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

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Art: Sam Dietz
The $\eta_{\odot}$ Problem

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

Pascucci et al. 2019 using Kepler dr25

Mercury

$\eta_{\odot}$: 36% (epos; Mulders+ 2018)
Possible explanations:

- XUV Photoevaporation (Owen+Wu 2013, 2017)
- Core-powered Mass Loss (Gupta+Schlichting 2019, 2020)
How do we quantify this contamination by the stripped cores of once sub-Neptunes?

The population of short-period small ($<1.8 \, R_{⊕}$) 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

By Ethan Kruse
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NASA TESS’s View
of the Sky

Sector 1
Jul 2018-Aug 2018
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 Wotan (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

<table>
<thead>
<tr>
<th>Cluster/Moving Group</th>
<th>Dist (pc)</th>
<th>Age (Myr)</th>
<th>Obs/Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>THA</td>
<td>$46^{+8}_{-6}$</td>
<td>$45\pm4$</td>
<td>201/214</td>
</tr>
<tr>
<td>IC 2602</td>
<td>146±5</td>
<td>$46^{+6}_{-5}$</td>
<td>502/504</td>
</tr>
<tr>
<td>UCL</td>
<td>130±20</td>
<td>16±2</td>
<td>719/937</td>
</tr>
<tr>
<td>UMa</td>
<td>$\sim25$</td>
<td>414±23</td>
<td>16/17</td>
</tr>
<tr>
<td>PiEri</td>
<td>80–226</td>
<td>120</td>
<td>153/254</td>
</tr>
</tbody>
</table>

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 transitleast squares (TLS)

• **Vetting:**
  
  - Orbital Period \( \neq \) stellar rotation rate
  - Consistency in individual transit depths
  - At least 2 transits with data
  - Individual Transits > 7 SDE
  - \( T_{dur} \) (obs) \( \sim \) \( T_{dur} \) (exp)
  - No secondary transit events at half times the detected period
Result 1: Recovery of Known Planets

Cluster: IC 2602
- Radius: 7.2 $R_{⊕}$
- Period: 8.3 days

Cluster: THA
- Radius: 5 $R_{⊕}$
- Period: 8.2 days

Cluster: IC 2602
- Radius: 3.5 $R_{⊕}$
- Period: 2.8 days

Newton et al. 2019

Nardiello et al. 2020

Fernandes et al. 2022 (in prep)
Result 1b: Recovery of Multi-Planet Systems

Cluster: Pisces-Eridani
Radius: 3.6 R⊕
Period: 16.4 days

Newton et al. 2021

Cluster: Pisces-Eridani
Radius: 2.6 R⊕
Period: 9.2 days

Fernandes et al. 2022 (in prep)
Result 2: Detection Efficiency

Fernandes et al. 2022 (in prep)
A closer look at Kepler’s Gyr short-period exoplanet population revealed the radius valley i.e. a much lower frequency of planets with $\sim 1.8R_e$ rather than $\sim 1.3R_e$ (super-Earths) or $\sim 2.4R_e$ (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, pterodactyls, has been optimized to be able to detrend young light curves from TESS FFIs.

Next steps:
• 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

- 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