Searching for GEMS: TOI-5916 b & TOI-6158 b are two Saturn-density planets orbiting M2 dwarfs

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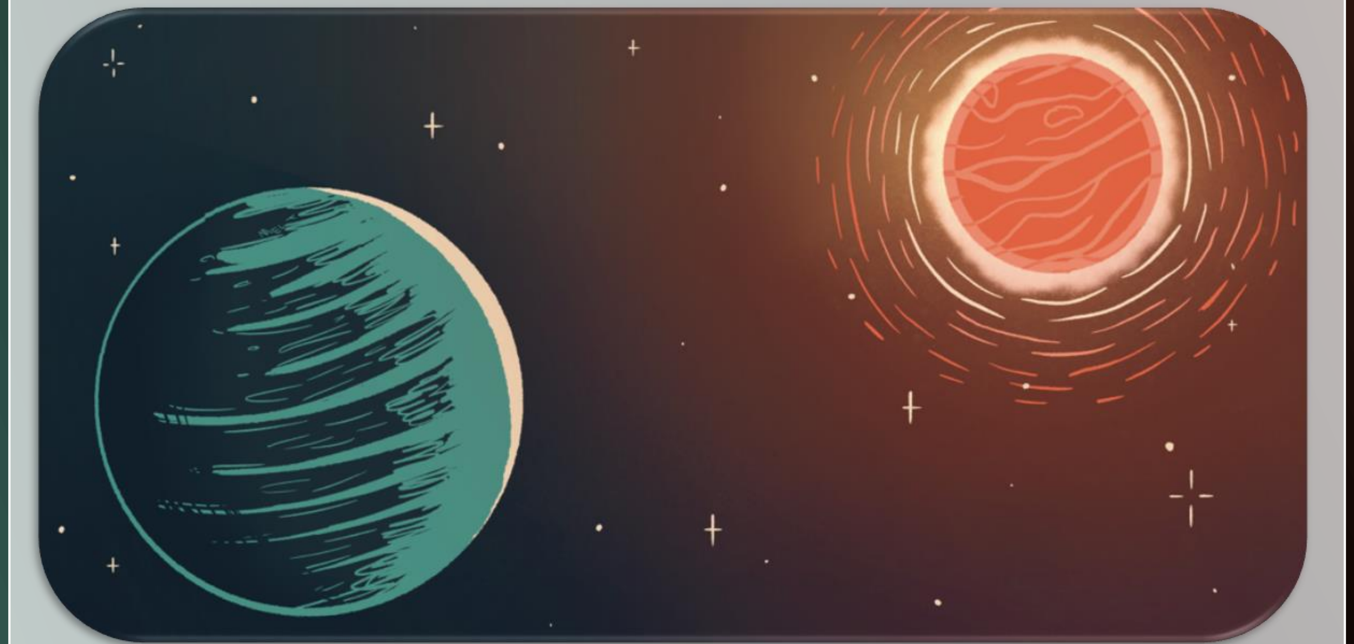
What are GEMS?

- Giant Exoplanets around M dwarf Stars (GEMS) are a class of extra-solar planets with radii of about 0.7 to 1.3 times that of Jupiter (or about 8 to 15 times the radius of the Earth) that orbit M dwarf stars
- M dwarf stars are small, low temperature stars between 0.08 and 0.6 times the size of our Sun and temperatures between 2,600K and 4,000K (where the Sun is about 5,700K), giving them a reddish hue
- Due to their small size and low temperatures, such stars should theoretically lack the required material to form planets and struggle to do so



(Illustration of a GEMS system)

