pterodactyls: A Uniform Search for Young Transiting Planets in TESS Primary Mission FFIs

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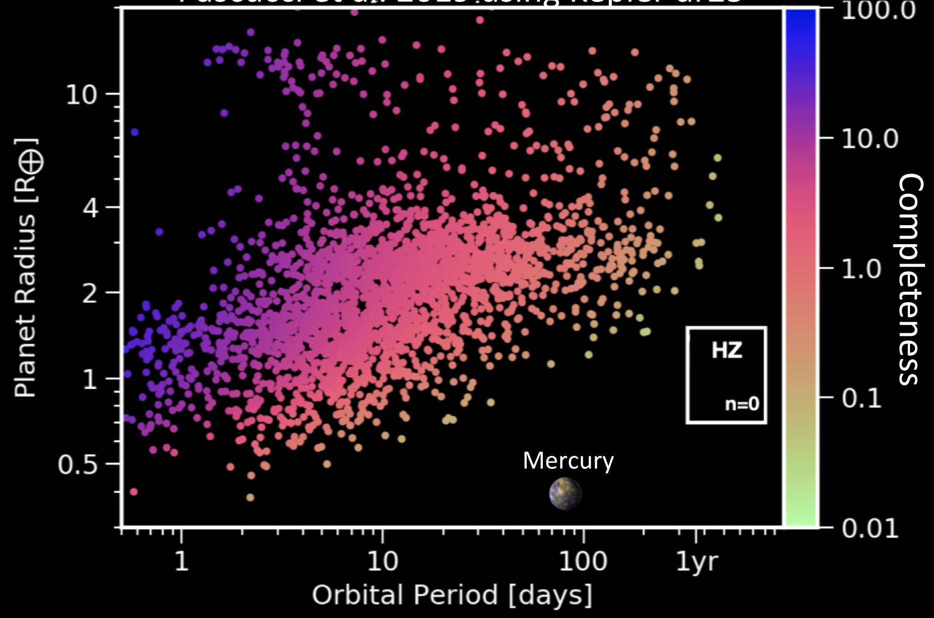
ALIEN EARTHS

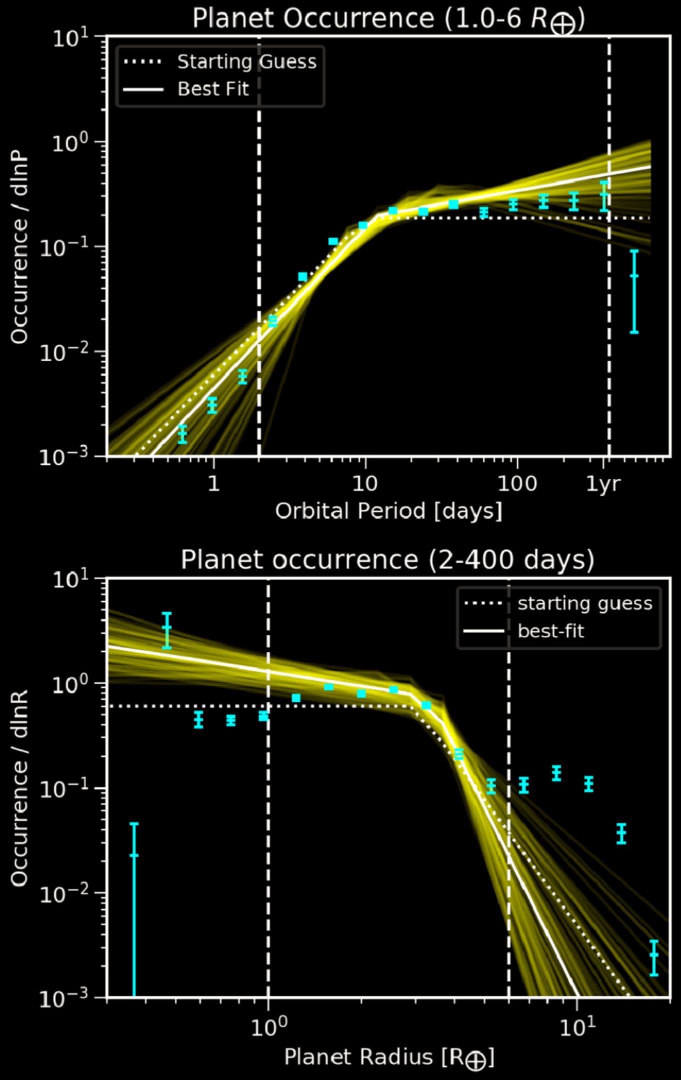
Art: Sam Dietz

The $\eta_\oplus$ Problem

$\eta_\oplus$: the frequency of Earth-sized planets in the Habitable Zone (0.9 – 2.2 $P_\oplus$; 0.7 – 1.5 $R_\oplus$) of a Sun-like star

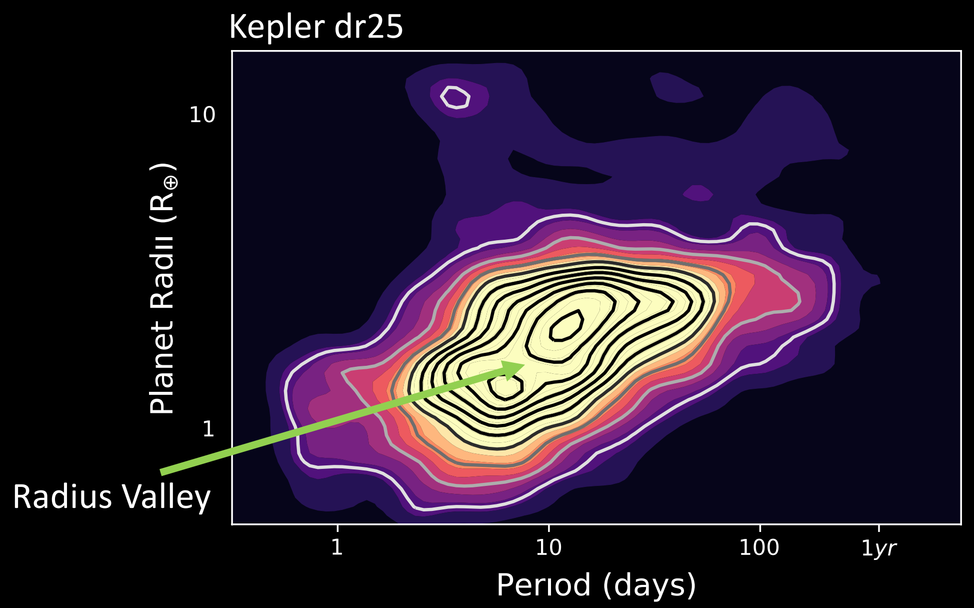
Pascucci et al. 2019 using Kepler dr25

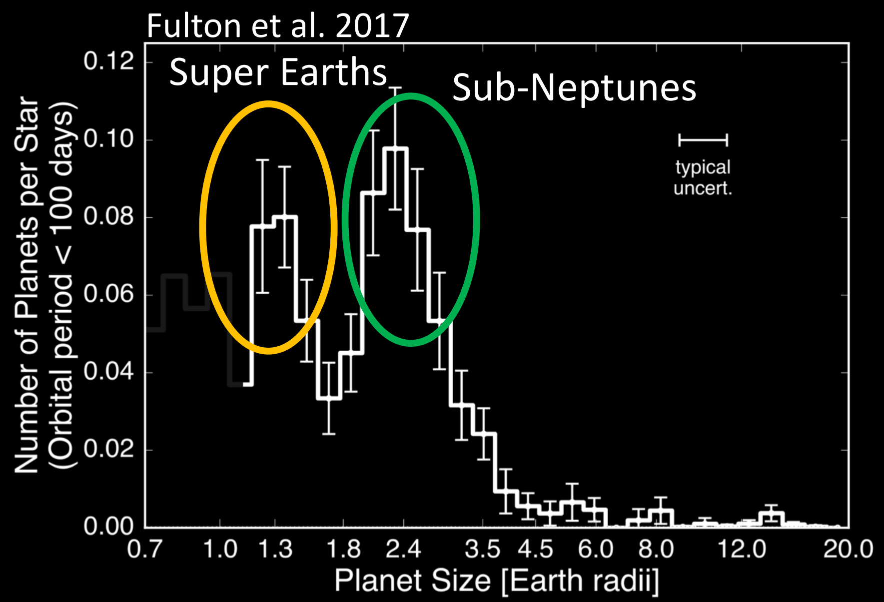




$\eta_\oplus$: 36% (epos; Mulders+ 2018)

