Planetary Archaeology: Exploring Planets Transiting Evolved Stars

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Distribution of Kepler target stars: mostly Sunlike

Huber+ (2014)
Distribution of K2 target stars: more M stars, more giants

Huber+ (2016)
More giants: galactic, planetary archaeology possible
Why should you care about planets orbiting giant stars?
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- To solve long-standing planet inflation mysteries
The Mechanism of Planet Inflation

Class I: planet interior inflated directly by increased stellar irradiation


Class II: cooling delayed after planet formation

How to distinguish between Classes I and II?

Class I: re-inflation

Class II: no re-inflation

- Data implies significant post-MS planet heating. But how?

K2-97b:
- $1.16 \, M_\odot$
- $0.48 \, M_J$
- 8,406 days

Grunblatt+ (2017)
Is K2-97b re-inflated? Probably.

Data implies significant post-MS planet heating. But how?

K2-97b: 1.16 M\(_{\odot}\)  0.48 M\(_{\text{J}}\)  8.406 days

Kepler-422b: 1.15 M\(_{\odot}\)  0.43 M\(_{\text{J}}\)  7.89 days

Grunblatt+ (2017)
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Why should you care about planets orbiting giant stars?

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- To study planet evolution: as star evolves, planets must react
  - inspiral, circularization, engulfment timescales still unknown (Villaver+ 2014, Fuller 2017, MacLeod+ 2018, Grunblatt+ 2018)
Close-in planets are in jeopardy, as their host stars evolve off the main sequence (MS) to the subgiant and red giant phases. In this paper, we explore the influences of the stellar mass (in the range $1.5 \text{-} 2 \, M_\odot$), mass-loss prescription, planet mass (from Neptune up to 10 Jupiter masses), and eccentricity on the orbital evolution of planets as their parent stars evolve to become subgiants and red giants. We find that planet engulfment along the red giant branch is not very sensitive to the stellar mass or mass-loss rates adopted in the calculations, but quite sensitive to the planetary mass. The range of initial separations for planet engulfment increases with decreasing mass-loss rates or stellar masses and increasing planetary masses. Regarding the planet’s orbital eccentricity, we find that as the star evolves into the red giant phase, stellar tides start to dominate over planetary tides. As a consequence, a transient population of moderately eccentric close-in Jovian planets is created that otherwise would have been expected to be absent from MS stars. We find that very eccentric and distant planets do not experience much eccentricity decay, and that planet engulfment is primarily determined by the pericenter distance and the maximum stellar radius.
Hot Jupiters and Cool Stars

Villaver, Livio, Mustill & Siess (2014)

Close-in planets in the late-evolution phases. In this phase, the planet mass (first) and the parent stars evolve in sensitive stages. The planetary mass or stellar mass can be sensitive to the mass-loss rates. The blue and red giant branches can find that as the mass-loss rates increase, a planet as small as a few Jupiter masses could have been born. A small planet may experience much more accretion of different matter, and the maximum
Close-in planets can be in highly eccentric phases. In this case, if the planet mass (in units of Jupiter mass) is $M_p = 1 M_J$ and the stellar mass is $M_\star = 1.5 M_\odot$, the eccentricity $e$ is given by:

$$e = \sqrt{1 - \frac{a_f}{a}}.$$
Do close-in giant planets orbiting evolved stars prefer eccentric orbits?

Grunblatt+ (2018)

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Do close-in giant planets orbiting evolved stars prefer eccentric orbits? 

\[ e = 0.15^{+0.08}_{-0.04} \]

Grunblatt+ (2018)
Do close-in giant planets orbiting evolved stars prefer eccentric orbits?

\[ e = 0.06 \pm 0.02 \]
\[ e = 0.15 \pm 0.08 \]

Grunblatt+ (2018)
Do close-in giant planets orbiting evolved stars prefer eccentric orbits?

orbital migration driven by stellar evolution?
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- To understand stellar variability: key to getting better star/planet parameters & finding currently undetectable planets with future missions
  - motivates new models to characterize stellar variability (Grunblatt+ 2015, Grunblatt+ 2017, Jones+ 2018, RVxK2, RVxTESS)

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SHO GP light curve model teaches us about stellar variability

- Traces stellar granulation & oscillation signals

Grunblatt+ (2017)
Giant Planet Occurrence Within 0.2 AU of Low Luminosity Red Giant Branch Stars

Grunblatt+ (in prep.)
A Search for Giants Orbiting Giants with K2

➤ >10,000 Low Luminosity Red Giant Branch (LLRGB) targets

➤ Transit detection limit: \(~9\) Rsun

➤ K2 limit for asteroseismology: 283 \(\mu\)Hz \((\sim3\) Rsun\)

➤ Temperature limits: 4500—5500 K (avoids horizontal branch stars)

Huber+ (2016)
Asteroseismic stellar parameters:

\[
\frac{R}{R_\odot} \approx \left( \frac{\nu_{\text{max}}}{\nu_{\text{max},\odot}} \right) \left( \frac{\Delta \nu}{f_{\Delta \nu} \Delta \nu_\odot} \right)^{-2} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{0.5}.
\]

\[
\frac{M}{M_\odot} \approx \left( \frac{\nu_{\text{max}}}{\nu_{\text{max},\odot}} \right)^3 \left( \frac{\Delta \nu}{f_{\Delta \nu} \Delta \nu_\odot} \right)^{-4} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{1.5}.
\]
Asteroseismic stellar parameters: 2542 LLRGB stars in K2

\[ \frac{R}{R_\odot} \approx \left( \frac{\nu_{\text{max}}}{\nu_{\text{max,\odot}}} \right) \left( \frac{\Delta \nu}{f_{\Delta \nu} \Delta \nu_\odot} \right)^{-2} \left( \frac{T_{\text{eff}}}{T_{\text{eff,\odot}}} \right)^{0.5} \]

\[ \frac{M}{M_\odot} \approx \left( \frac{\nu_{\text{max}}}{\nu_{\text{max,\odot}}} \right)^3 \left( \frac{\Delta \nu}{f_{\Delta \nu} \Delta \nu_\odot} \right)^{-4} \left( \frac{T_{\text{eff}}}{T_{\text{eff,\odot}}} \right)^{1.5} \]
LLRGB Planet Occurrence

Grunblatt+ (in prep.)

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planet occurrence decreases with radius around MS stars…

Grunblatt+ (in prep.)

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planet occurrence decreases with radius around MS stars…
…but seems to *increase* with radius around evolved stars!
What’s next?
Better statistics with TESS!

Grunblatt (2018)

Planet Radius ($R_{\text{Jup}}$)

$R_* > 3R_\odot, T_{\text{eff}, *} < T_{\text{eff}, \odot}$

Previous studies

Orbital Period (days)
Test migration dependencies on star, planet properties with $>10x$ planets!

Summary: we should all care about planets orbiting giant stars!

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Thanks!