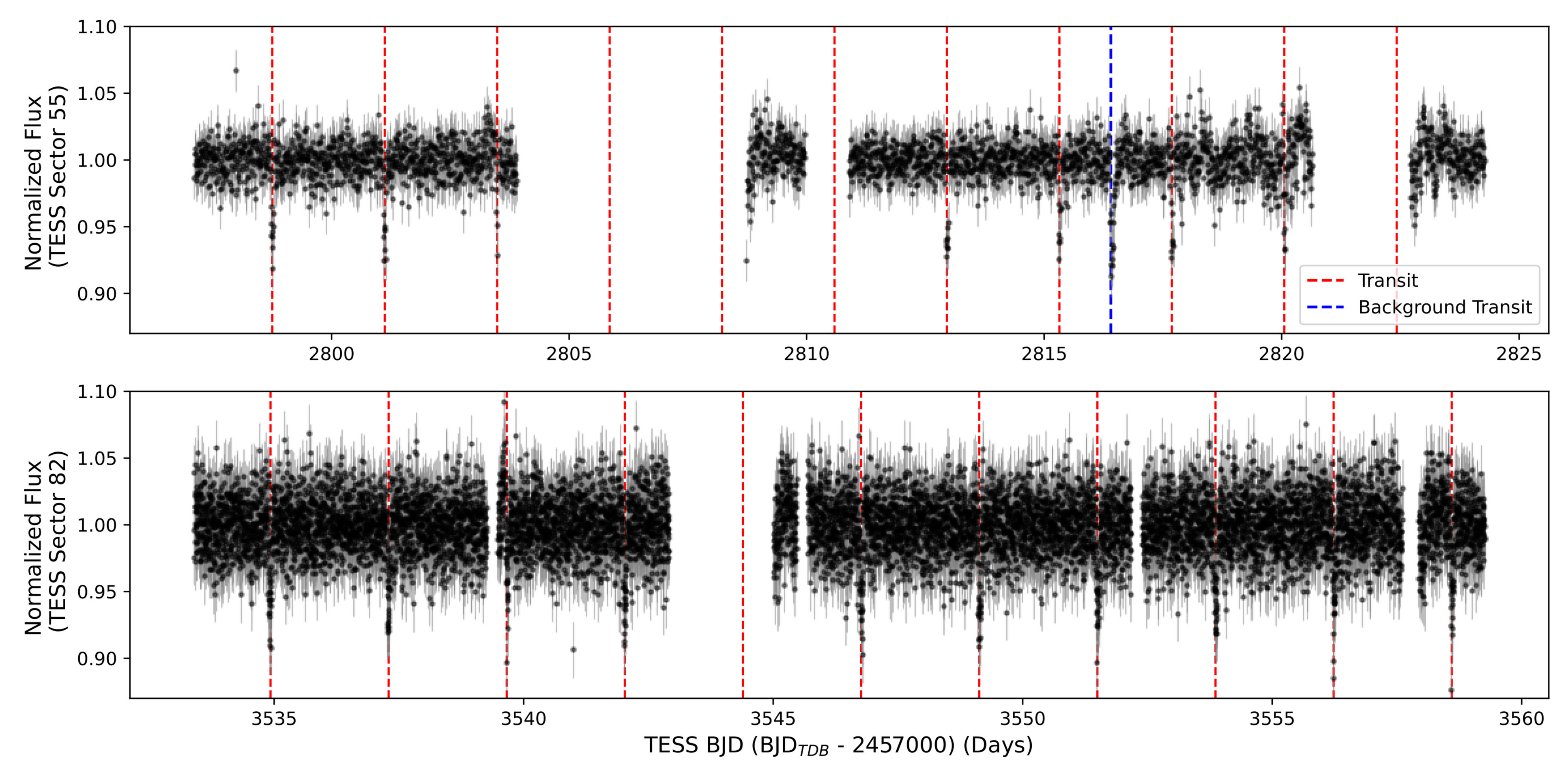
- Despite this, the amount of GEMS systems that have been detected defy the occurrence rate predictions of GEMS
- **Investigating and characterizing more of these GEMS systems can help us to understand this discrepancy between occurrence rate and observation, and hopefully give us more insight as to how they come to form**
- The desire to better understand the formation mechanisms of GEMS has led to the *Searching for GEMS* survey, the larger survey of which this project is a part of

