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TESS Ultracool Dwarfs 1: Rotation and Flares in Cycle 1 Short Cadence Data

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ABSTRACT

Present initial results from the TESS Ultracool Dwarfs Survey. Includes over 100 objects M6 and later observed in 2-minute cadence. Some awesome rotation periods were found, as well as plenty of flares.

1. INTRODUCTION

- General activity/rotation on ultracool dwarfs: Fully convective, inefficient spin down, Hα emission common, dichotomy between radio-loud auroral stuff and a handful staying on the Geudel-Benz.
- Rotation on ultracool dwarfs: Mid-to late-M dwarfs were found to remain rapid rotators for $\sim$5 Gyr and then spin down very suddenly (Newton et al. 2016). Fast rotators from vsini (Reiners & Basri 2010) and period measurements (Harding et al. 2013). Need TESS data for fast rotators.
- Flares on ultracool dwarfs, including in surveys: History of Hα only flares on ultracool dwarfs during spectroscopic observations (Liebert et al. 1999; Hall 2002; Schmidt et al. 2007). Dedicated monitoring found some of the first white-light flares on the latest M dwarfs, indicating they could flare as strongly as more massive, warmer mid-M dwarfs Rockenfeller et al. (2006); Stelzer et al. (2006). Flare frequency not well-defined for a while, with a contribution from dedicated monitoring from Hilton (2011). With the advent of modern surveys, found evidence of even more powerful white-light flares on late-M (Schmidt et al. 2014b) and (Schmidt et al. 2016) in the All Sky Automated Survey for Supernovae (Shappee et al. 2016, ASAS-SN).
- Surveys and Why TESS is great for this: New way of being able to analyze flares with data from first Kepler and then K2. I don't know what refs there are for late-M's in Kepler, but then there's the white-light flares on the L dwarf (Gizis et al. 2013). Advancing with the Gizis/Paudel K2 work that found white-light flares are common in ultracool dwarfs who found more flares on an L dwarf and also evidence that white-light flares are ubiquitous on the smallest stars and young brown dwarfs (Gizis et al. 2017a,b; Paudel 2017). TESS provides a new opportunity to expand on the K2 results because the all-sky coverage allows observations of the brightest nearby dwarfs, building up a larger sample and a longer total observation time than the K2 observations.
- Grand plans of project and paper outline: We initiated the TESS Ultracool Dwarfs Survey to examine the variability of the M6 and later dwarfs bright enough to be observed by TESS in either 2-minute or 30-minute cadence observations. Here, we examine the short-cadence data from Cycle 1.

2. SAMPLE OVERVIEW

The TESS Ultracool dwarf sample was selected from a variety of literature focused on finding bright, nearby dwarfs with spectral types M6 and later. We restricted our sample to objects with a spectral type of M6 or later, as assigned based on either optical or infrared spectroscopy.

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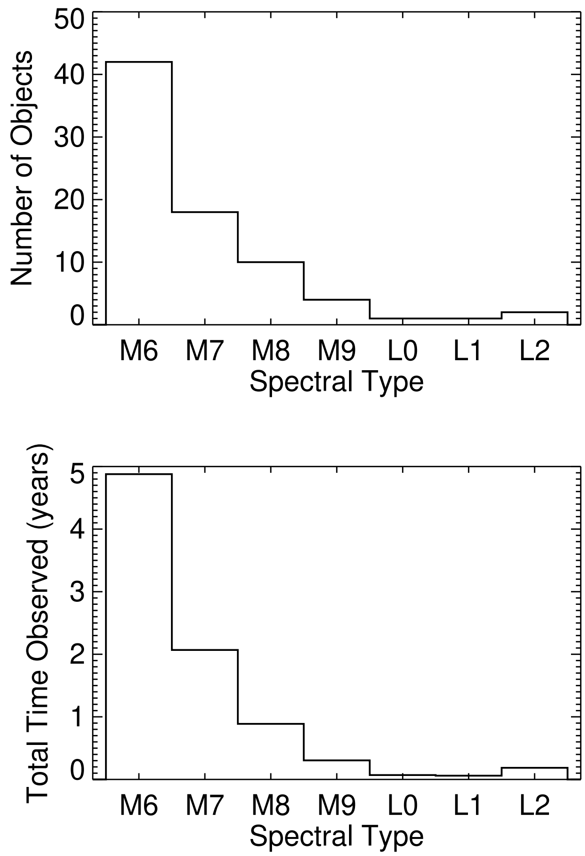

Figure 1. Number of objects (top panel) and total time observed in TESS so far (bottom panel) as a function of spectral type for the TESS UCD cycle 1 short cadence sample. The strong decline, both in number of objects and time observed, is due both to early-type objects being more common and also to the declining brightness with later types.