The Population of Small, Short-period Planets

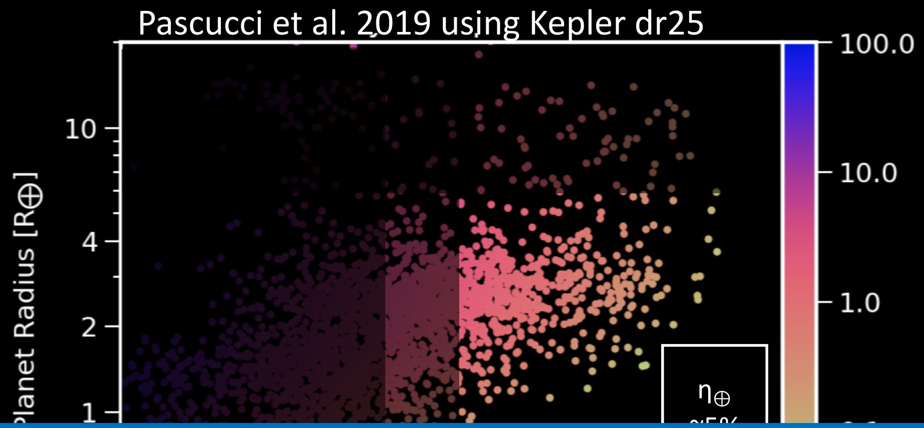




Possible explanations:

- XUV Photoevaporation (Owen+Wu 2013, 2017)
- Core-powered Mass Loss (Gupta+Schlichting 2019, 2020)

Impact of Stripped Cores on $\eta_\oplus$

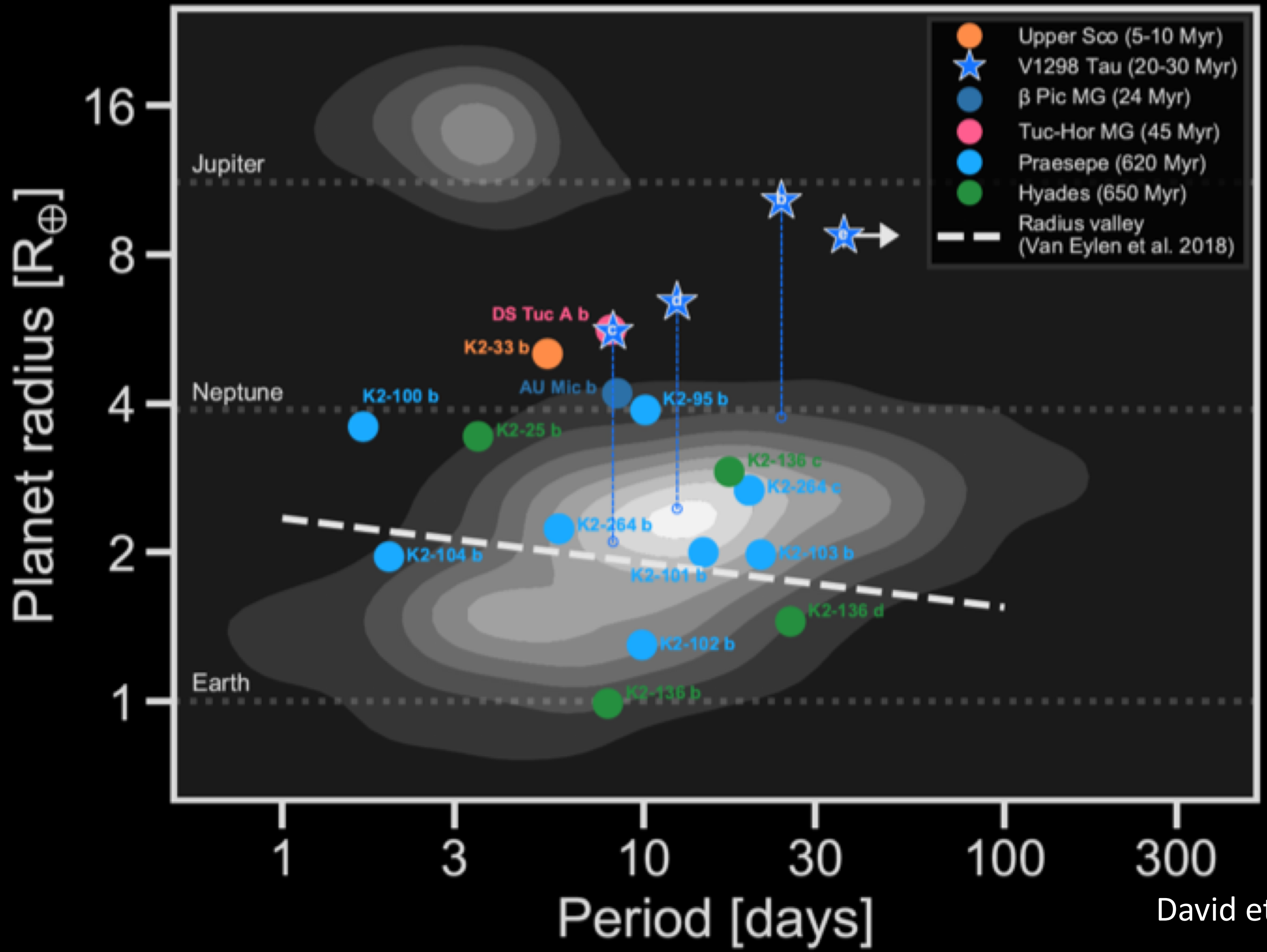


How do we quantify this contamination by the stripped cores of once sub-Neptunes?

The population of short-period small (<1.8 $R_\oplus$) planets maybe contaminated by the stripped cores of once sub-Neptunes and hence is not representative of planets that formed like Earth

The Transiting Exoplanet Sky Satellite (TESS) Mission

Detections of young planets with K2+TESS

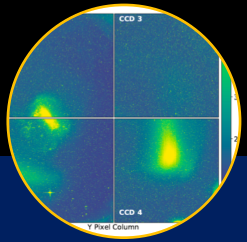


David et al. 2019

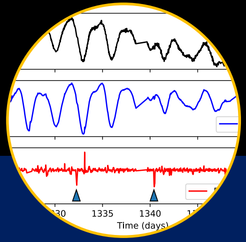
Finding Planet Candidates

pterodactyls

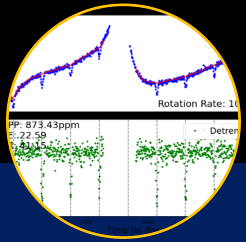
Python Tool for Exoplanets: Really Outstanding Detection and Assessment of Close-in Transits around Young Local Stars



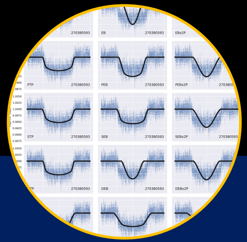
Extract Light Curves from Full Frame Images using eleanor (Feinstein+ 2019)



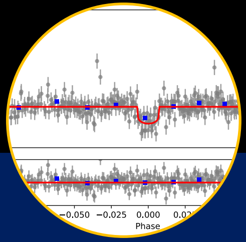
Detrend Light Curves using Wōtan (Hippke+ 2019)



Search for Planets using TLS (Hippke+Heller 2019)