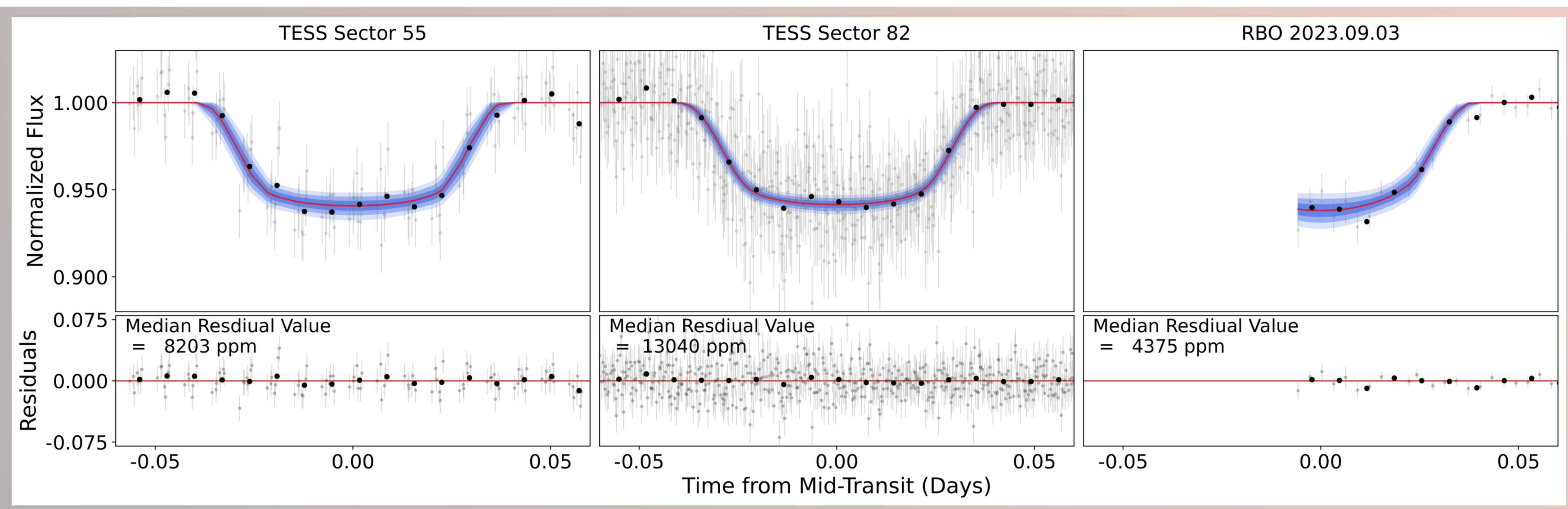
Introduction to this Work:

- In this work, **we confirmed two candidate exoplanet systems** that were first identified by the *Transiting Exoplanet Survey Satellite* (TESS) as objects of interest
- This confirmation was done by comparing data from TESS, the Habitable-zone Planet Finder (HPF) radial velocity (RV) spectrograph, and other ground-based observations
- Their astrophysical parameters were derived through a Bayesian inference pipeline using Markov Chain Monte Carlo (MCMC) sampling
- The resulting parameters were then compared to other GEMS systems as well as some FGK dwarf systems, allowing us to see where our two systems fit amongst similar giant exoplanet systems