2.1. *Selection and Properties*

Describe the sources of the sample, and any cleaning/querying that went into the sample.

The TESS magnitudes provided as part of the TIC were not accurate, as they were calculated using a color relation calibrated based on warmer, bluer stars with different spectral energy distributions. We derived a new relationship for TESS magnitudes using the spectrophotometry of ultracool dwarf SEDs, deriving $T - J = 1.386 + 0.145 * ST$, where ST is spectral type with M0 = 0 and L0 = 10. We then limited our sample of objects of $T < 16$ mag and brighter, based on calculations that this would allow us to see variations in brightness at 1-2% and measure rotational modulation in 30-minute cadence data. We further selected a subset of dwarfs with $T < 14.5$ and/or L dwarfs, objects near the ecliptic poles, and particularly active objects to obtain 2-minute cadence observations. Overall, this sample included 375 in cycle 1, of which 120 were requested in short cadence data, and 975 in cycle 2, of which 167 were for short cadence.

Maybe I should describe a Gaia cross-match here? Not sure I've done the whole sample but I should...

2.2. *TESS Observations of Cycle 1 Short Cadence Data*

We requested a total of 120 targets in short cadence data, of which # fell on artifacts or between chip gaps. The # targets observed in Sectors 1-13 This encompasses a total of # targets with # observations. Figure 1 shows the spectral type distribution and total time observed in the sample.

To confirm that the lightcurves were accurately extracted from the target pixel files, we reviewed the aperture placement on the target pixel files (I haven't done them all yet, but I do want to -SJS). For targets where the extraction selected the appropriate source, we adopted the SAP flux from the lightcurve files. For the other targets, we re-extracted the lightcurves from the target pixel files using a magic incantation.

3. ROTATION ANALYSIS

3.1. *Variability amplitudes*

3.2. *LC Morphologies*

4. FLARES IN THE TESS UCD SAMPLE

We identified and found energies for our flares.

4.1. *Flare Finding*

To find flares in the TESS UCD sample, we used the AltaiPony flare finding code (Ilin et al. 2018; Ilin 2019, in prep.). Here, we should describe background fitting, picking out of flares, and measuring of amplitude, duration, and equivalent duration and their associated uncertainties. We also reviewed the flares by eye to confirm that each was a flare. We confirmed a total of # flares on # objects.

The distribution of flares with respect to spectral type is shown in Figure 2. The fraction of objects that flare and the overall flare rate both decline with spectral type. This is in direct contrast to the increase in number of objects showing magnetic activity in the Hα emission line (Schmidt et al. 2015), but may instead trace the well-known decline in strength of that emission line.

White light flares do exist on L dwarfs (Schmidt et al. 2016; Paudel 2017), and may simply be too rare at energies strong enough to be detected in our TESS short cadence sample. With the incomplete dataset, there's 5 sectors on L0 and later. I'd like to be able to say something a little more firm about whether the lack of flares is totally expected or not!

(Schmidt et al. 2015)

Injection recovery, and how that affects our flares and the uncertainties.

4.2. *Flare Energies from Quiescent UCD Luminosities*

To calculate energies for our flares, we multiplied the equivalent duration, measured from the TESS lightcurve, by the quiescent flux in the TESS band. To estimate the quiescent flux, we used spectrophotometry of template spectra of ultracool dwarfs (Bochanski et al. 2007; Schmidt et al. 2014a) combined with spectra from the SpeX library (cite or site or both I forget), anchored to their Gaia magnitudes (Gaia Collaboration et al. 2018).

We obtained updates TESS fluxes and magnitudes. Then calculated TESS luminosities using the distances from Gaia (nearby low uncertainty so 1/parallax is totally fine).

And yes, I should figure out what to do for objects not in Gaia.

