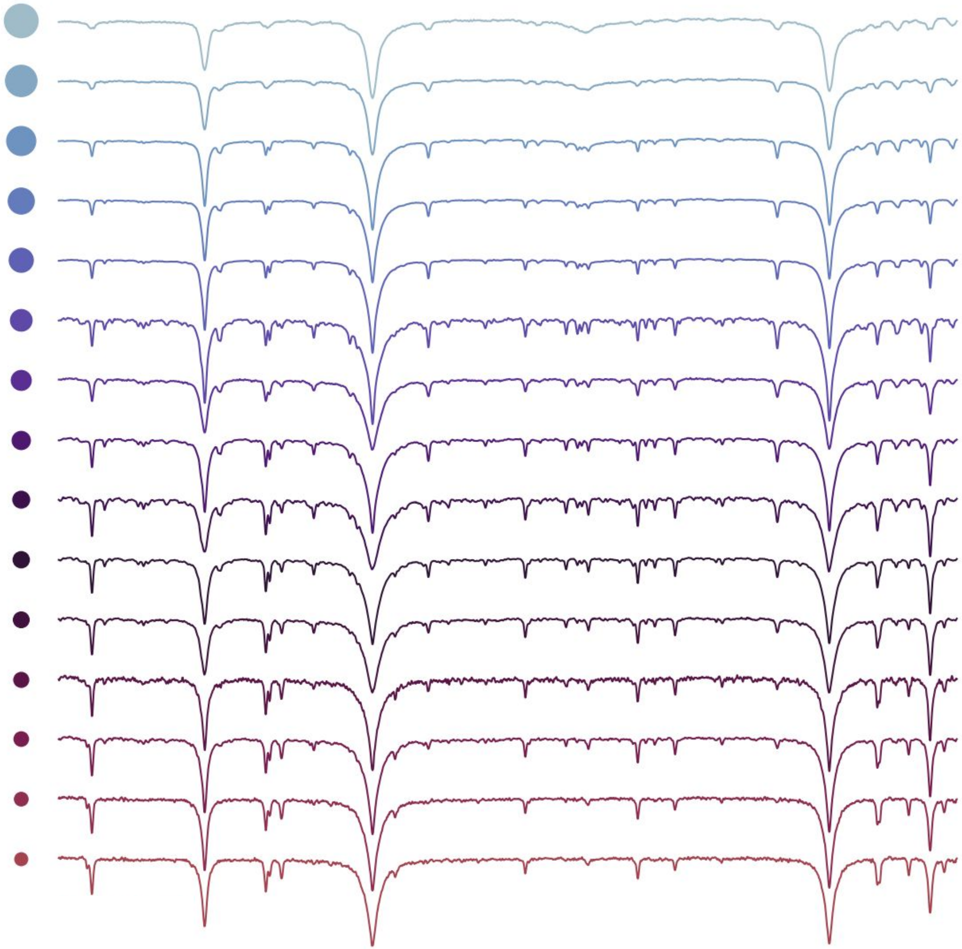


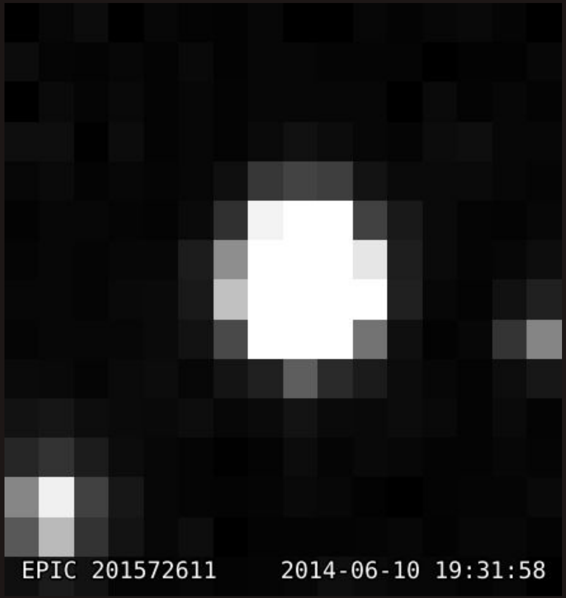
A Data-Driven Spectral Model of Main Sequence Stars in Gaia DR3

Isabel Angelo (UCLA)

Collaborators: Megan Bedell, Erik Petigura, Smadar Naoz, Melissa Ness

ExSoCal December 11, 2023

Most known planets were identified using photometry



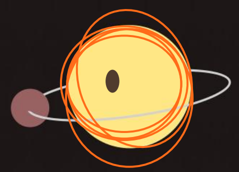
Kepler pixel image
(credit: Kepler GO)

5,550 confirmed planets

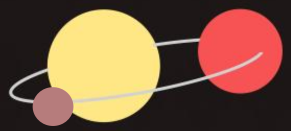
2,778 from Kepler
548 from K2
410 from TESS

plus >10,000 candidates
from photometry

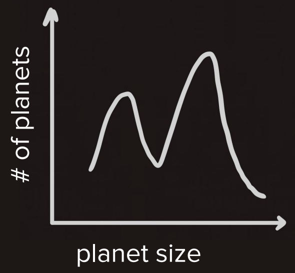
We need high resolution spectroscopy to learn more about Kepler, K2 and TESS planets



How often do planets orbit active stars?



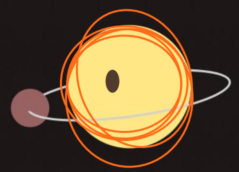
How often do planets form in binaries?



What are the demographic trends in the population? (e.g., radius gap, Fulton et al. 2017)

we need spectroscopy to answer these science questions!

We need high resolution spectroscopy to learn more about Kepler, K2 and TESS planets



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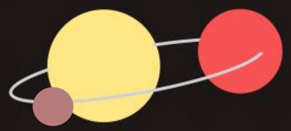

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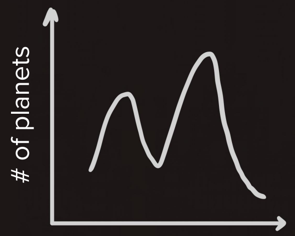


What are the demographic trends in the population? (e.g., radius gap, Fulton et al. 2017)