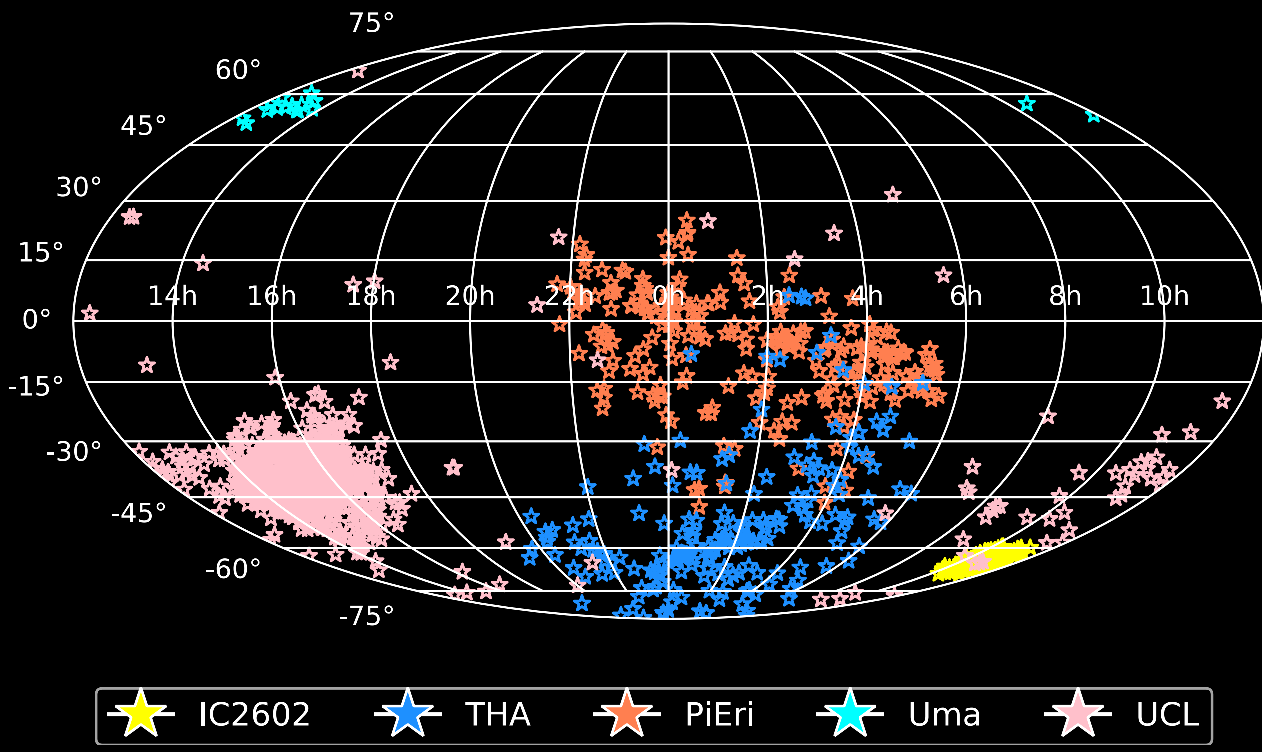
Vet exoplanet candidates using EDI-Vetter and triceratops (Zink et al.; Giacalone et al. 2020)



Fit phase-folded light curve using EXOTIC (Zellem et al. 2020)

Our (Current) Sample of Young Stellar Clusters

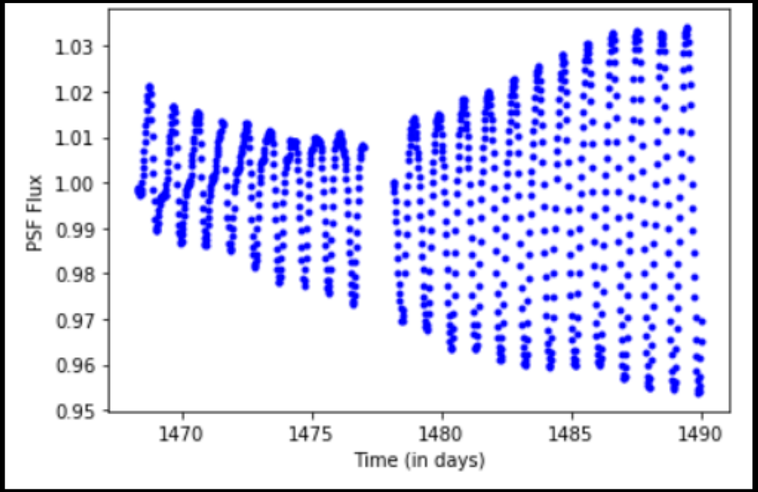
Cluster/Moving Group	Dist (pc)	Age (Myr)	Obs/Total
THA	46^{+8}_{-6}	45 ± 4	201/214
IC 2602	146 ± 5	46^{+6}_{-5}	502/504
UCL	130 ± 20	16 ± 2	719/937
UMa	~25	414 ± 23	16/17
PiEri	80–226	120	153/254

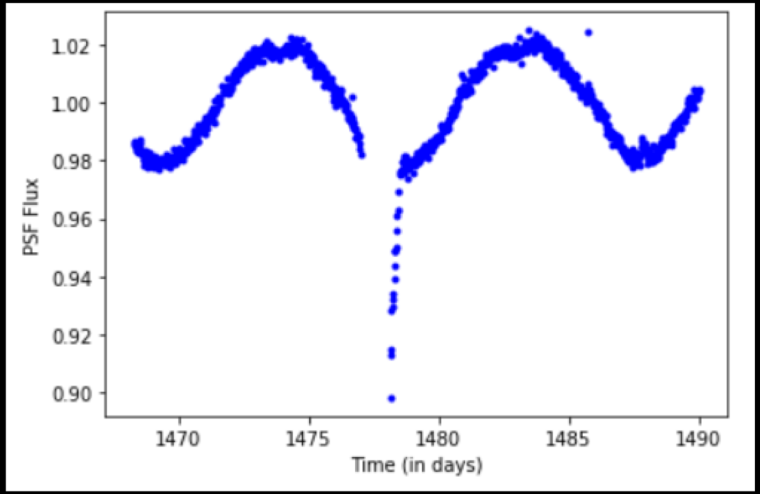


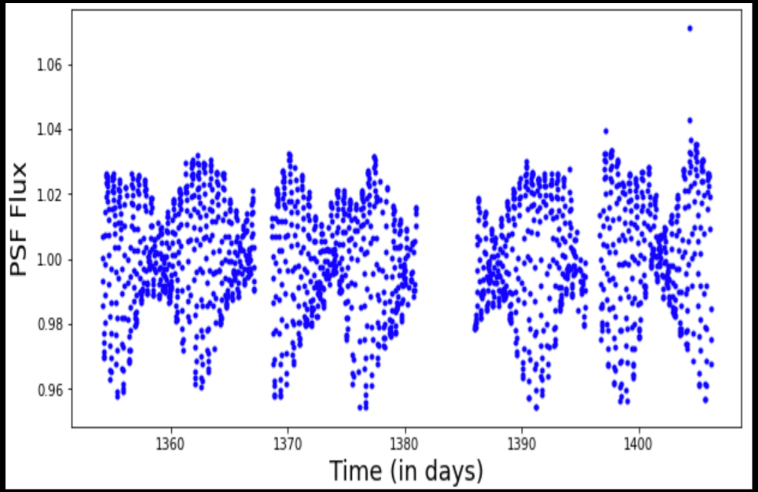
Distance, age, and membership are from

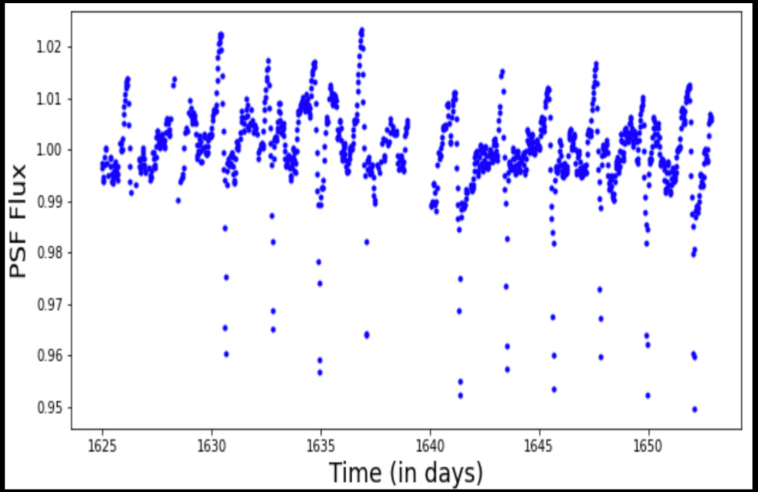
Gagné et al. (2018) and Babusiaux et al. (2018)