4.3. *Flare Frequency distributions*

The flare frequency distribution, binned by spectral type, is shown in Figure 3. Overall, the M6 and M7 dwarfs flare more than those in previous work.

Here, we will probably also talk a lot about the power law fits.

5. SUMMARY/CONCLUSIONS

Facilities:

Software:

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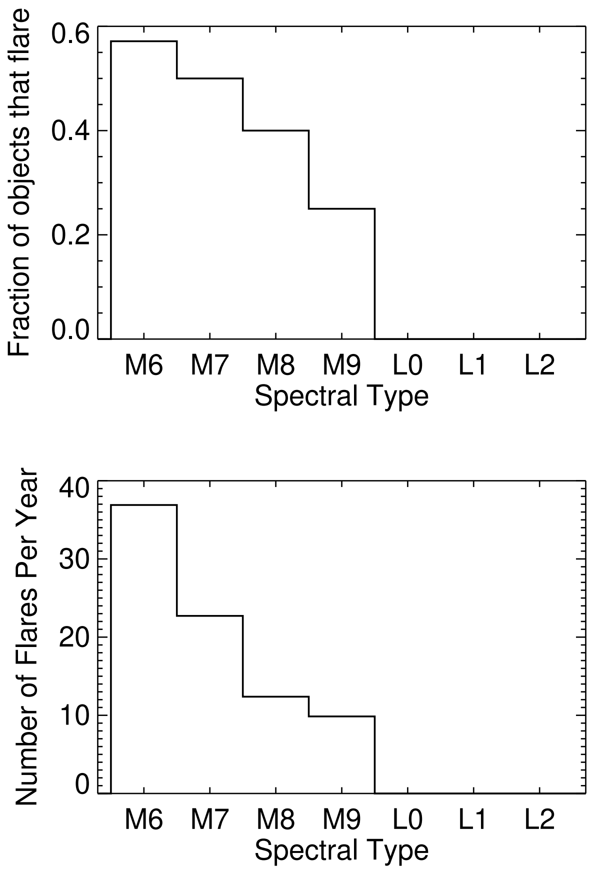

Figure 2. Fraction of objects that flare (top panel) and number of flares per year (bottom panel) in the TESS UCD cycle 1 short cadence sample. The flaring fraction and the rate of flares both show a decline from M6 to L spectral types, with no flares yet found in L0 and later dwarfs.

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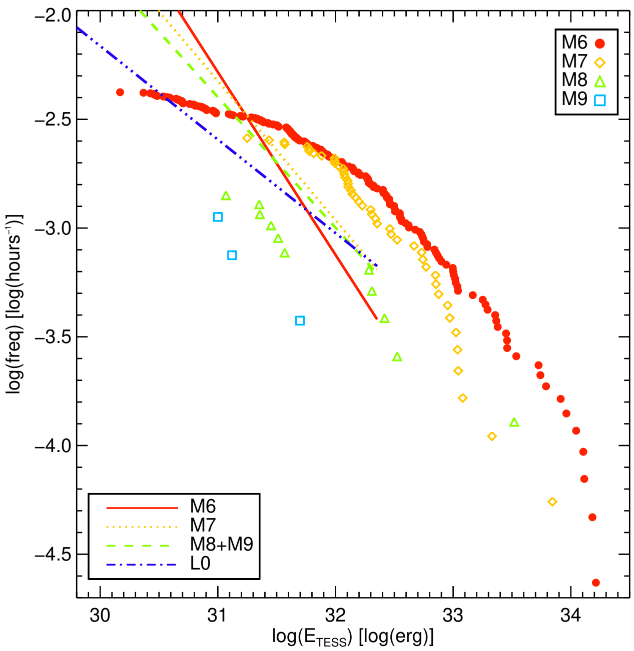

Figure 3. Log of flare frequency as a function of TESS band flare energy for the TESS Cycle 1 short cadence sample (individual symbols) and the K2 ultracool dwarfs of Paudel (2017). The TESS observations overall extend to lower frequencies and higher energies due to the larger total observing time. The M6 and M7 dwarfs in TESS flare more strongly and frequently than those of K2, though the M8 and M9 dwarfs show only a handful of flares at lower energies and frequencies of K2.