A Survey of Planet Populations in the TESS Continuous Viewing Zone

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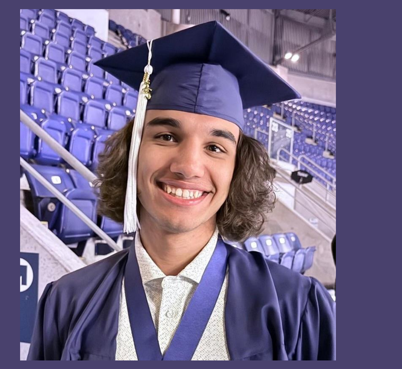
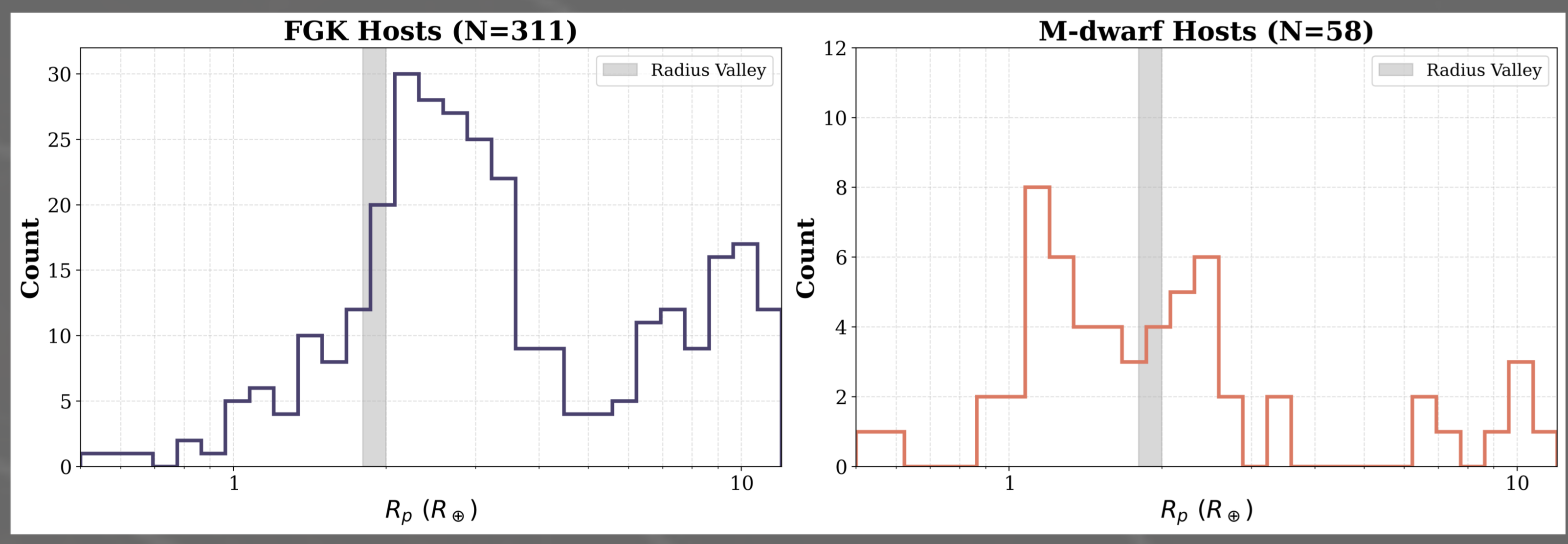


Motivation: We are conducting an exoplanetary survey of the Northern Continuous Viewing Zone (CVZ) from TESS. We plan to use this uniform search of the CVZ to compare TESS's planet population to that of Kepler and K2. This work focuses on searching for planets around the 1.6 million stars in the Primary Mission (PM; 30-min cadence) and Extended Mission 1 (EM1; 10-min cadence) Full Frame Images (FFIs).

Stellar Sample: We start by creating a uniform catalog of stellar parameters (T_{eff}, L_*, R_*, M_*) for all stars in the sample that are brighter than 16th Tmag using Gaia and 2MASS, following the methodology in Hardegree-Ullman et al. 2023 [1]. The same stellar characterization is currently being worked on for the Southern CVZ.

