AT LAST! CONFIRMATION OF KEPLER'S SECOND PLANETARY CANDIDATE

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EXOPLANETS IN MULTI-STAR SYSTEMS

- Nearly half of stars in the solar neighborhood have stellar companions, but less than 10% of the known exoplanetary host systems have stellar companions
  - Stellar companions may (partially) quench or change planetary formation and evolution processes
  - Discovery and characterization studies tend to avoid multi-star systems
- Little is known about the properties of planetary systems in single vs multiple star systems

*This is the (abbreviated) story of KOI-5: A promising early Kepler planetary detection that was abandoned because ... it was complicated.*
KEPLER OBJECT OF INTEREST (KOI) 5

- Discovered in first 10 days of Kepler data in 2009
- Second Kepler candidate (KOIs 1 – 3 previously known)
- Initially believed to be a Neptune-sized planet orbiting an older Sun-like star in a 5 day orbit

Kepler Light Curve and Transit For KOI 5

Borucki et al. 2011
Ciardi et al. 2021
THEN THINGS STARTED TO GO WRONG ...
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"Injustice anywhere is a threat to justice everywhere." – MLK, Letter from a Birmingham Jail
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KOI-5 discovered to have a stellar companion

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Kraus et al. 2014
Furlan, Ciardi, et al. 2015
Ciardi et al. 2021
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And in fact ... there are two companion stars

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- Radial velocities didn’t match the transit orbit
- With the plethora (thousands!) of other Kepler candidates — left KOI-5 abandoned
AND ALONG CAME TESS: TOI 1241 = KOI 5

• TESS saw the same transit event 10 years later and it got me thinking “Why didn’t we ever confirm KOI-5?”

• Stellar companions were too far away from the primary star to be responsible for the transits ... there must be a 4th body in the system causing the transits.

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COMBINED THE RADIAL VELOCITIES AND IMAGING DATA TO SOLVE FOR THE SECONDARY STAR (B) ORBIT

Stellar Mass A ~ 1.13 Solar Masses
Stellar Mass B ~ 1.09 Solar Masses
Orbital Period ~ 29 years

Ciardi et al. 2021
AFTER SUBTRACTION OF THE STELLAR ORBIT FOR STAR B, RADIAL VELOCITIES REVEAL THE PLANET

Planet Mass ≈ 57 Earth masses; Planet Radius ≈ 7 Earth Radii

Ciardi et al. 2021
BUT THE ORBITS ARE NOT ALIGNED

- Planet orbit is edge-on (transit) but the Stellar orbit is face-on
- Stars and planet did not all form from the same circumstellar disk?
- Did the stellar companion push the planet into its current orbit?

KOI-5 Triple Star System

Exoplanet KOI 5Ab 5-day orbit

KOI-5A

KOI-5B 30-year orbit

KOI-5C 400-year orbit

Diagram not to scale
KEPLER’S SECOND CANDIDATE KOI-5b is a Planet!

- KOI 5 is a triple star system
- Planet orbits the primary star
  - 60% mass of Saturn
  - 75% radius of Saturn
  - 25% denser than Saturn
- Stellar orbit and planetary orbit are not in the same orbital plane
- The scientific detective work was made possible by the Kepler and TESS follow-up programs and the willingness of the community members to share publicly their observations, data, and thoughts

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KOI-5A
KOI-5B 5-day orbit
KOI-5C 400-year orbit
Exoplanet KOI 5Ab 30-year orbit

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