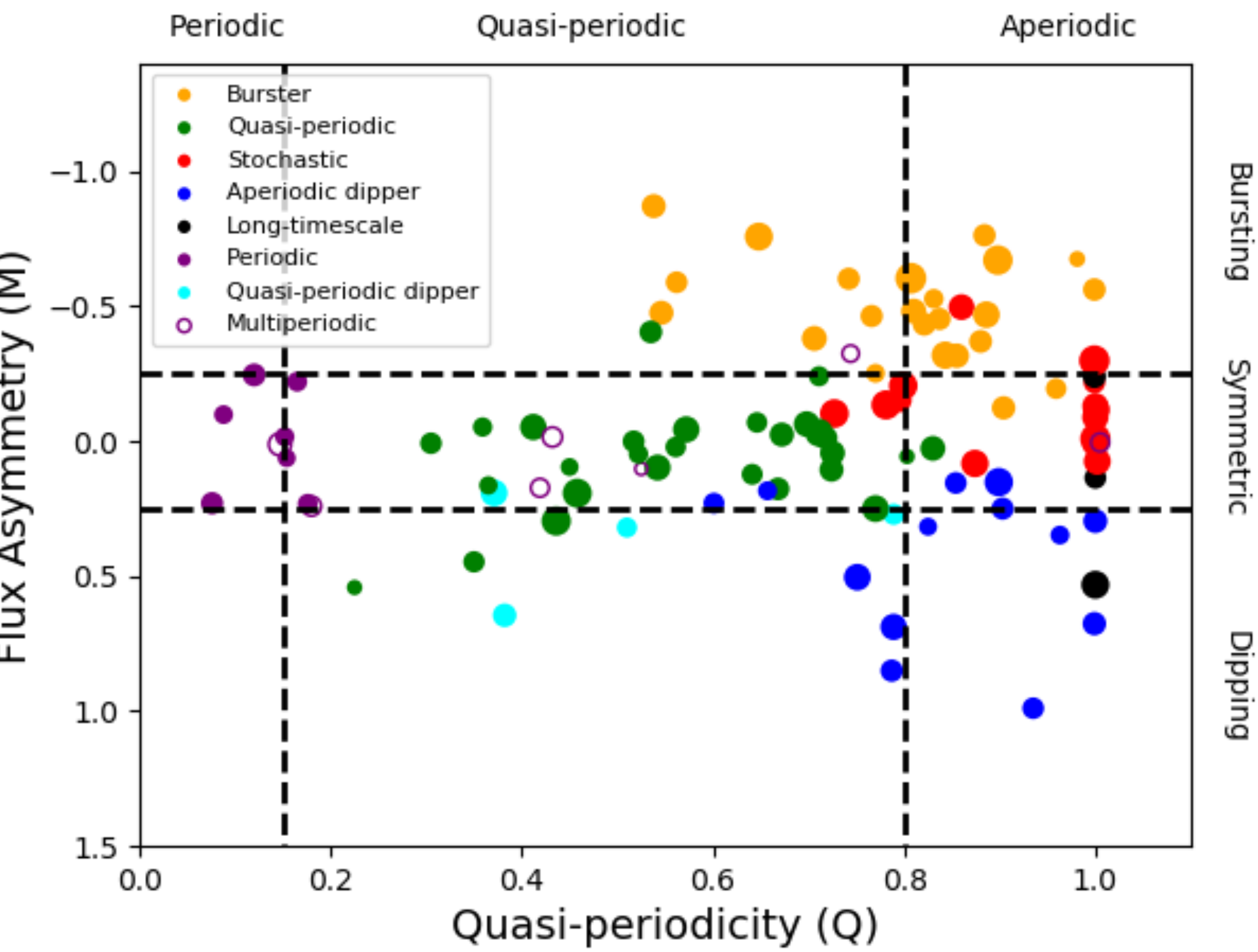
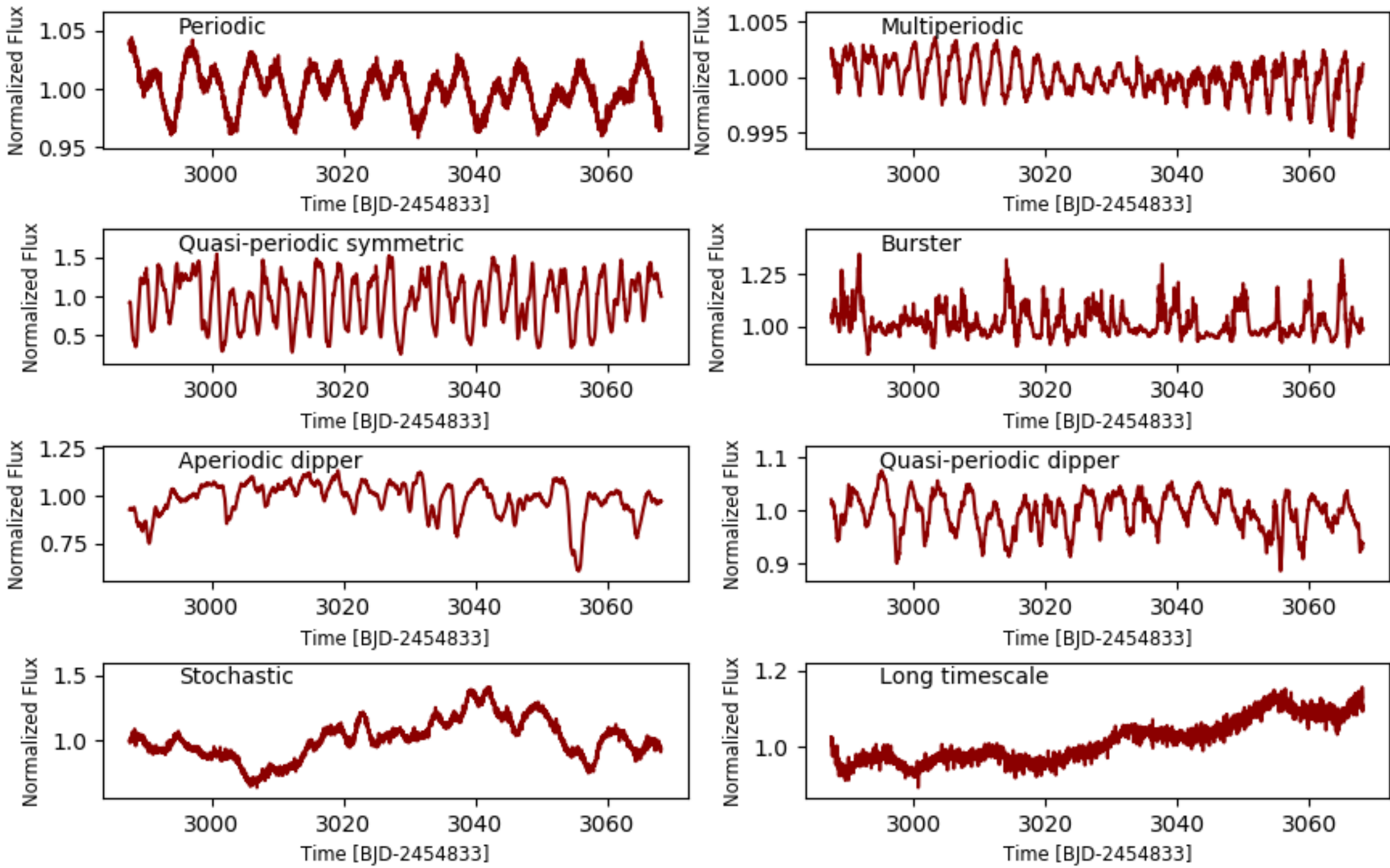
The *Kepler* Space Telescope observed Taurus as part of its 4th and 13th K2 Campaigns from 2015 7 February to 23 April and 2017 March 8 to May 27, respectively. While many of the stars were included deliberately as known members from the literature, a handful of previously unknown young stars also fell within the field of view. We referred to the analysis performed in Rebull et al. (2020) to assess the entire K2 Campaigns 4 and 13 datasets for likely Taurus members based on stellar colors, magnitudes, parallaxes, and proper motions. Our principal interest here is the variability of disk-bearing stars, so we retained only those sources reported by Rebull et al. (2020) to have infrared excesses indicative of circumstellar dust. This resulted in a final sample of 101 disk-bearing stars in Taurus observed as part of K2. Their spectral types are primarily K and M; hence, stellar masses are mostly sub-solar.