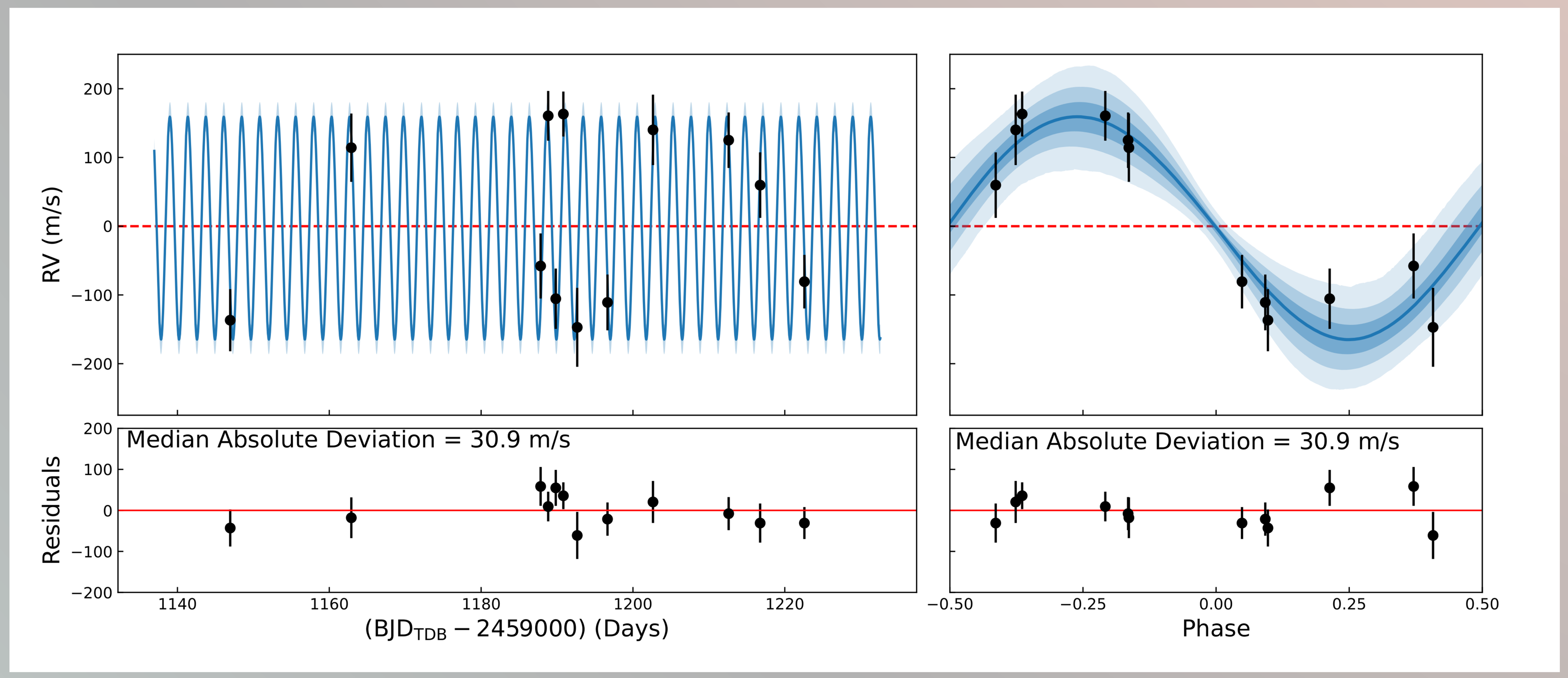
Methods: Detection & Sampling:

- **Transit Detection via TESS & Ground-Based Sources:**
  - When exoplanets cross in front of their host star, the resulting dip in brightness can be detected by instruments like TESS, which we can then compare with other ground-based telescope sources to further verify





- **Radial Velocity Measurements via HPF:**
  - By analyzing the spectrum of light from the host star, instruments like HPF can see periodic shifts in the wavelength of light due to the planet's gravitational pull on the host star, giving us further evidence of the presence of an exoplanet



- **Bayesian Inference via MCMC Sampling (Joint-Fitting):**
  - Once we have both transit and RV data, we put it through a data pipeline that derives a set of parameters for each system
  - Our pipeline does this by taking in the observed prior data and outputting a posterior set of parameters that give us some further insight into our targets

Results: Planetary & Stellar Parameters:

- Through use of our joint-fitting pipeline, and with stellar spectrum analysis, we were able to derive a set of astrophysical parameters for both planets as well as their host stars:

Table 1. Summary of Parameters for TOI-5916 b & TOI-6158 b.

