Improving Planet Parameters through Composite Limits on Stellar Companions

Mackenna Wood, Andrew Mann, UNC Chapel Hill Dept. of Physics and Astronomy

THE UNIVERSITY *of* NORTH CAROLINA *at* CHAPEL HILL

Background

A non-detection of stellar companion(s) does not guarantee they do not exist. Such binary companions hidden below the detection limits impact the inferred parameters of a transiting planet, and may change our interpretation of a transit-like signal. Limits can be placed on the orbital and physical parameters of an undetected companion by combining commonly available data for planet hosts, including adaptive optics images, spectra, and astrometry from Gaia. We present a tool that provides posteriors on orbital and physical parameters of possible binary companions given upper limits from a wide variety of data sources, utilizing (user-adjustable) priors on the binary population. This also provides a tool to explore rates of binarity and planet occurrence, as it fully explores the parameter space and accounts for companions missed by chance.

Monte Carlo Simulation

Monte Carlo simulation of binary companions is used to determine the parameters of possible hidden companions. Orbital parameters of the companions are generated using prior distributions from the literature.

Adaptive Optics Imaging

Contrast curves from adaptive optics imaging is used to put limits on mass and semi-major axis. Using stellar models from Baraffe et al. (2015), the magnitude of the hypothetical companions are found, and compared with the given contrast curve.

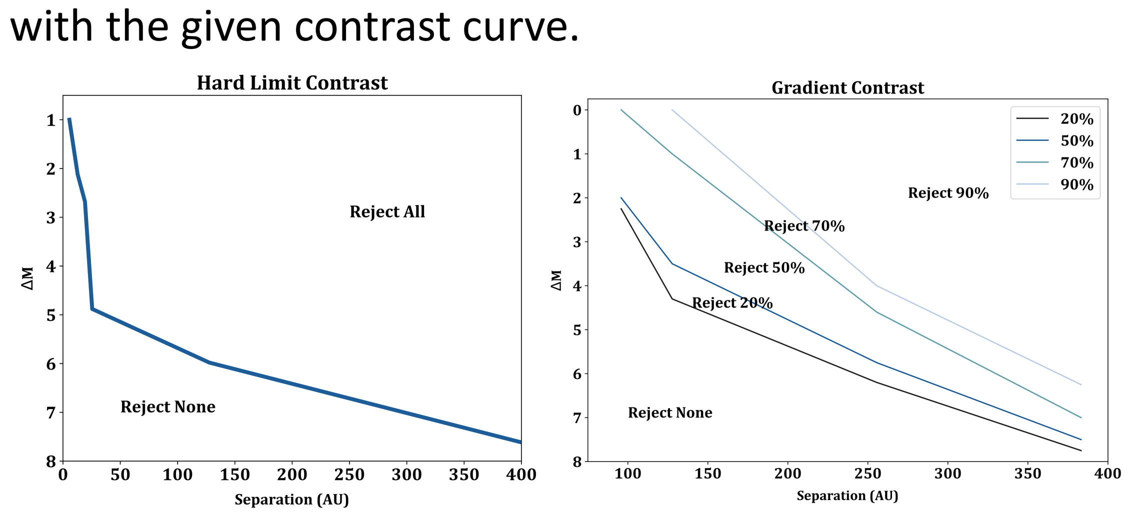

Figure 1: Example of hard limit (left) and gradient (right) contrast curves.

Radial Velocity & Jitter

This code can do a more complete analysis than a traditional RV analysis (e.g. Figure 2), by taking into account (at the user's discretion) a range of eccentricities, inclinations, in addition to the usual exploration of period and mass ratio. An optional stellar jitter term to account for RV variation not due to Keplerian signal can be added. The results can be converted into a simple detection limit curve (e.g. Figure 4) or analyzed in more detail to see what kinds of undetected companions are present in the data. For example, if certain companion inclinations are allowed that might give clues to the dynamical origin of a misaligned planet (e.g., from Kozai-Lidov).

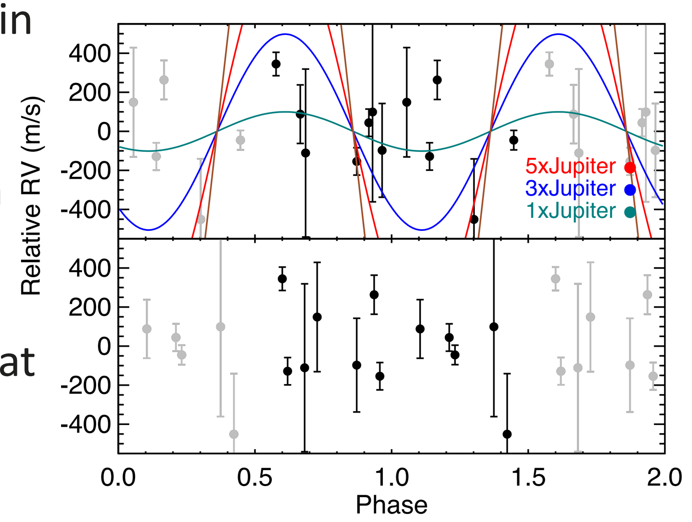

Figure 2: Traditional RV curve fitting

Gaia Constraints

Gaia also provides a test of the possibility of nearby companions. The detection probabilities for companions in Gaia were calculated in Zeigler et al. (2018) and Rizzuto et al. (2018). These can be used to limit the mass and separation of the companion, similar to Adaptive Optics Imaging, but adding strong constraints outside of 1".