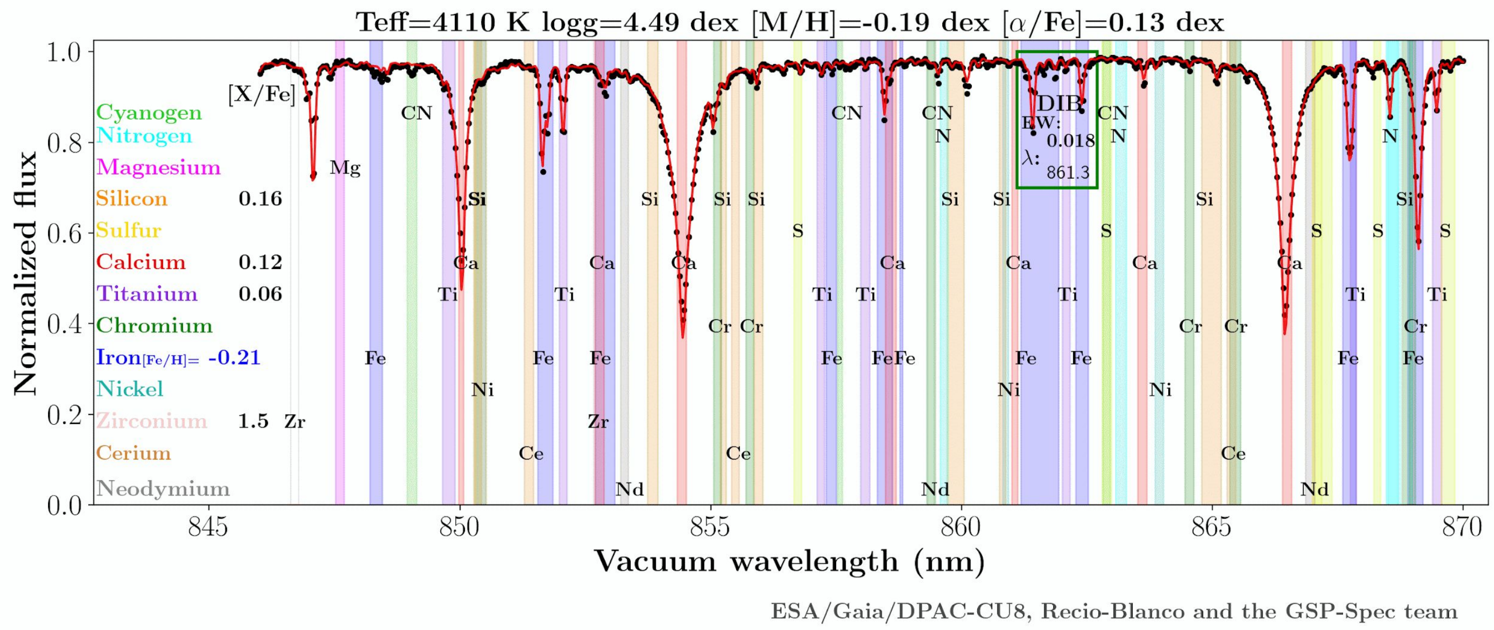
we need spectroscopy to answer these science questions!

...

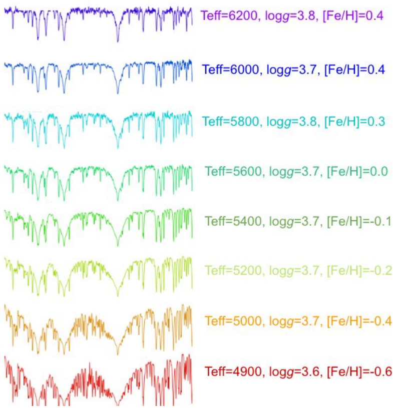
but this is challenging :/

What if you didn't need Keck or Gemini to characterize planet hosts?

Gaia DR3 published spectra for 10,000 Kepler field stars and 37,000 TESS field stars!
(∼6% of Kepler planet hosts ∼20% of TESS planet hosts)

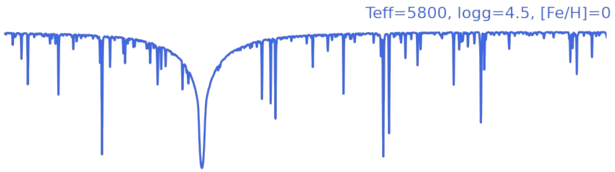


We used the Cannon to train a data-driven spectroscopic model that enables precise characterization of stars with Gaia DR3 spectra



training set: Gaia RVS spectra + corresponding labels (T_{eff}, logg, [Fe/H], [α/Fe], v_{broad}) of single stars

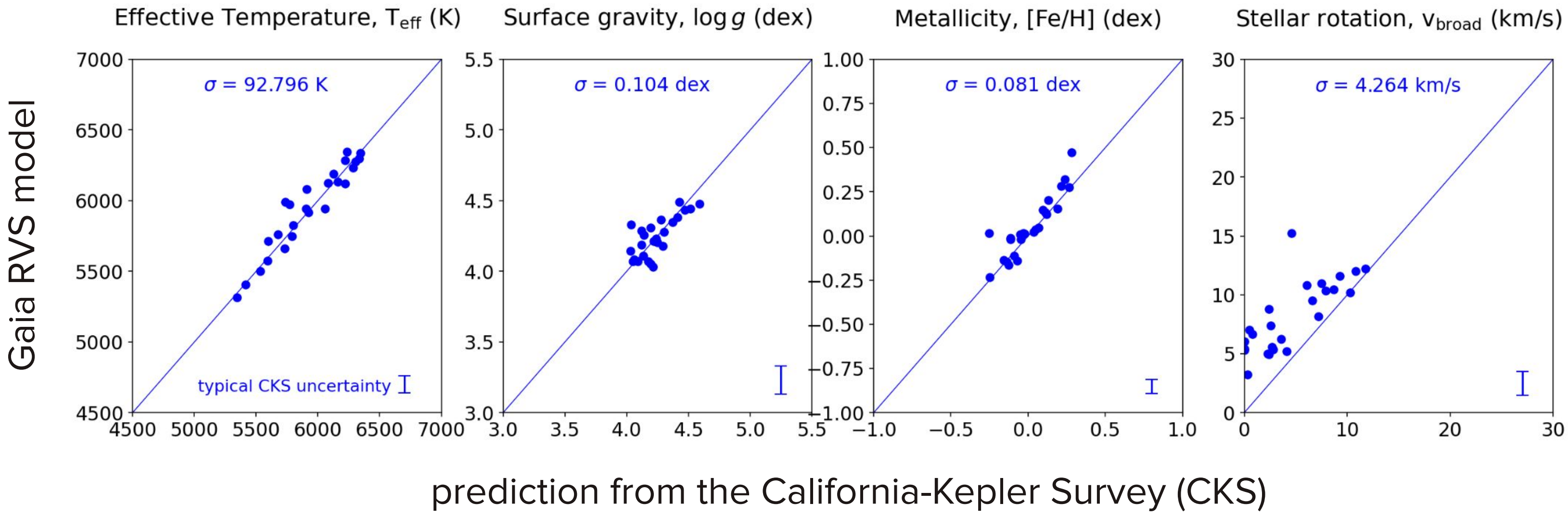
→ training step: supervised learning algorithm fits flux of real spectra to previously determined labels →