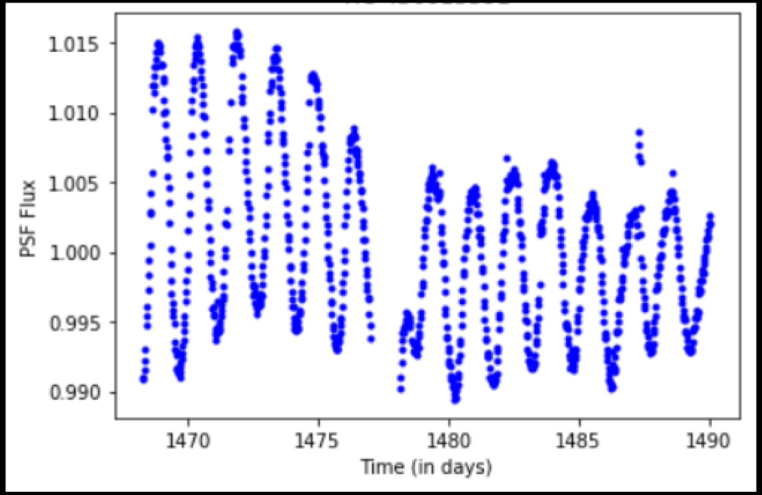
Step 1: Extraction with `eleanor`

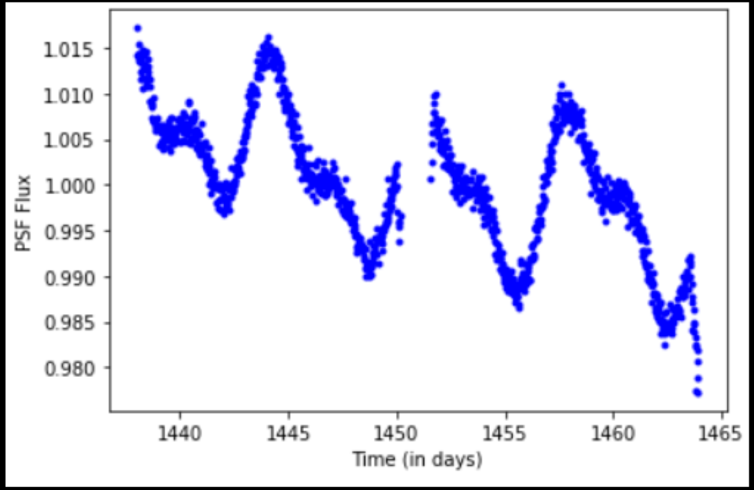




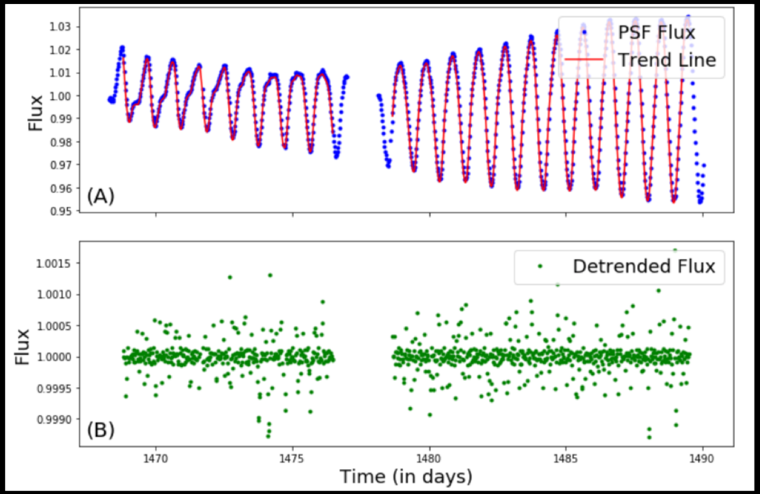


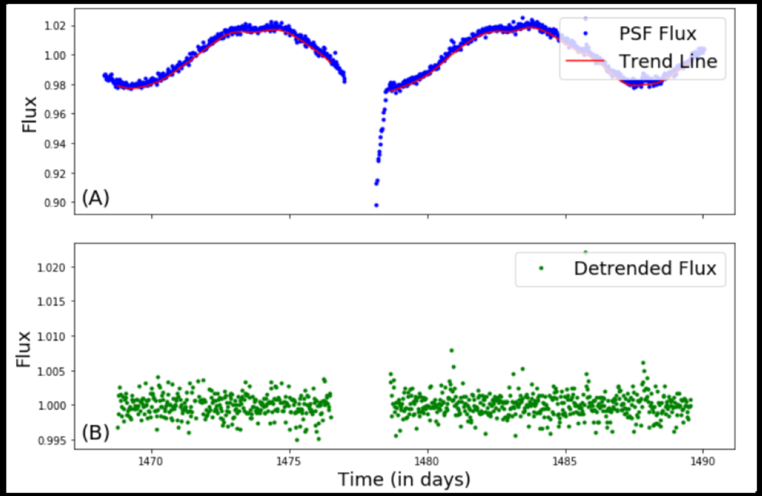


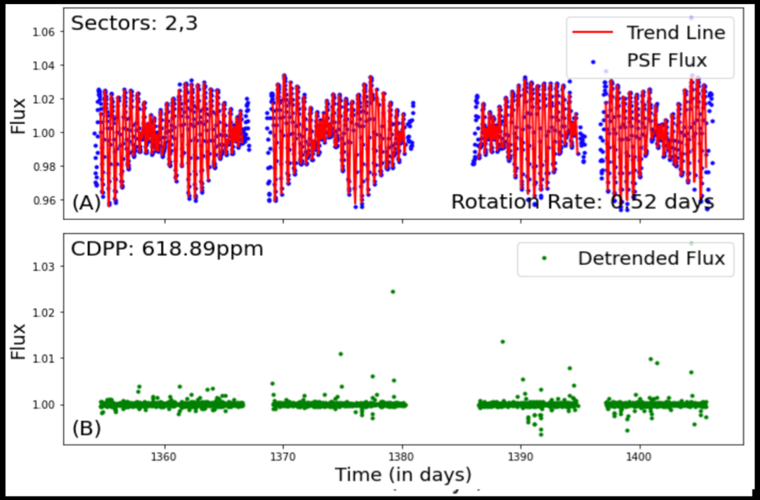




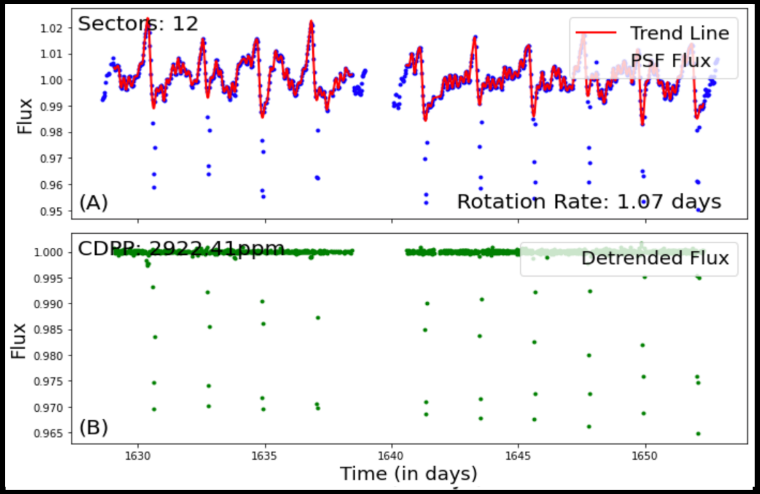
Step 2: Detrending with Wōtan

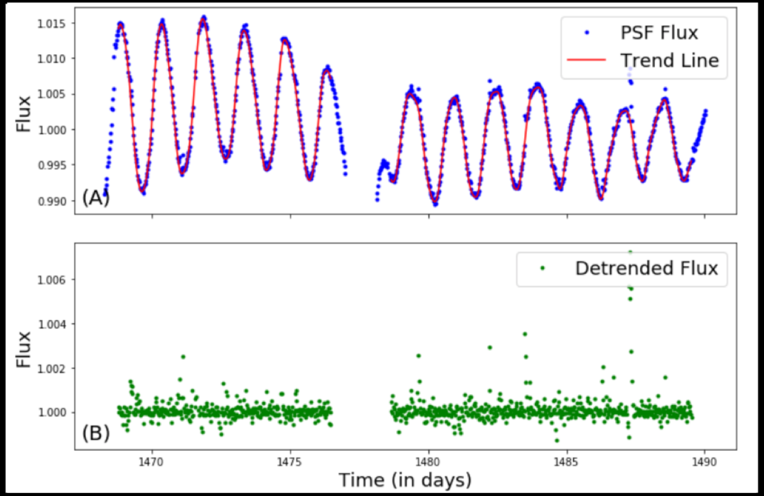


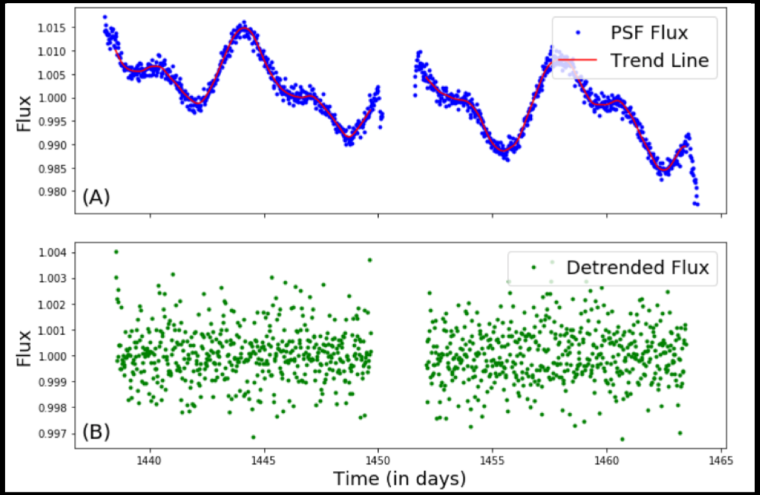




Penalized Spline With Knot Optimization Based on Stellar Rotation Rates







Step 3: Search and Vet Planet Candidates

- Search: SDE > 7; snr >7 with `transitleastsquares` (TLS)