Variability Types in Taurus

As was done for previous work on the Upper Scorpius region and ρ Ophiuchus and NGC 2264 clusters, we classified the set of light curves into eight distinctive morphology types:

- Periodic variables
- Multi-periodic variables
- Bursters
- Quasi-periodic dippers
- Aperiodic dippers
- Quasi-periodic symmetric variables
- Stochastic
- Long timescale

Typical behaviors for each of these types are shown at right.



Statistical validation

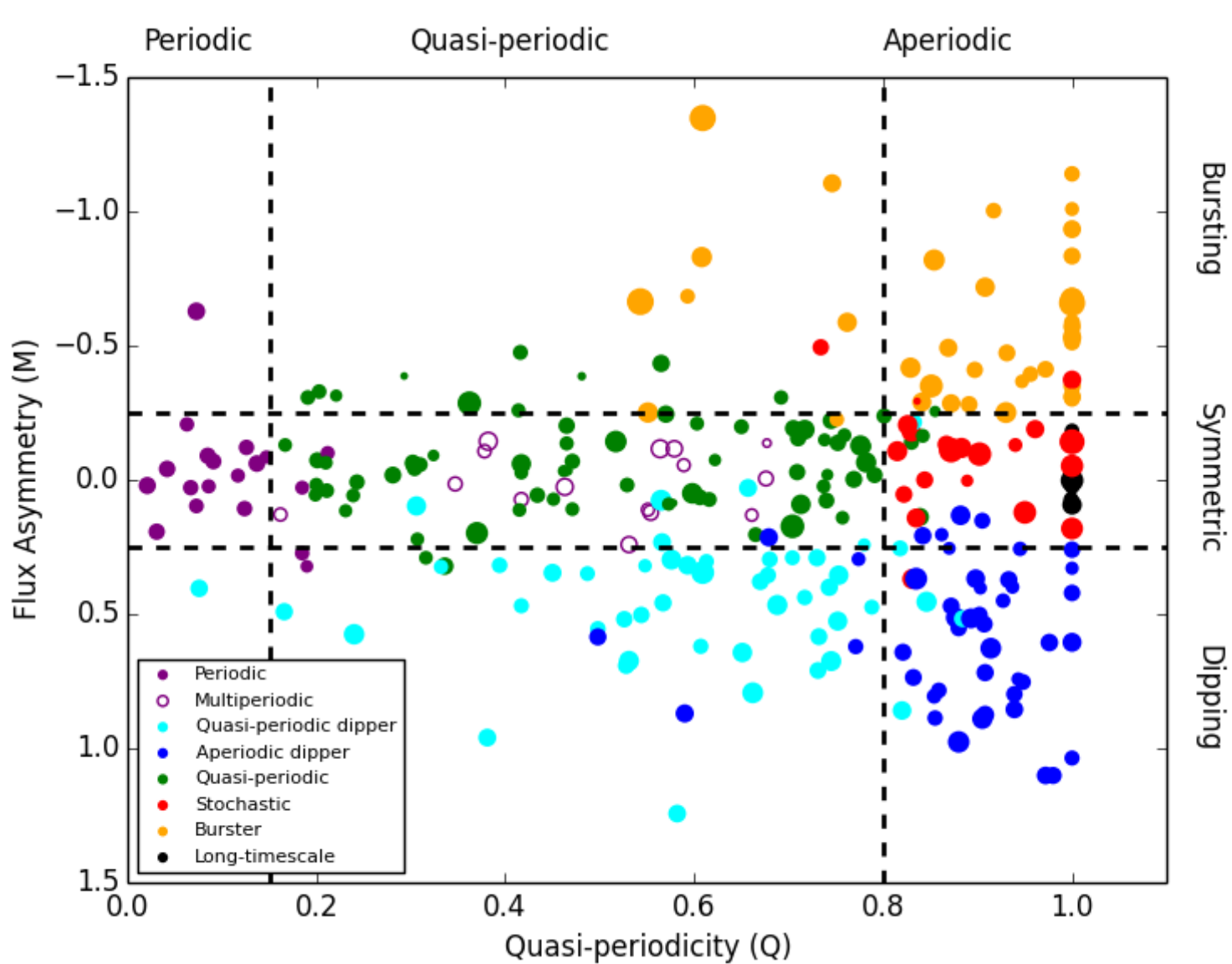
To validate the variability types selected by eye, we developed to statistical parameters, "Q" and "M" (see Cody et al. 2014). The Q parameter indicates whether a light curve is highly periodic (value close to 0), aperiodic (value close to 1), or quasi-periodic midway between 0 and 1. The M parameter is a measure of flux symmetry and is negative when a light curve displays brightening events, or positive when a light curve is dominated by fading (it is close to zero if neither brightening or fading dominates). At left is the Q-M diagram for our Taurus sample, color coded with the by-eye variability classification. Dashed lines indicate numeric boundaries established for the division of our different variability classes; one can see that the light curve morphologies noted by eye match predictions from statistical classification quite well.