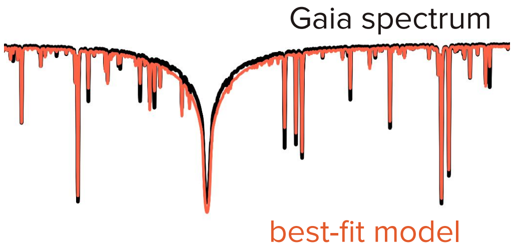
single star model = f(λ, labels)

see: Ness at al. 2015, Casey et al. 2016, Rice & Brewer 2020

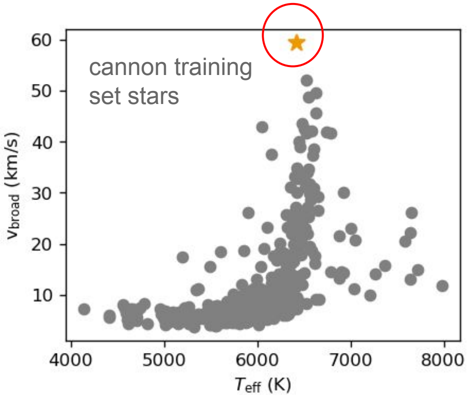
Our Gaia RVS model computes stellar properties with comparable accuracy to ground-based surveys



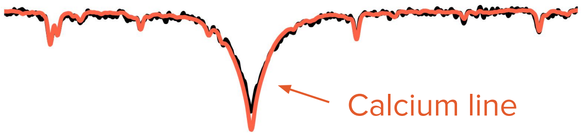
Our model also computes metrics to identify spectroscopic anomalies



χ^2: measures how well the model fits the data

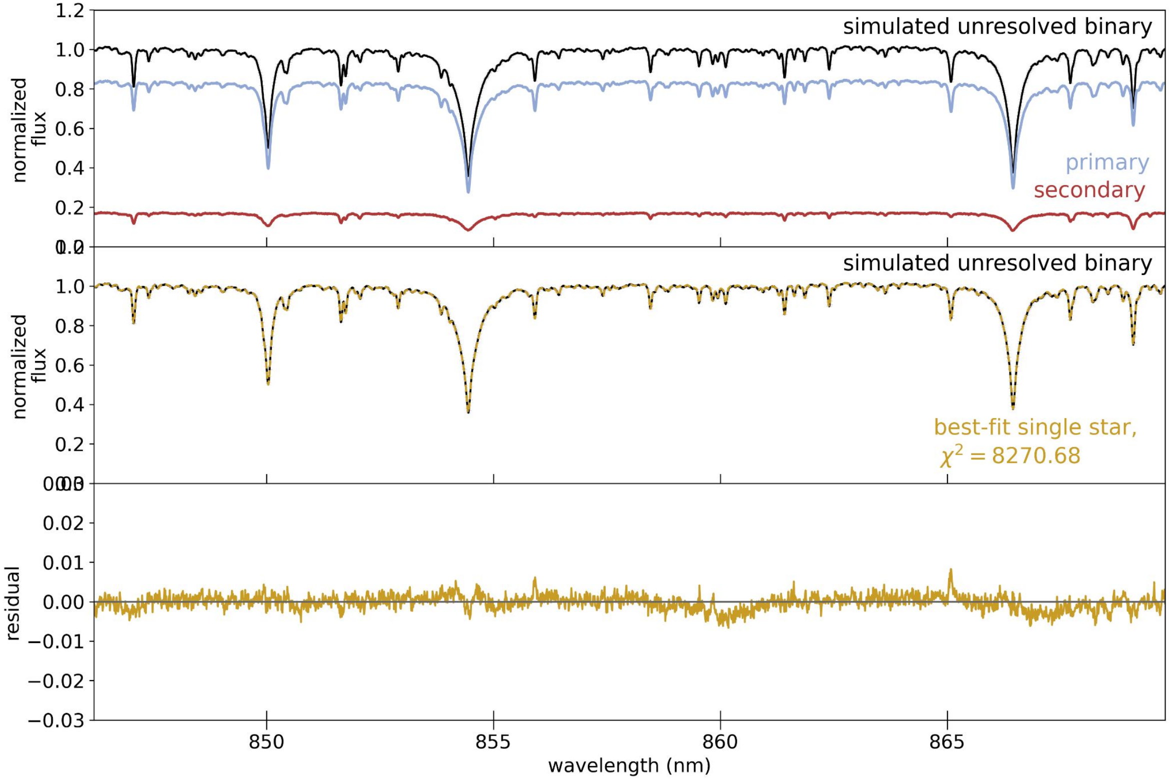


$\rho_{training}$: measures how reasonable the predicted star properties are



$\chi_{Ca}{}^2$: measures how well the model fits the data around activity-correlated Calcium features

A fourth metric, $\Delta\chi^2_{binary}$ helps to identify spectroscopic binaries by comparing fits of single star and binary (i.e., composite) spectra



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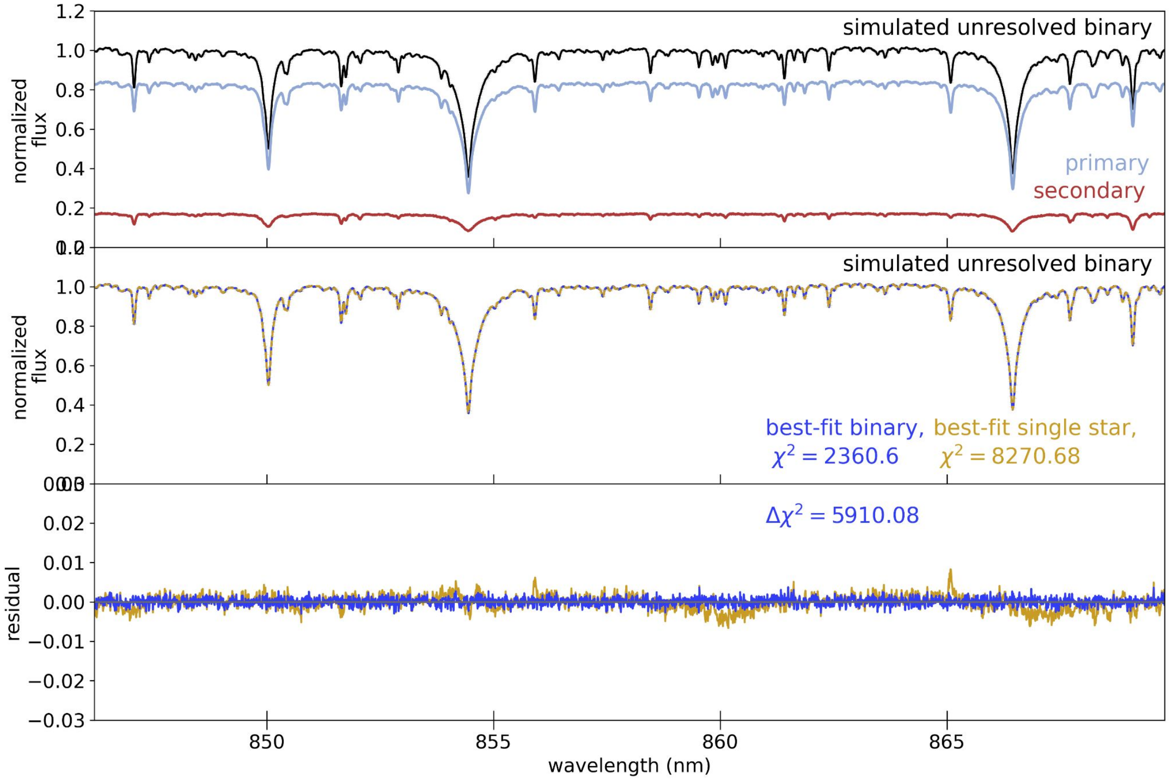