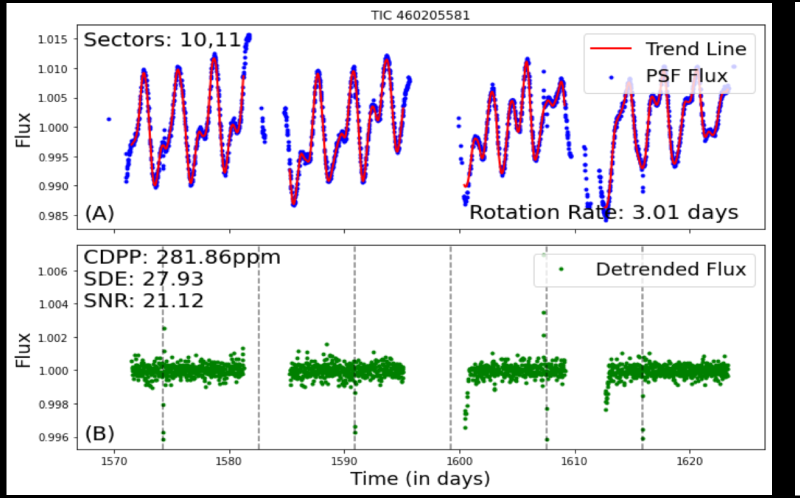
- Vetting:

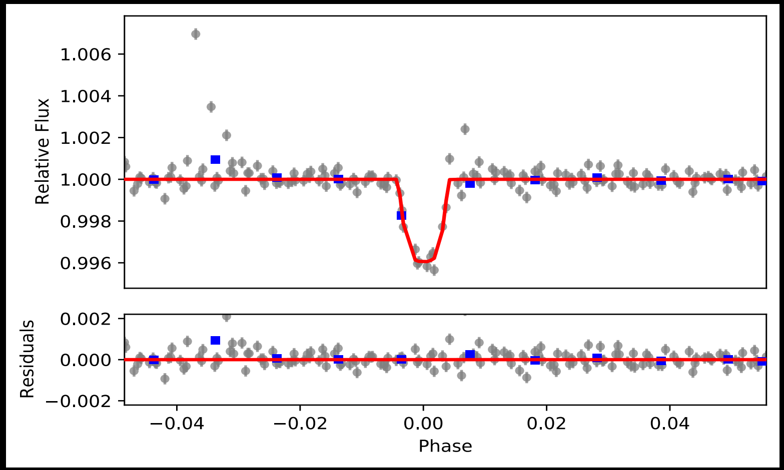
Orbital Period $\not\approx$ stellar rotation rate	At least 2 transits with data	Tdur (obs) ~ Tdur (exp)
Consistency in individual transit depths	Individual Transits > 7 SDE	No secondary transit events at half times the detected period

Result 1: Recovery of Known Planets

Nardiello et al. 2020

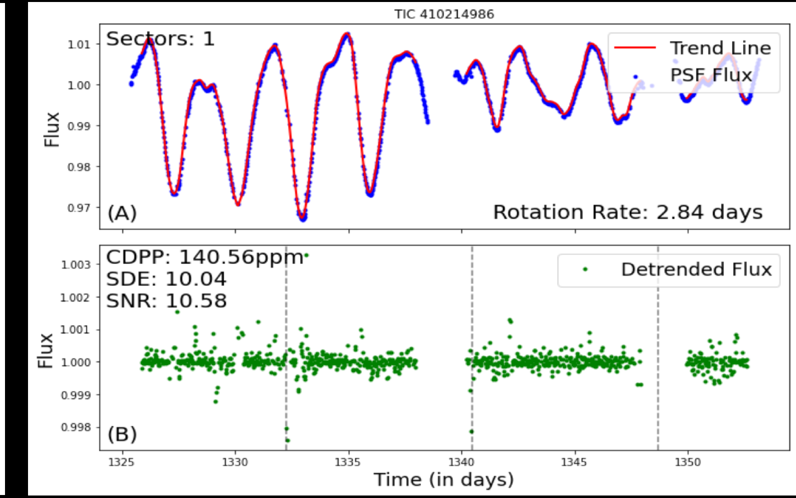
Cluster: IC 2602
Radius: 7.2 $R_\oplus$
Period: 8.3 days

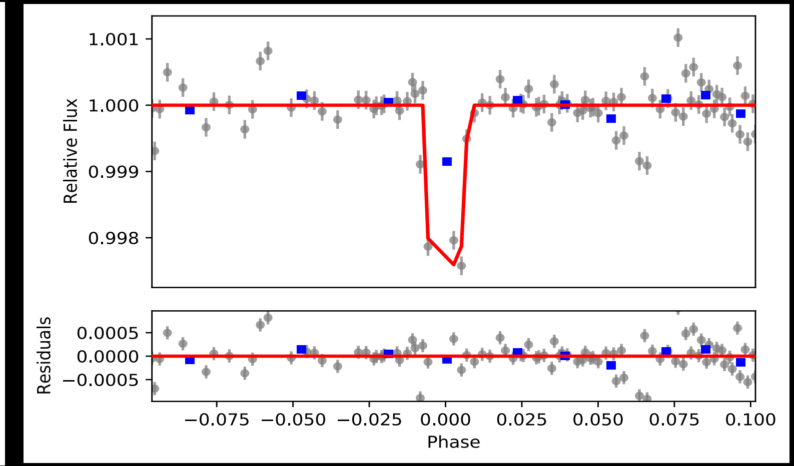




Newton et al. 2019

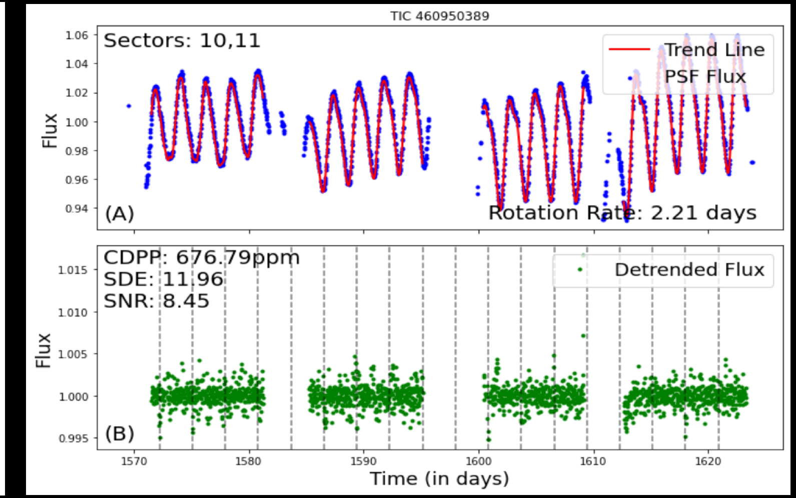
Cluster: THA
Radius: 5 $R_\oplus$
Period: 8.2 days