TOI Sample: Using the TESS data from the CVZ provides long baseline data that stretches from 10 months to 1 year. This allows us to find multiple transits of planets <180 days (assuming two transits per planet). There are currently a list of 220 TOIs in the Northern sample and 149 TOIs in the Southern sample.



Our TESS-CVZ Pipeline

Download TESS-SPOC FFI Light Curves [2] → Detrend using a wotan-defined biweight model [3] → BLS Period Search Using GERBLS (SNR > 6) [4] → Fit for a Planetary Parameters using EXOTIC [5]

Threshold Crossing Events (TCEs)

False Alarm Tests

1.) SNR Test Model Fit Test
2.) Sine Wave Event Evaluation Test (SWEET)
3.) Unphysical Transit Duration Tests
4.) Transit Asymmetry Test
5.) Depth Mean-to-Median (DMM) Ratio Test
6.) SNR Consistency Tests 7.) Chases Test
8.) Uniqueness Tests 9.) Transit Shape Test
10.) Single Event Domination Test
11.) Data Gap Test 12.) Individual Transit Tests

False Positive Tests

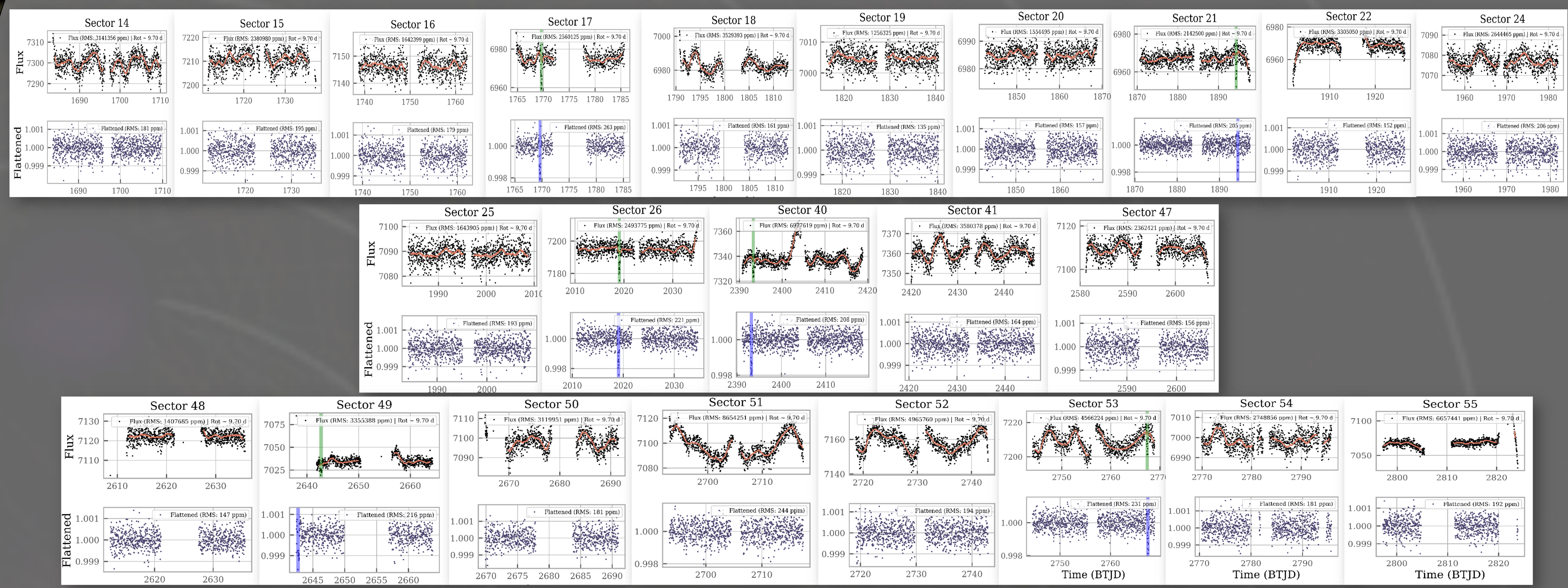
1.) Candidate Size Test
2.) V-Shaped Test
3.) Significant Secondary Test
4.) Odd-Even Test
5.) Centroid Offset Test

Validation with triceratops [7]