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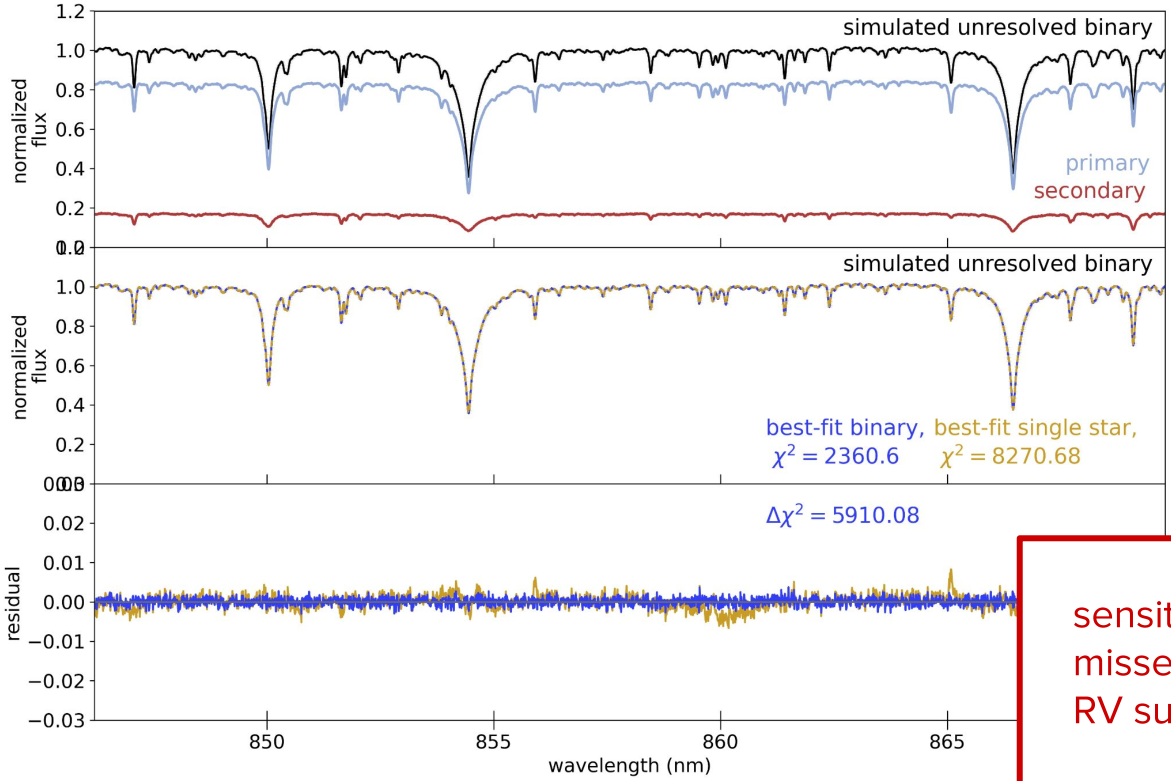
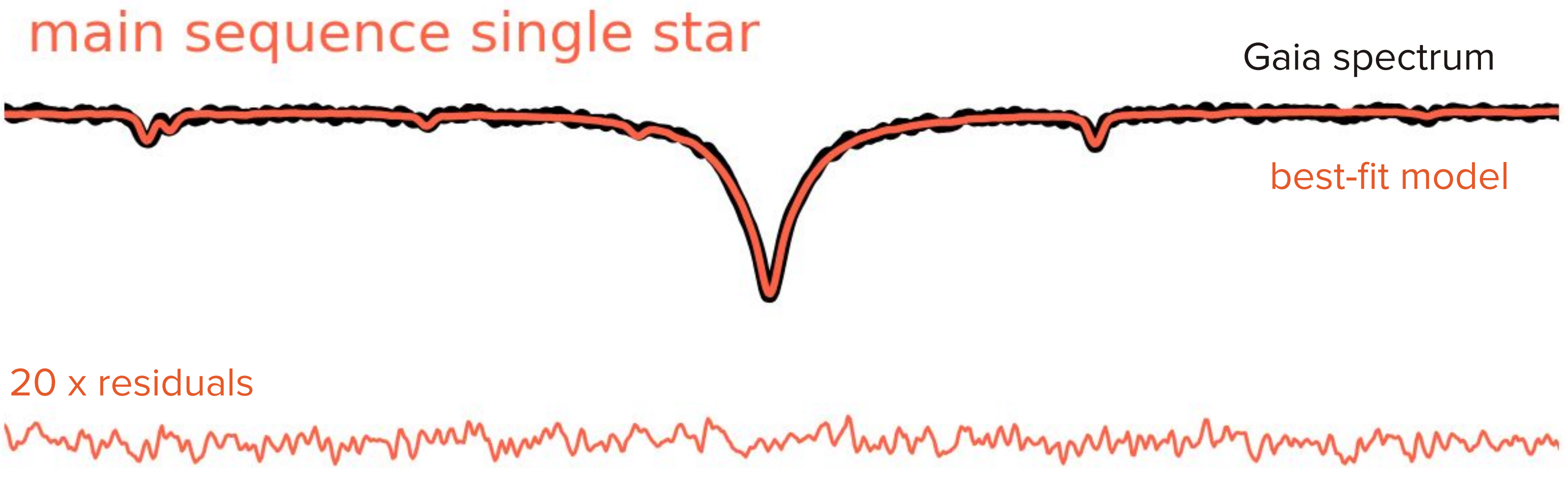