Parameter	Description	TOI-5916 b	TOI-6158 b
Orbital Parameters:			
P	Orbital Period (Days)	$2.36712341^{+0.0000033}_{-0.0000032}$	$3.04468990^{+0.00000551}_{-0.00000534}$
e	Eccentricity	$0.045^{+0.050}_{-0.032}$	$0.059^{+0.066}_{-0.042}$
ω	Argument of Periastron (Degrees)	-81^{+190}_{-68}	88^{+57}_{-148}
K	Semi-amplitude Velocity (m/s)	164 ± 20	95 ± 13
$\sigma_{\rm HPF}$	RV Jitter (m/s)	19^{+20}_{-13}	32 ± 12
Transit Parameters:			
T_C	Transit Midpoint ($BJD_{\rm TDB}$)	2459817.6882 ± 0.0008	2459826.8508 ± 0.0008
$R_p/R_\star$	Scaled Radius	$0.2213^{+0.0080}_{-0.0080}$	$0.2017^{+0.0510}_{-0.0210}$
$a/R_\star$	Scaled Semi-major Axis	$12.23^{+0.35}_{-0.32}$	$14.84^{+0.35}_{-0.36}$
i	Orbital Inclination (Degrees)	$89.13^{+0.60}_{-0.69}$	$86.51^{+0.25}_{-0.32}$
b	Impact Parameter	$0.19^{+0.15}_{-0.13}$	$0.86^{+0.09}_{-0.06}$
T_{14}	Transit Duration (Days)	$0.0740^{+0.0020}_{-0.0024}$	$0.0551^{+0.0030}_{-0.0022}$
Planetary Parameters:			
M_p	Mass ($M_\oplus$)	219 ± 28	135^{+19}_{-18}
	Mass ($M_{\rm J}$)	$0.688^{+0.087}_{-0.088}$	$0.425^{+0.060}_{-0.058}$
R_p	Radius ($R_\oplus$)	$11.8^{+0.52}_{-0.51}$	$10.4^{+2.70}_{-1.11}$
	Radius ($R_{\rm J}$)	1.05 ± 0.05	$0.93^{+0.24}_{-0.10}$
ρ_p	Density (g/cm^3)	$0.73^{+0.14}_{-0.13}$	$0.66^{+0.41}_{-0.23}$
a	Semi-major Axis (AU)	0.02789 ± 0.00040	0.03275 ± 0.00040
S	Planetary Insolation ($S_\oplus$)	43.8 ± 3.8	27.3 ± 2.2
$T_{\rm eq}$	Equilibrium Temperature (K)	716 ± 15	636 ± 13
$\langle F \rangle$	Average Incident Flux (10^4 W/m^2)	5.10 ± 0.58	3.70 ± 0.41
Host Star Stellar Parameters:			
α	Right Ascension (RA)	21h41m11.88s	22h15m34.66s
δ	Declination (Dec)	+09d35m56.59s	+16d17m07.41s
μ_α	Proper Motion (RA, mas/yr)	-8.933 ± 0.120	62.883 ± 0.118
μ_δ	Proper Motion (Dec, mas/yr)	-25.592 ± 0.127	-35.263 ± 0.117
ϖ	Parallax (mas)	4.98 ± 0.08	5.50 ± 0.11
$A_{\nu,\ \rm max}$	Maximum Visual Extinction	0.030	0.040
$T_{\rm eff}$	Effective Temperature (K)	3541 ± 59	3467 ± 59
[Fe/H]	Metalicity (dex)	0.04 ± 0.16	0.11 ± 0.16
$M_\star$	Mass ($M_\odot$)	0.518 ± 0.023	$0.503^{+0.022}_{-0.023}$
$R_\star$	Radius ($R_\odot$)	$0.487^{+0.013}_{-0.012}$	$0.476^{+0.013}_{-0.013}$
$L_\star$	Luminosity ($L_\odot$)	0.0349 ± 0.001	$0.03082^{+0.001}_{-0.00099}$
$\rho_\star$	Density (g/cm^3)	$6.17^{+0.54}_{-0.48}$	$6.66^{+0.49}_{-0.47}$
A_ν	Visual Extinction (mag)	0.014 ± 0.01	$0.018^{+0.014}_{-0.013}$
d	Distance (pc)	196 ± 1.6	$181.6^{+2.2}_{-2.1}$

NOTE—An albedo of 0 is assumed

Conclusion:

- We have confirmed that TOI-5916 b and TOI-6158 b are indeed two new GEMS exoplanet systems that appear to add to a growing trend that GEMS systems exhibit Saturn-like densities
- Through confirming these two new GEMS systems, we helped strengthen the notion that FGK dwarfs and M dwarfs may share a similar formation pathway independent of stellar mass
- Read our pre-print by scanning the QR code!

Acknowledgements:

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