Objects of Interest

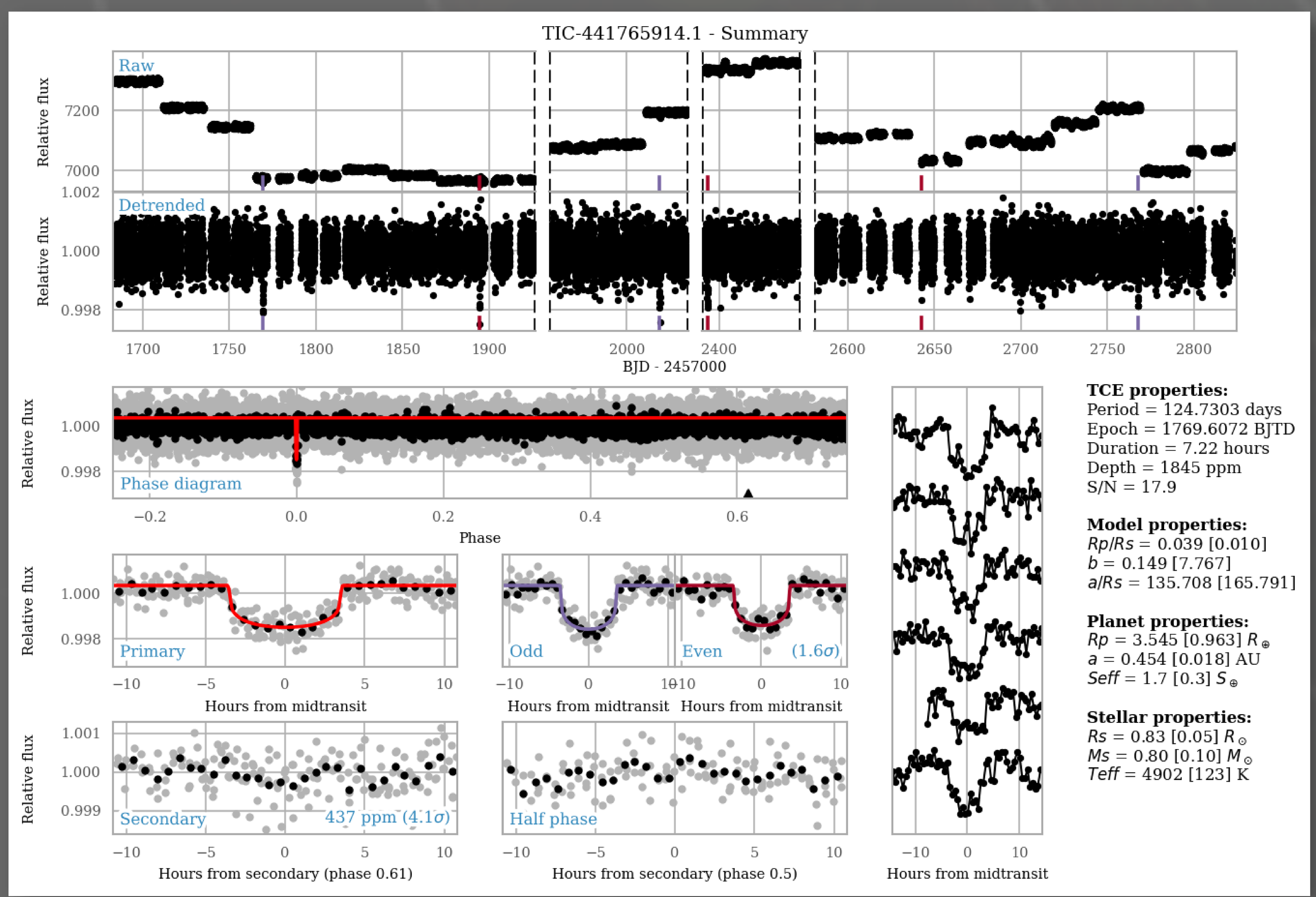
Planet Candidates | Astrophysical False Positives