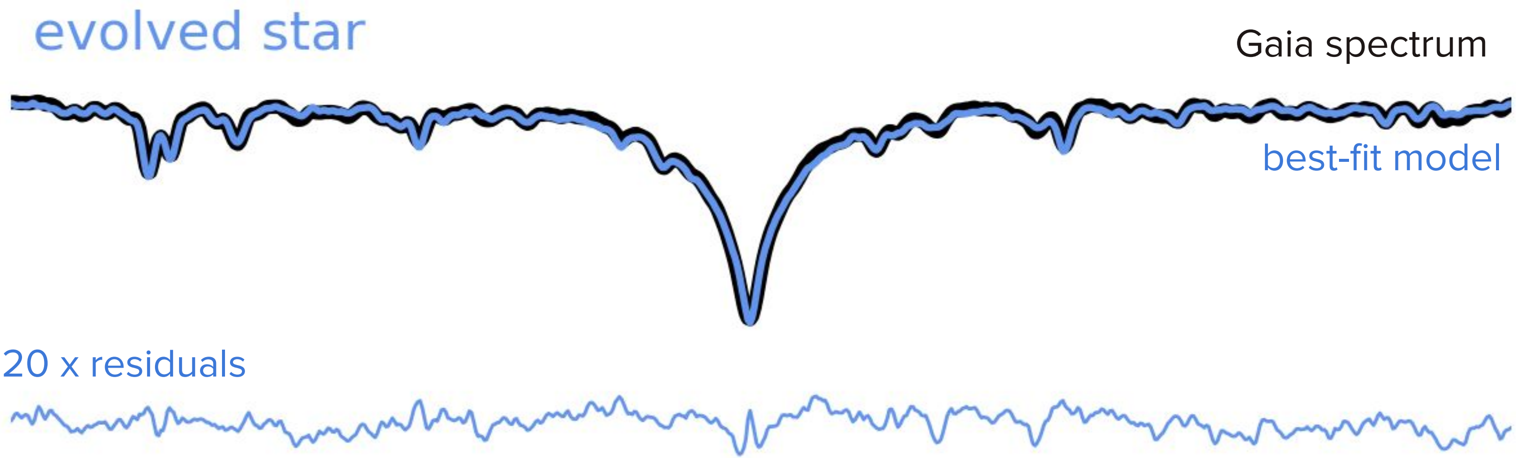
sensitive to binaries missed by AO and RV surveys!

Our spectral model metrics can be used to identify stellar activity, binary stars, and evolved stars



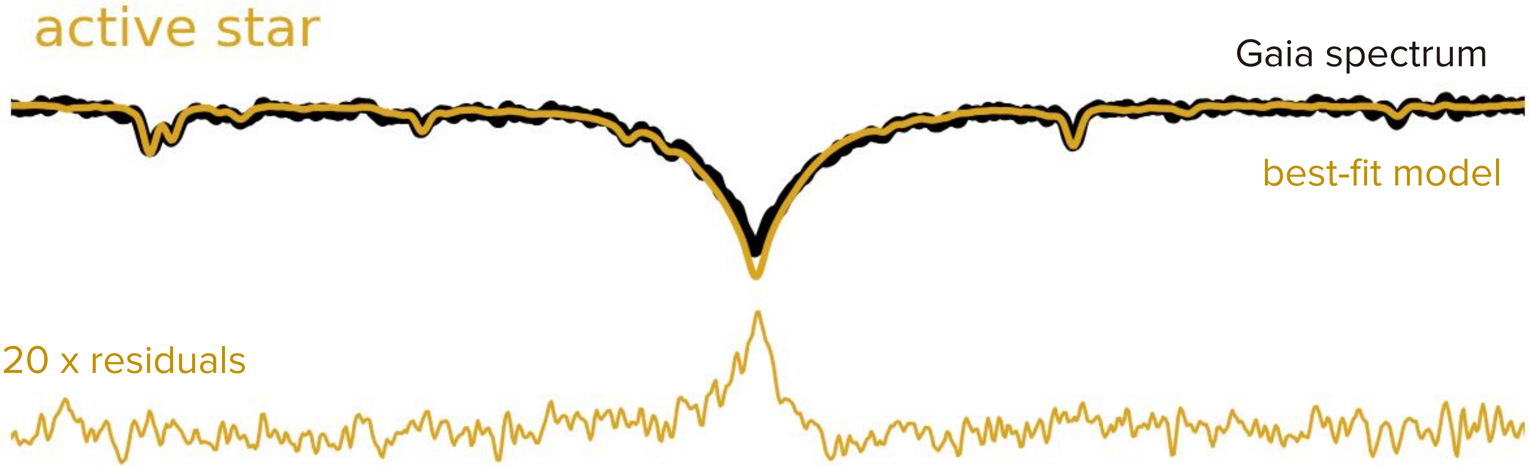
model produces good fit, metrics are reasonable

Our spectral model metrics can be used to identify stellar activity, binary stars, and evolved stars



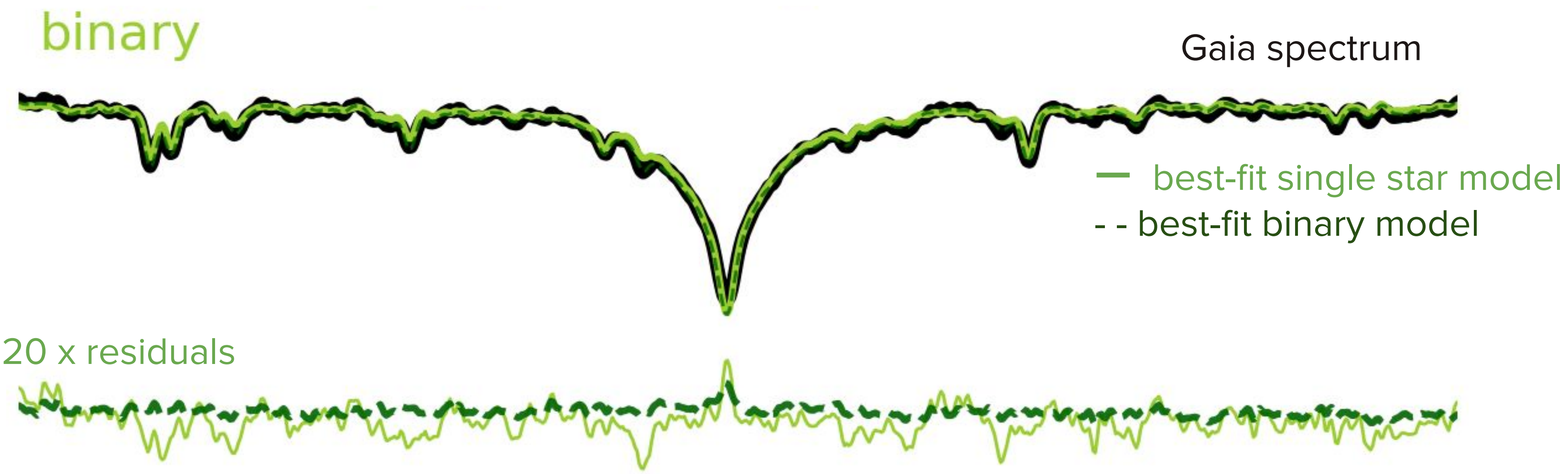
model produces poor fit everywhere, χ^2 is large and $\rho_{training}$ is small