Cross-cluster comparison

Having classified the variability seen among low-mass YSOs in Taurus with K2, we are now in a position to compare the fractions of different types with those observed in several other young star regions. We find the following divisions:

VARIABILITY TYPES AMONG YOUNG DISK-BEARING STARS					
Morphology class	Taurus	Oph	Sco	Sco/Oph composite	NGC 2264
	%	%	%	%	%
Categories based on periodicity and stochasticity					
All Bursters	23 ⁺⁴ ₋₄	14 ⁺⁵ ₋₃	13 ⁺³ ₋₃	14 ⁺² ₋₂	13 ⁺³ ₋₃
Aperiodic symmetric (Stochastic)	15 ⁺⁴ ₋₄	12 ⁺³ ₋₃	6 ⁺² ₋₂	8 ⁺² ₋₂	13 ⁺³ ₋₃
Quasi-periodic symmetric	28 ⁺⁵ ₋₅	20 ⁺⁵ ₋₅	29 ⁺³ ₋₃	26 ⁺³ ₋₃	17 ⁺³ ₋₃
Aperiodic dippers	13 ⁺⁴ ₋₄	9 ⁺⁵ ₋₃	18 ⁺³ ₋₃	16 ⁺² ₋₂	11 ⁺³ ₋₃
Quasi-periodic dippers	4 ⁺³ ₋₃	14 ⁺⁵ ₋₃	18 ⁺³ ₋₃	17 ⁺² ₋₂	10.5 ⁺² ₋₂
Periodic symmetric	7 ⁺² ₋₂	6 ⁺² ₋₂	7 ⁺² ₋₂	7 ⁺² ₋₂	3 ⁺² ₋₁
Other Categories					
Multiperiodic	7 ⁺³ ₋₃	7 ⁺⁴ ₋₄	4 ⁺² ₋₂	5 ⁺² ₋₂	1 ⁺² ₋₂
Long timescale	3 ⁺¹ ₋₁	8 ⁺⁴ ₋₄	0 ⁺⁰ ₋₀	3 ⁺¹ ₋₁	1 ⁺² ₋₂
Unclassifiable	0 ⁺⁰ ₋₀	2 ⁺⁰ ₋₀	0 ⁺⁰ ₋₀	1 ⁺¹ ₋₁	11 ⁺² ₋₂
Non-variable	1 ⁺⁰ ₋₀	6 ⁺⁴ ₋₂	3 ⁺¹ ₋₁	4 ⁺¹ ₋₁	19 ⁺³ ₋₃

A lack of quasi-periodic dippers in Taurus?



The most stunning result from the table at left is that there are very few quasi-periodic dippers in the Taurus region, as compared with other young clusters. This type of variability is characterized by repeated fading events which can vary in amplitude and shape from one cycle to the next; it has been attributed to the periodic passage of dusty inner disk material through our line of sight to the central star. The relative lack of dippers in Taurus is borne out in the table at left but also becomes clear when comparing the Q-M plot above with a similar plot for Upper Scorpius and ρ Ophiuchus at left.