TOI Light Curve Detrending and Search



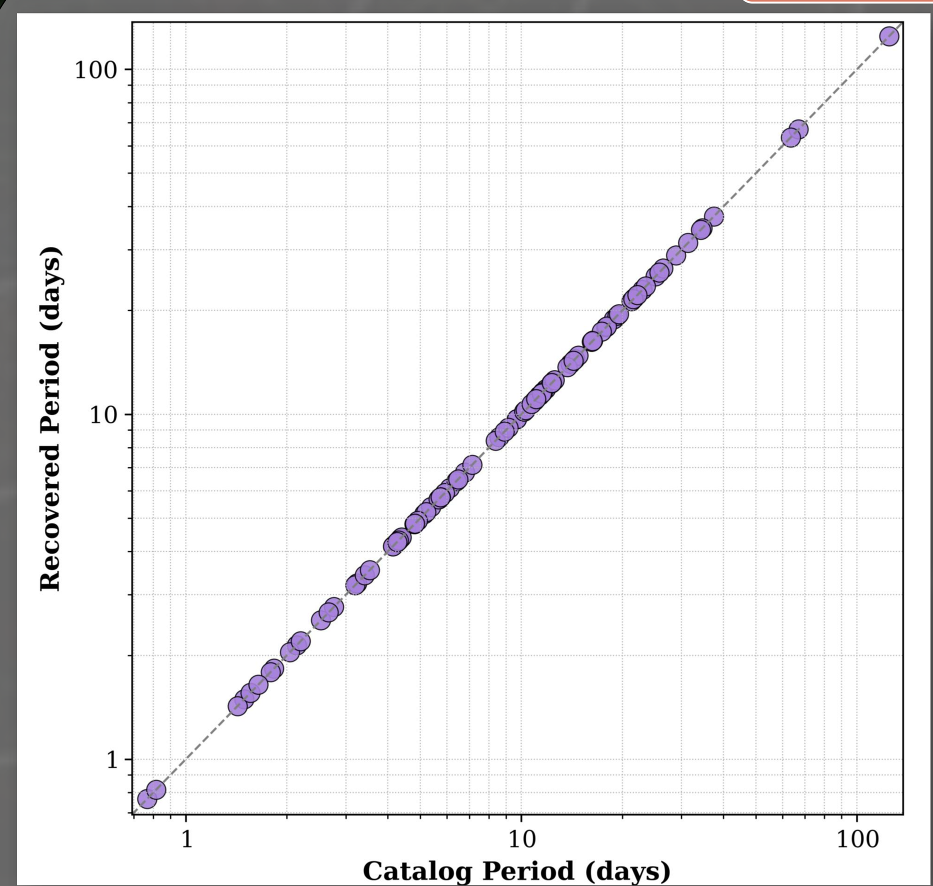
As an example of our planet search procedure, we analyzed TOI 2088, a 3.5 $R_\oplus$ Neptune-sized planet candidate with a period of 124.73 days. Above are the detrended light curves for each sector of TESS's PM and EM1 data for this target. We applied a biweight filter from the wotan package [3] with a window length of 0.5 days, as it recovers the most TOIs in our North CVZ sample without over-detrending. We then pass it through the GERBLS Python package's fast folding BLS algorithm, allowing us to fit hundreds of thousands of periods in seconds [4]. We then pass the period, semimajor axis, and planet radius from the BLS fit as priors for the EXOTIC planetary parameter fitting Python package [5].