Our spectral model metrics can be used to identify stellar activity, binary stars, and evolved stars



model produces poor fit everywhere except activity-correlated lines,
χ_{Ca}^2 *is large*

Our spectral model metrics can be used to identify stellar activity, binary stars, and evolved stars



model is significantly better fit by binary model, $\Delta\chi^2_{binary}$ is large

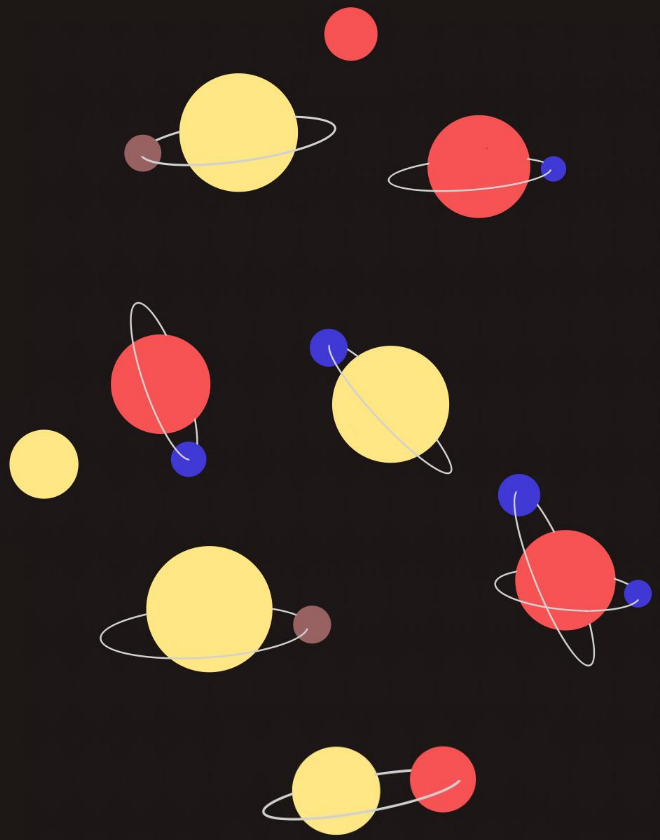
Summary

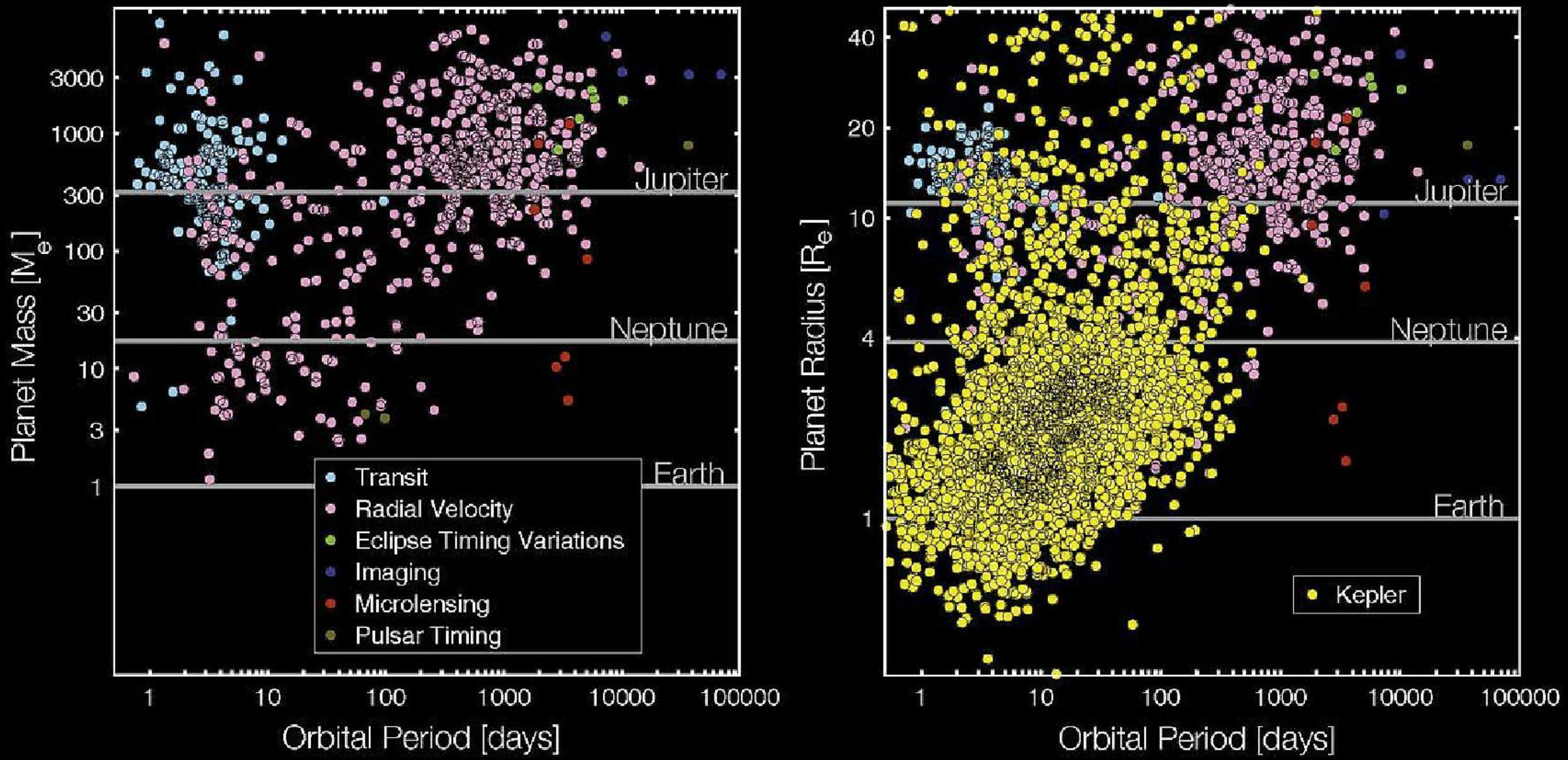
- most planets are discovered with photometry and **require spectroscopic follow-up** to characterize

- Gaia DR3 released **spectra for thousands of stars in the Kepler and TESS fields** (with more to come in DR4!)