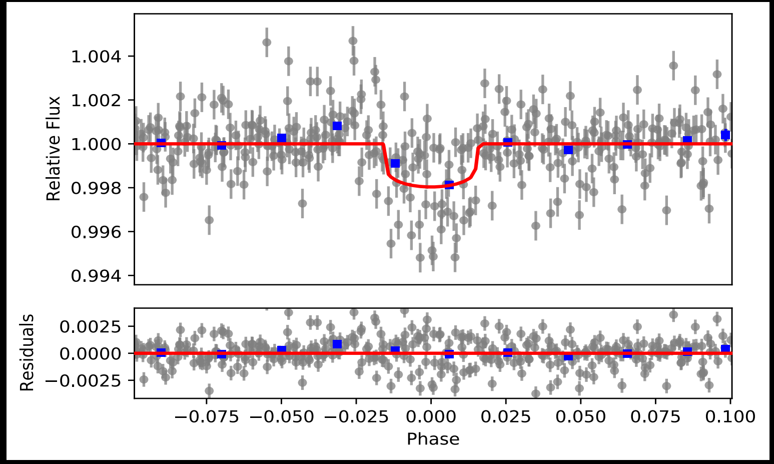




Nardiello et al. 2020

Cluster: IC 2602
Radius: 3.5 $R_\oplus$
Period: 2.8 days





Fernandes et al. 2022 (in prep)

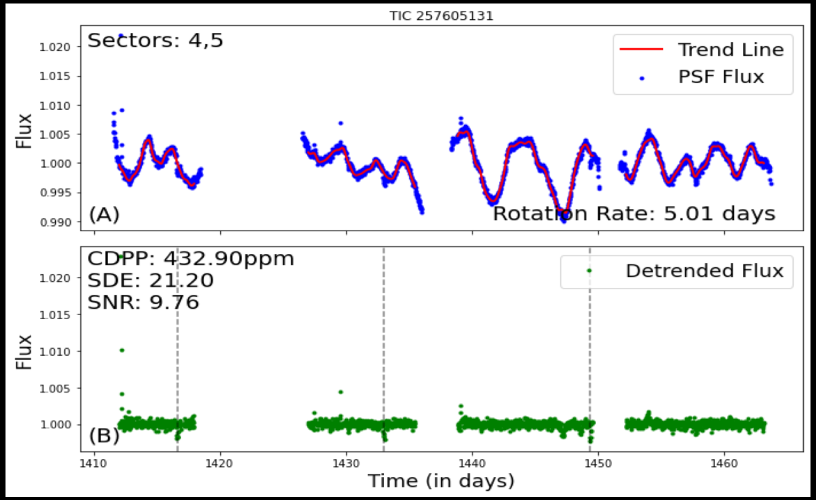
Result 1b: Recovery of Multi-Planet Systems

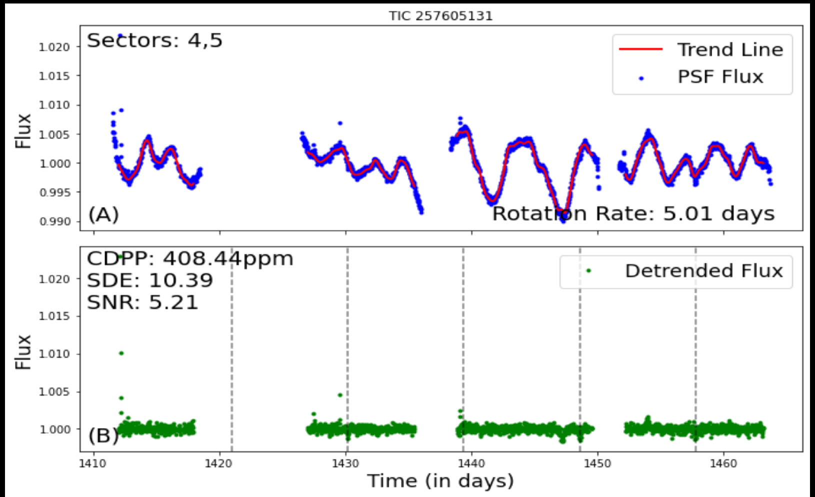
Newton et al. 2021

Cluster: Pisces-Eridani
Radius: 3.6 $R_\oplus$
Period: 16.4 days

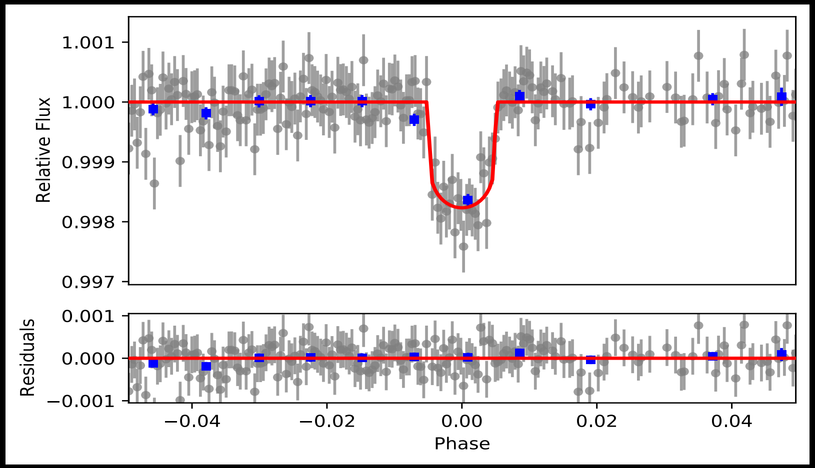
Newton et al. 2021

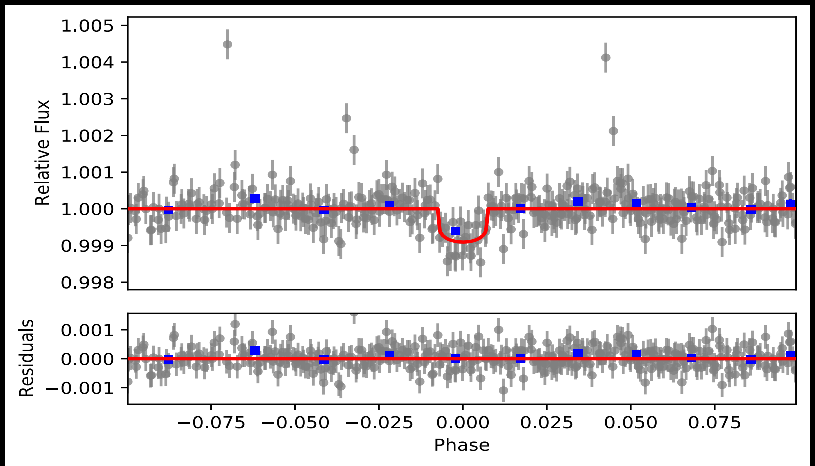
Cluster: Pisces-Eridani
Radius: 2.6 $R_\oplus$
Period: 9.2 days





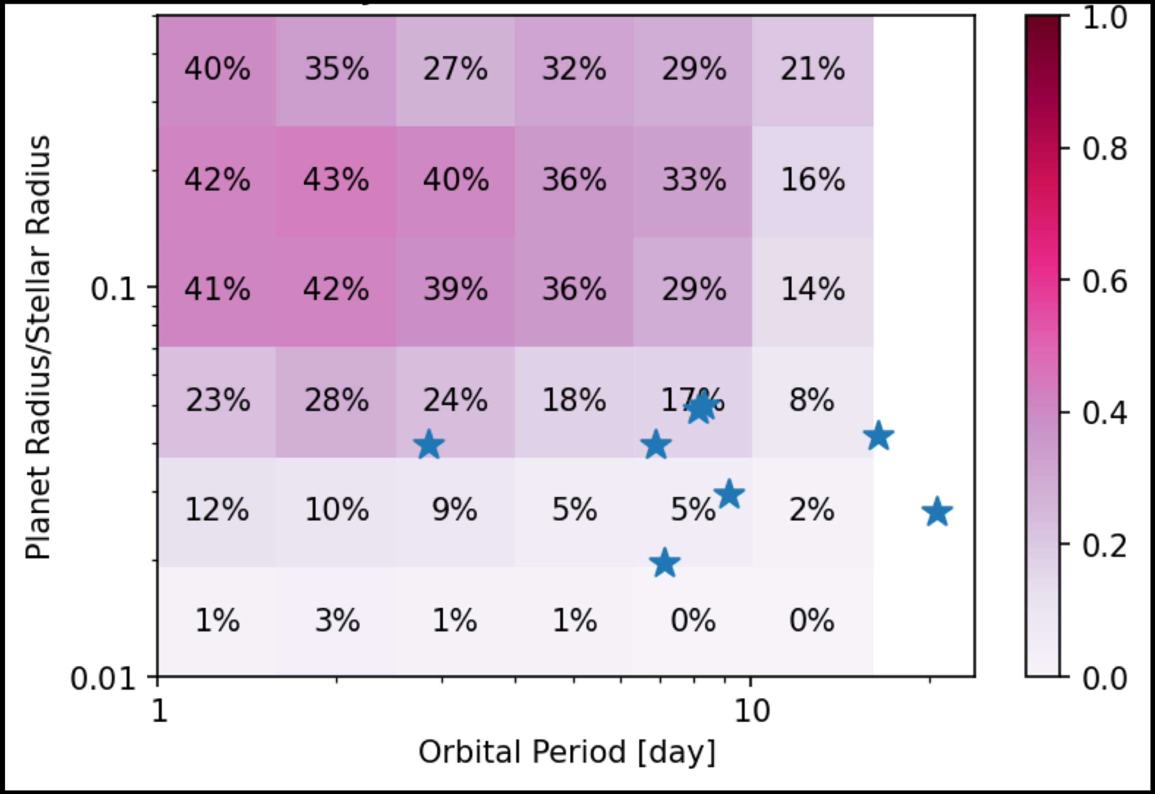
Fernandes et al. 2022 (in prep)