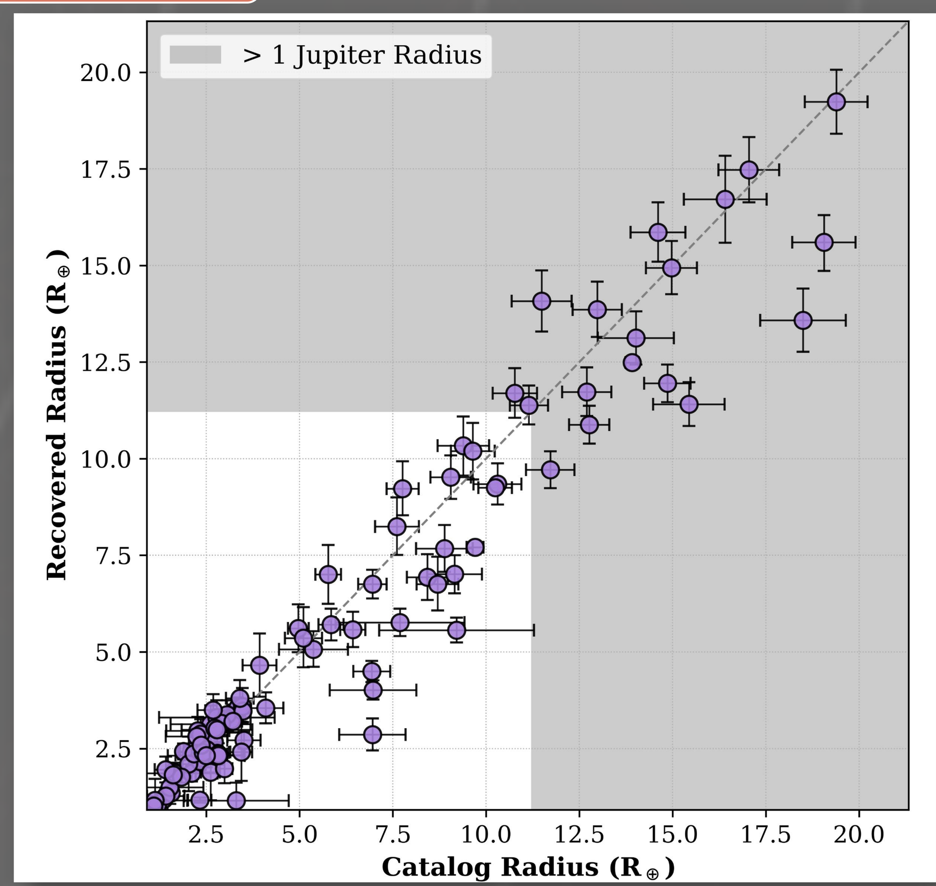
TOI Vetting



Following the derivation of the transit parameters, we pass the planet period, epoch, and duration to the LEOVetter Python package [6]. This will vet the signal by determining if it is a false alarm, a false positive, or an object of interest. Following this, we statistically validate the planet candidate signal by transit shape modeling using triceratops to determine if the signal is a real planet candidate or an astrophysical false positive [7]. Using our fully automated pipeline, we can exactly recover both the orbital period and radius of TOI 2088.

TOI Search Results





We tested 163 TOI Planet Candidates (PCs), 18 TOI Confirmed Planets (CPs), and 34 TOI False Alarms (FAs) or False Positives (FPs) in the Northern CVZ, plotted above. We can recover most known TOIs; however, we cannot recover those with "bad" data, i.e., riddled with TESS systematics. For multi-planet systems, we can recover at least the planet with the strongest signal. During the search, we do not treat known astrophysical FPs differently as they appear like planetary transits and are successfully recognized as FPs during the vetting and validation stage.

Future Work: Now that our pipeline has been tested on known TOIs, we will conduct a blind search on the combined PM and EM1 data for the 1.6 million stars in the northern hemisphere to produce a uniformly vetted and validated sample of planet candidates in the Northern CVZ (Hotnisky et al., in prep). Future work will include expanding to the southern hemisphere; using the pipeline and a homogeneous catalog of stars and planets, performing a demographic analysis of both short- and long-period planet populations, with comparisons to those discovered by Kepler.

References:

[1] Kevin K. Hardegree-Ullman et al., The Astronomical Journal 165 (June 1, 2023): 267, https://doi.org/10.3847/1538-3881/acd1ec.
[2] Douglas A. Caldwell et al., Research Notes of the American Astronomical Society 4, no. 11 (November 2020): 201, https://doi.org/10.3847/2515-5172/abc9b3.
[3] Michael Hippke et al., The Astronomical Journal 158 (October 1, 2019): 143, https://doi.org/10.3847/1538-3881/ab3984.
[4] Kristo Ment et al., In Prep
[5] Robert T. Zellem et al., Publications of the Astronomical Society of the Pacific 132, no. 1011 (May 2020): 054401, https://doi.org/10.1088/1538-3873/ab7ee7.
[6] Michelle Kunimoto et al. Submitted
[7] Rachel B. Fernandes et al., The Astronomical Journal 164 (September 1, 2022): 78, https://doi.org/10.3847/1538-3881/ac7b29.

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