- our data-driven spectral model **computes stellar properties** with comparable precision to ground-based surveys, and establishes metrics to **identify binaries, stellar activity, and evolved stars**!

stay tuned for published model and planet host properties! (Angelo et al 2024)

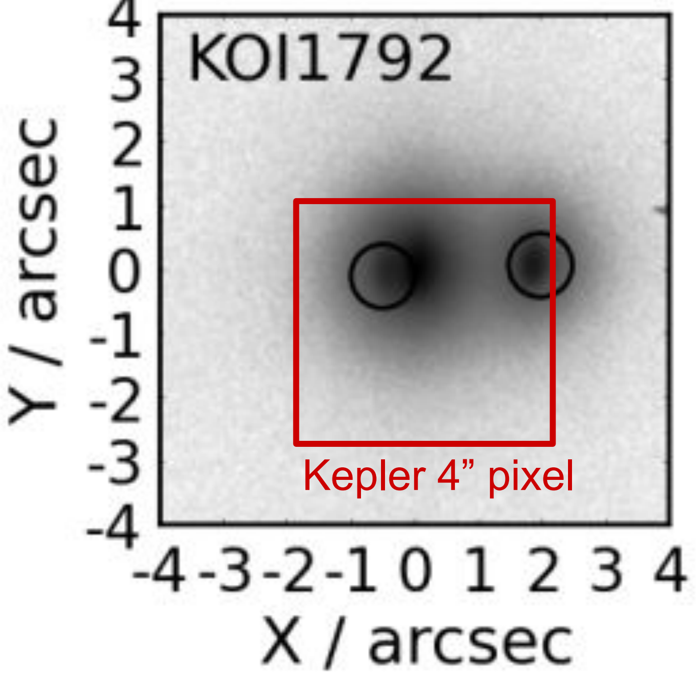




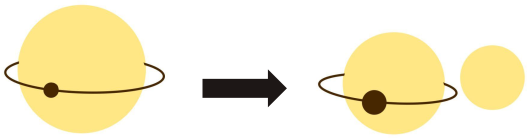
Planet Mass [M_e]
3000
1000
300
100
30
10
3
1
Jupiter
Neptune
Earth
Transit
Radial Velocity
Eclipse Timing Variations
Imaging
Microlensing
Pulsar Timing
1
10
100
1000
10000
100000
Orbital Period [days]
Planet Radius [R_e]
40
20
10
4
1
Jupiter
Neptune
Earth
Kepler
1
10
100
1000
10000
100000
Orbital Period [days]

Close binaries in Kepler are mistaken for single stars

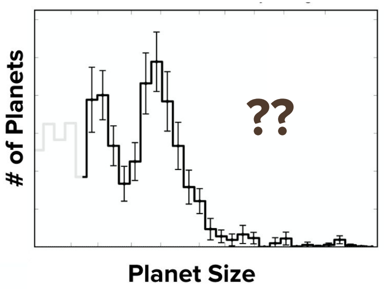
Ziegler et al. 2017



This can lead to:

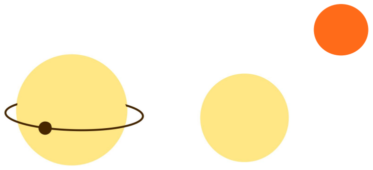


diluted transits +
underestimated planet radii



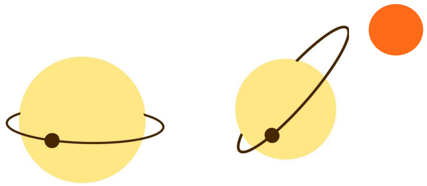
errors in planet demographic trends like the radius gap (Fulton et al. 2017)

A complete sample of binaries among planet hosts will allow us to test theories of how binaries sculpt the exoplanet population



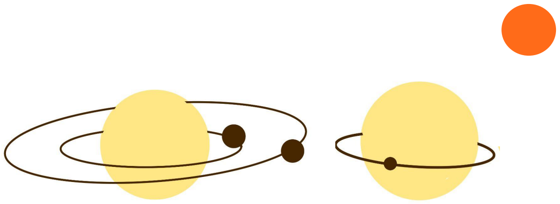
do binaries suppress planet formation?

e.g., Kraus et al. 2016, Hirsch et al. 2021



do binaries sculpt dynamically rich orbits?

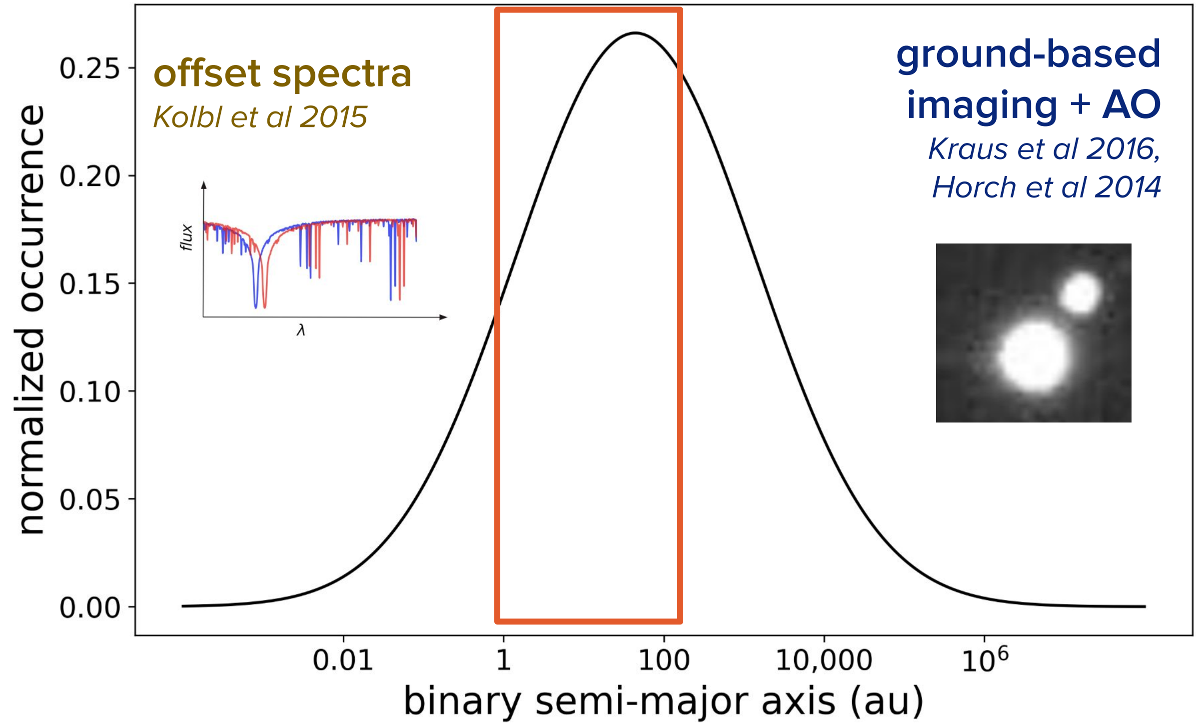
e.g., Naoz et al. 2012, Becker & Adams 2017, Li et al. 2014



do binaries deplete planet reservoirs?