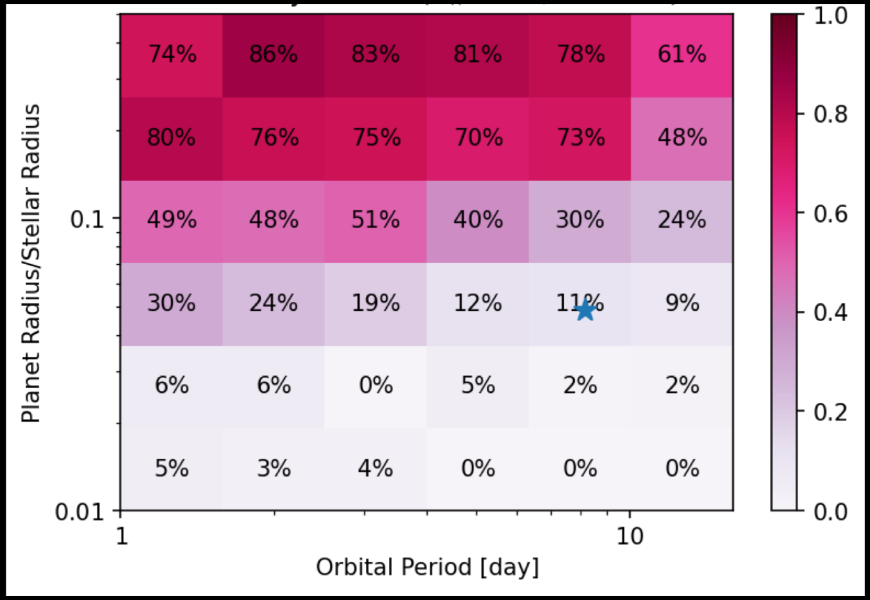
Result 2: Detection Efficiency

Overall

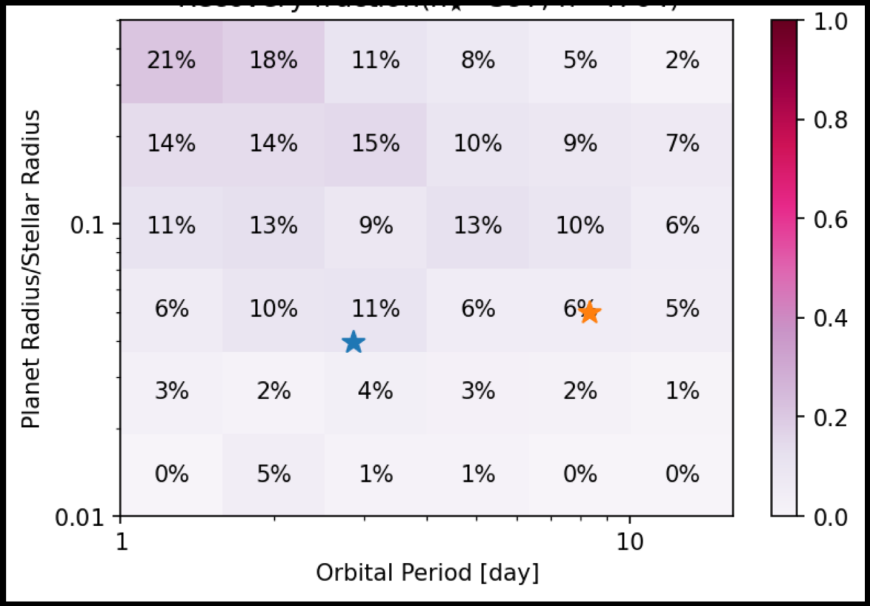


Fernandes et al. 2022 (in prep)

THA

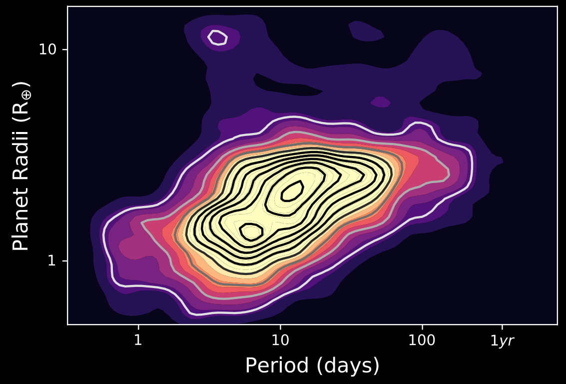


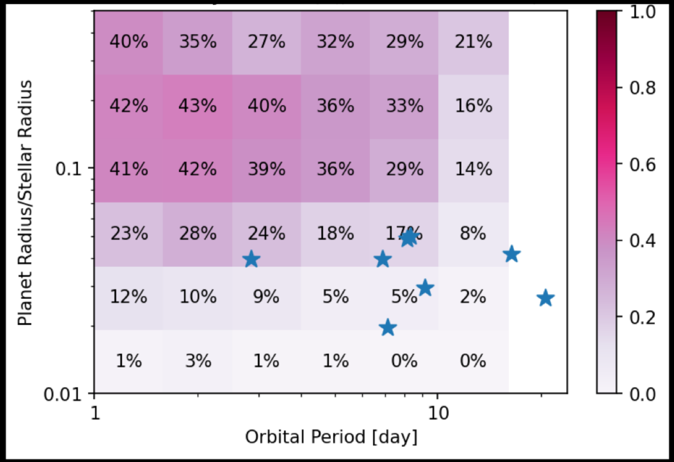
IC2602



Summary & Future Work

A closer look at Kepler's Gyr short-period exoplanet population revealed the radius valley i.e. a much lower frequency of planets with ~1.8Re rather than ~1.3Re (super-Earths) or ~2.4Re (sub-Neptunes). Since this feature is thought to be evolutionary, it suggests that the primordial population could be very different than Kepler's Gyr population.





