Revealing the Fundamental Properties of Exoplanets and their Host Stars with ‘Alopeke

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See other ‘Alopeke talks by Elliott Horch (Monday) & Nic Scott (Thursday)
High-Resolution Exoplanet Host Star Observations: Validation and Characterization

- False planets?
- Correct planet radii
- Correct planet mean density
- Occurrence rate studies (Kepler +)
- Exoplanet / Host star formation & evolution
- Habitable Zone (in or out – which star?)
- Exoplanet statistics
- Host Star Properties
- Zodiacal Light characterization (w/ LBTI)
- Resolve RV discovery “trends”
- Define orbital planes (planet vs. companion)
- Etc....

e.g., Vanderberg+; Mayo+; Borkovits+ 2018; Livingston+; Lugger+ 2017
Exoplanet Host Star Binarity:
40-50% of all exoplanet host stars are bound binaries -
Kepler (Horch et al., 2015); K2 (Matson et al., 2018); TESS

Why do we care to detect close (bound) companions?

Kepler 437 - planet was a super earth, corrected to Neptune size (assuming it orbits the primary)
KEPLER HOST STARS WITH COMPANIONS (E.G., 2015 A,B)

- 5 sigma detection line
- Typical ROBO-AO, delta-mag ~1-2
- Horch+ 2015 (Kepler); Matson+ 2018 (K2)
Reconstructed Image & Data Products

Speckle Contrast Curve

Box is ~2" on a side

We obtain ~1 mas astrometry, ~0.1 mag relative photometry

Howell+ 2011, Horch+ 2016
When a planet transits its star, scientists can measure its **size** from the fraction of the star’s light that it blocks.

If it were actually a binary system with two equally-bright stars, the planet has to be **bigger** to block the same total fraction of light.

And if the planet orbits the fainter of two stars, to have the same effect it must be **even larger**!

But this assumes that there is only **one star** in the system.

In actuality, half of the stars with planets are probably **binaries**!

This is important because even modern space telescopes like Kepler have limited resolution, and can’t always distinguish between **one star** and a binary system of **two close stars**.
Accurate Planet Radii From Transits

- Require Accurate Stellar Radii
- Proper accounting of Blending by Companion Stars
- Assessment of which star the planet might orbit

$$\delta_0 = \left( \frac{F_t}{F_{\text{total}}} \right) \left( \frac{R_p}{R_{t\star}} \right)^2$$

Ciardi+ 2015
This Star is Kepler-1002

- KOI list assumes star is a single star
  - Rp = 1.4 Rearth
  - Boundary of rocky and non-rocky planets
  - In gap of planet distribution found by Fulton et al.

- Binary – If planet orbits primary star
  - Rp = 1.8 Rearth
  - Non-rocky super-earth/mini-Neptune and no longer in planet distribution gap

- If planet orbits secondary star
  - Rp = 3.5 Rearth
  - Neptune-like planet
Kepler Exoplanets Radius Correction: Mean Density & Occurrence Rate

Dashed lines are Fe, Rock, Water to H₂,He compositions

Furlan & Howell 2018; Bouma+ 2018; Teske+ 2018

Planet size bins: Grey = uncorrected; Purple is average corrected; Blue is 50% corrected
Are Companions Physically Bound?

Use isochrone fits and common proper motions to determine bound companions and produce stellar properties.

Everett+ 2015; Hirsch+ 2016; Hess+ 2018
Are Companions Physically Bound?

Discover coplanar orbits: $a \sim 39$ AU, $P \sim 180$ years

Hess+ 2018
Formation Scenarios
Wide doubles $\rightarrow$ Triples
Cause for migration in Hot Jupiter systems?

Fragmentation: more wide components are themselves binary. A-BC architecture, as above. Essentially only ‘Alopeke can do this work.
THE EFFECTS OF STELLAR COMPANIONS ON KEPLER'S EXOPLANET RADIUS DISTRIBUTION

Binary Companion Suppression? Maybe not!

Matson et al. 2018
TRAPPIST-1: Speckle Observations

Imaging found no (sub)stellar companion. Small planet radii confirmed.
‘Alopeke on Gemini provides the highest spatial resolution imaging available today on any single telescope

- 10 mas @442 nm
- 17 mas @550 nm
- 28 mas @880 nm

~1/2 of TESS exoplanet host stars will have close (< 1") companions (Bound and Light Of Sight) - over 90% of these will be within 0.5”.

‘Alopeke will peer into <0.5-1 AU for many K2 and TESS exoplanet host stars.
Exoplanet Science Enabled by ‘Alopeke @ Gemini

• Exoplanet Validation – Essentially the only way to fully validate small, rocky planets
• Exoplanet Characterization
  – Exoplanet radii and density
  – Occurrence rates
• Host star properties
  – ~50% of host stars are binary (multiple)
  – Stellar masses, separation, orbital period
• Host star – Exoplanet Interactions
  – Astrometry – stellar orbits
  – Formation – planet suppression?
  – Evolution – planet migration?

Thanks to the Gemini Observatory Staff who have made ‘Alopeke@Gemini possible!