e.g., Quintana et al. 2007, Jang-Condell 2015

Previous searches for binaries among Kepler planet hosts

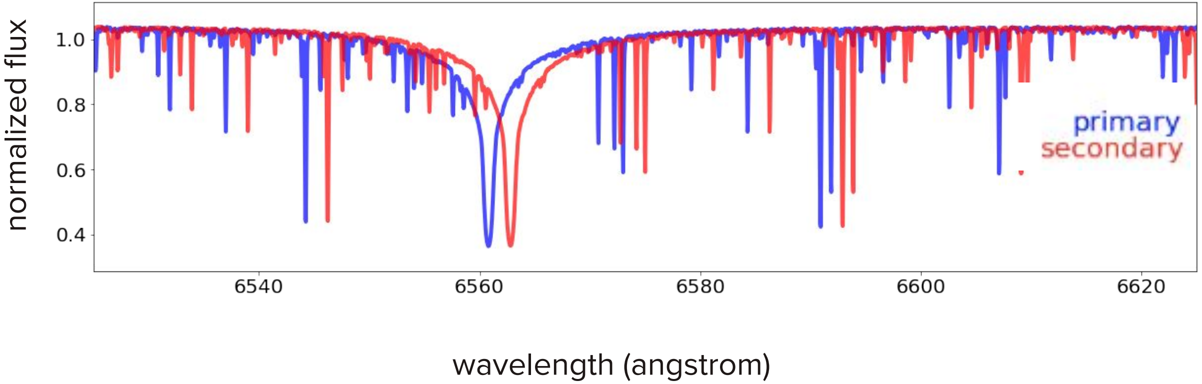


see: Moe & Di Stefano 2017, Raghavan et al. 2010

Spectroscopic binaries are traditionally identified by their characteristic double-lined spectra *(e.g., Kolbl et al. 2015)*

traditional method: identify 2 sets of spectral features

simulated binary



caveat: requires >10 km/s relative velocity between stars (i.e. a≲1au)

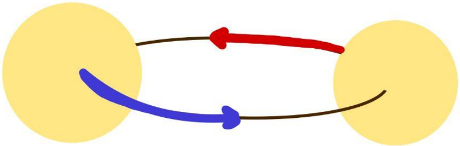
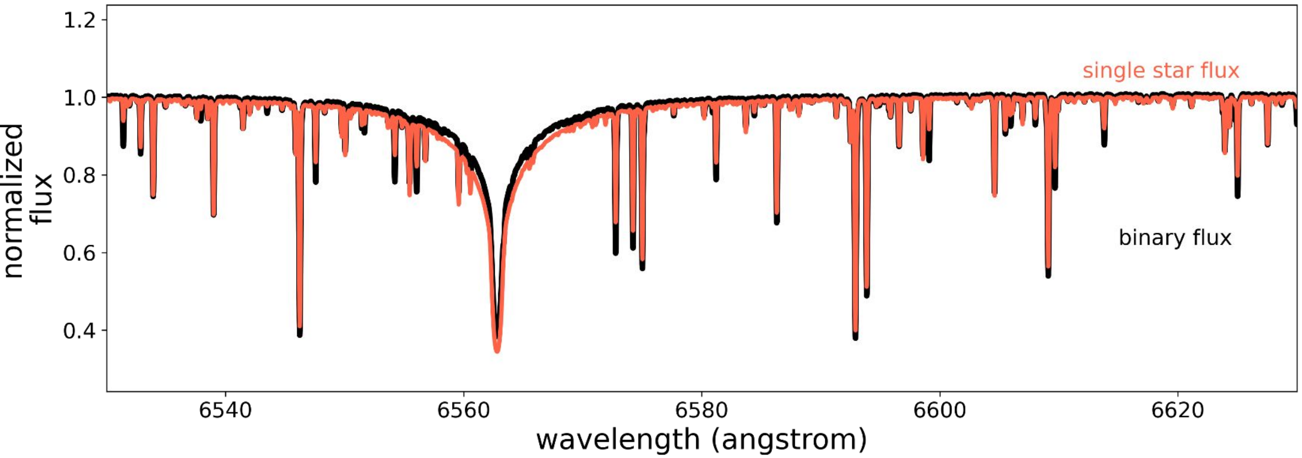


figure credit: Angelo et al., in prep

Advances in spectrum modeling allow us to identify binaries with *overlapping* spectral features, thereby increasing sensitivity

(e.g., Burgasser et al. 2010, El-Badry et al. 2018)

simulated binary + single star



sensitive to binaries with a=1-200au!

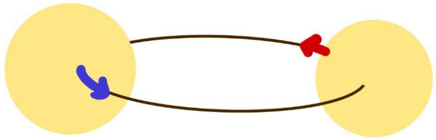
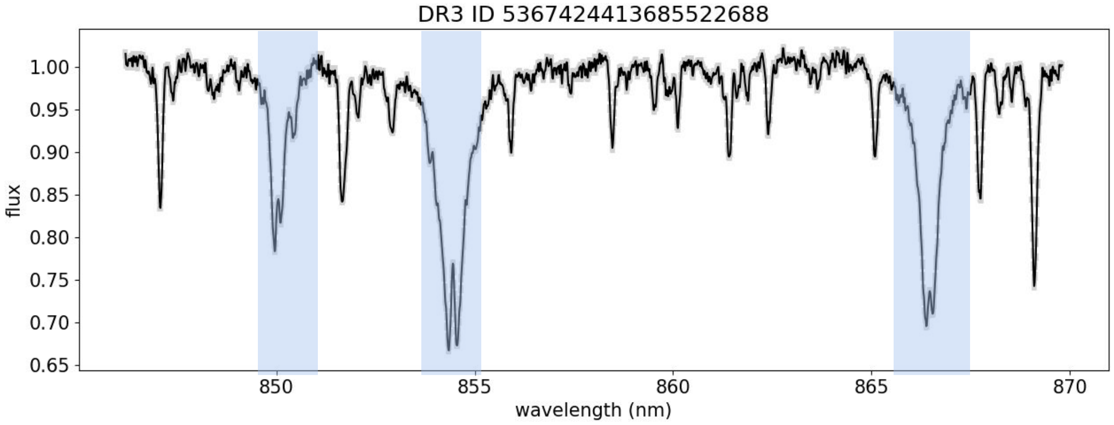


figure credit: Angelo et al., in prep

We've also uncovered a number of stars with superimposed Calcium emission + absorption



possible explanations:

interacting binaries

young accreting T Tauri stars

chromospheric activity in GKM main-sequence stars

emission linked to the accretion of matter in the stellar magnetosphere