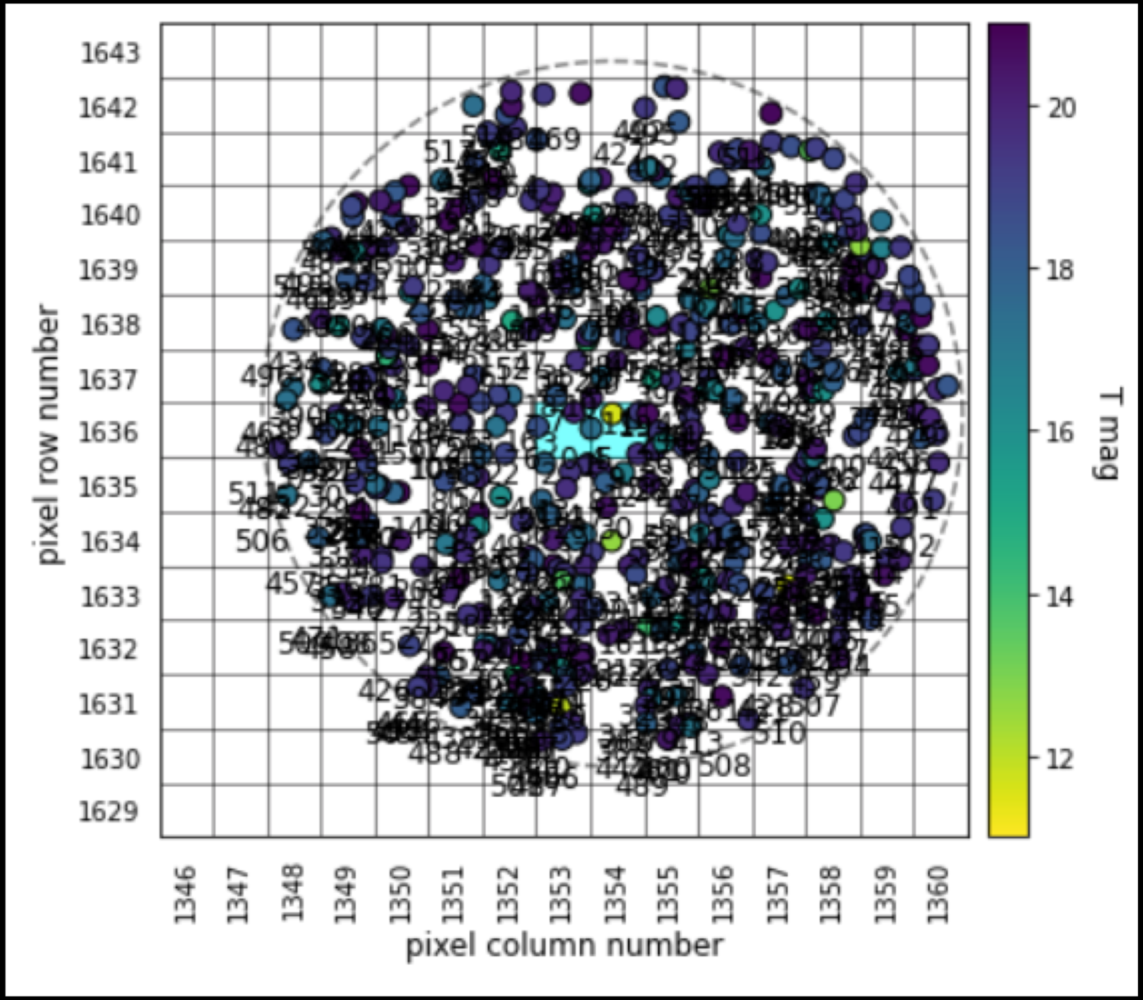
Therefore, in order to understand what the primordial population of short-period planets looked like, we need to detect planets in young stellar clusters. My pipeline, `pterodactlys`, has been optimized to be able to detrend young light curves from TESS FFIs.

<u>Next steps:</u>

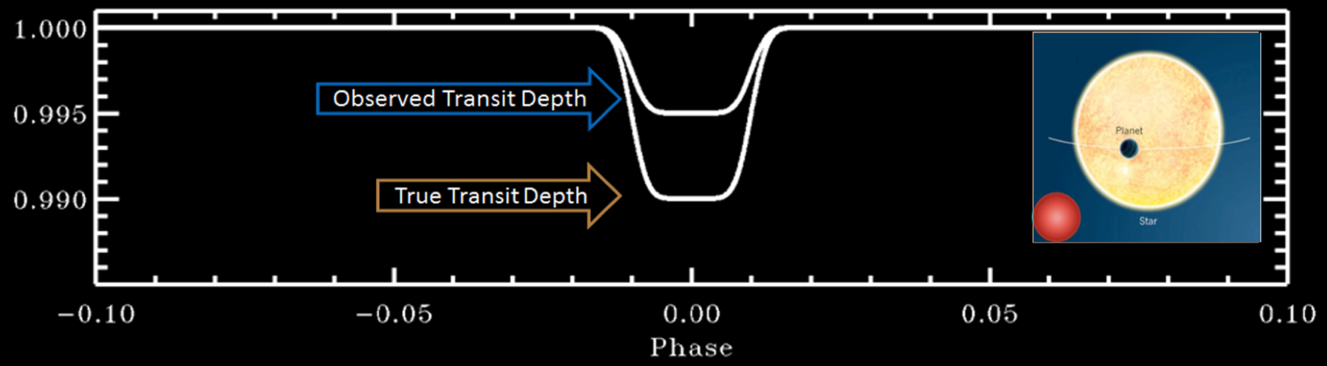
- Search and vet planet candidates in nearby clusters and moving groups + Community Follow-up of planet candidates
- Uniform characterization of stars in young clusters
- Occurrence of short period planets in young stellar clusters

Backup Slides

Step 4a: Flux Contamination



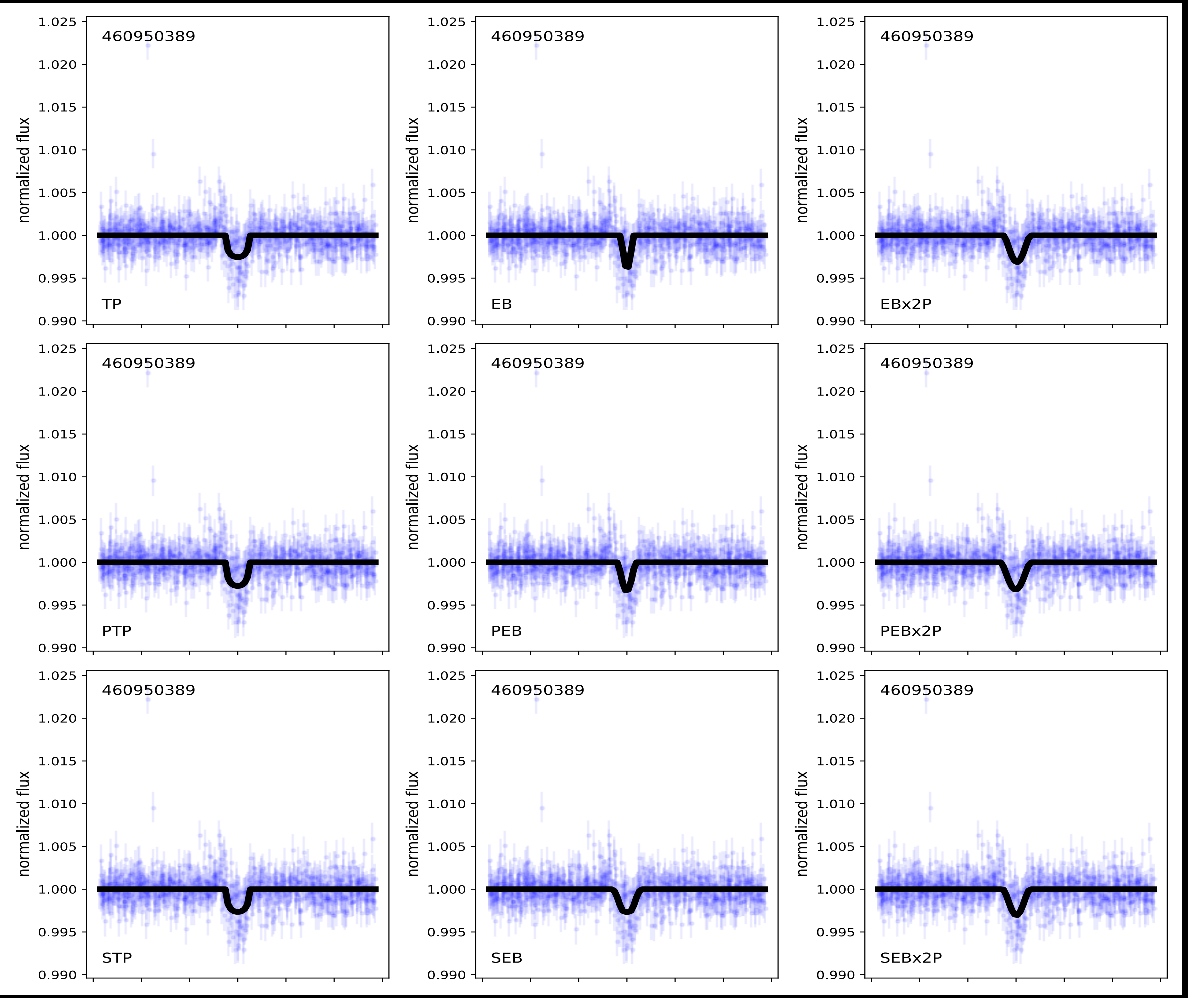
David Ciardi



- Planet Radius -> Transit Depth
- Transit Depth Dilution
  - Crowded fields
  - Inaccurate planetary radii
- `triceratops` -> flux contamination
  - Queries Gaia DR2 for nearby sources
  - TESS Pixel Response Function

Step 4b: Vetting the Phase-folded Light Curve

- Transiting Planet or Eclipsing Binary around
  - Target star
  - Nearby star
  - Background star
  - Unresolved Bound Companion
    - Primary star
    - Secondary star
  - Unresolved Background star



Comparison of Planetary Parameters