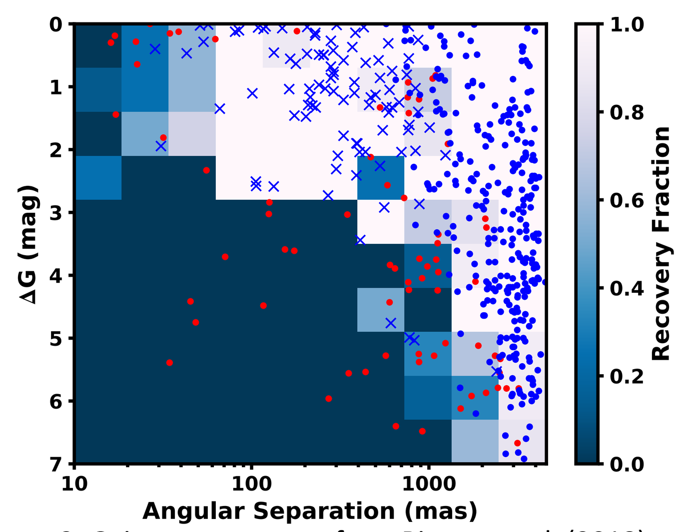

Figure 3: Gaia recovery rates from Rizzuto et al. (2018)

Gaia RUWE

The Gaia RUWE metric is a measure of how well a star fits the expectation for a single star pfd. It is normalized so that the ideal measurement of a single star with have an RUWE of 1. A star with an RUWE significantly higher than 1 is likely to not be a single star. By compiling lists of known single and binary stars, and determining their RUWEs, the RUWE distribution for each population of stars was compiled. This is used to calculate the probability that the system is a binary given the Gaia RUWE, which is used as an overall suppression rate on the survivors.

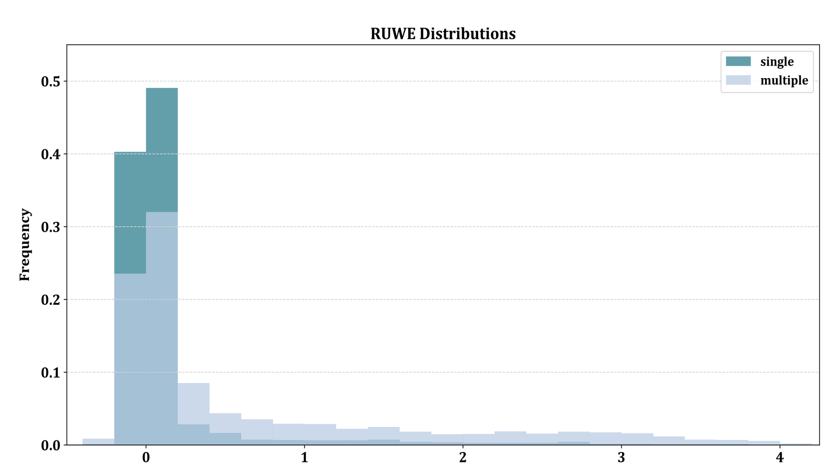

Figure 4: The RUWE of single and binary star populations. The shorter peak and long tail of the multiple star distribution makes this a useful test of possible binarity.

Testing and Results

This software has been tested on two newly detected planets described in Newton et al. (2019) and Rizzuto et al. (in prep).

DS Tuc A

DS Tuc A is a star with a newly detected planet around it, and a known companion. RV data was used to produce these limits.

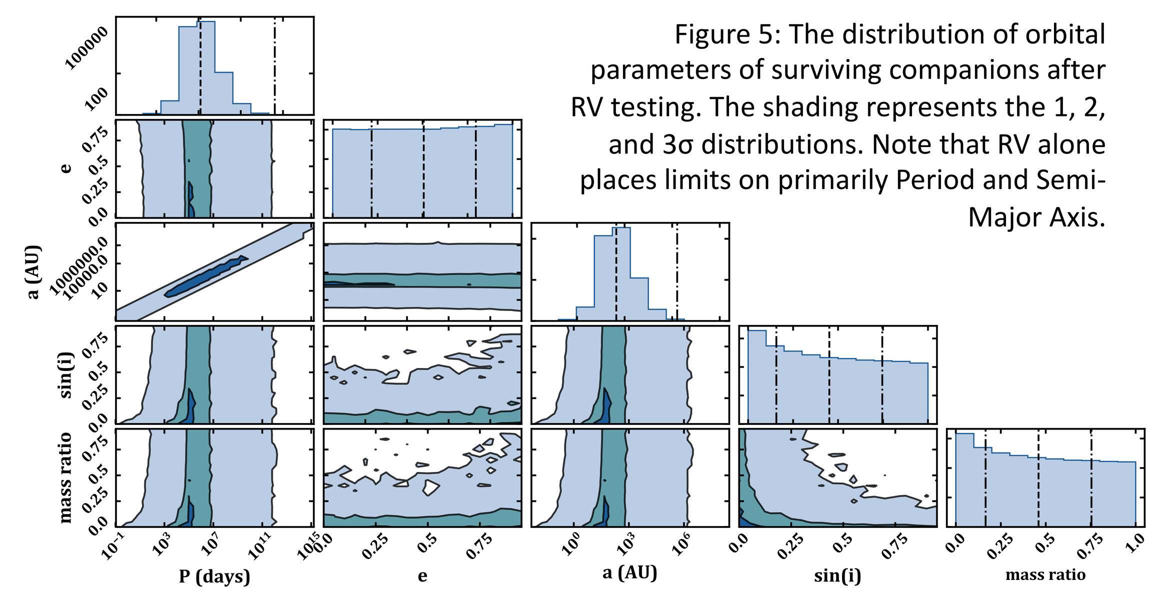

Figure 5: The distribution of orbital parameters of surviving companions after RV testing. The shading represents the 1, 2, and 3σ distributions. Note that RV alone places limits on primarily Period and Semi-Major Axis.

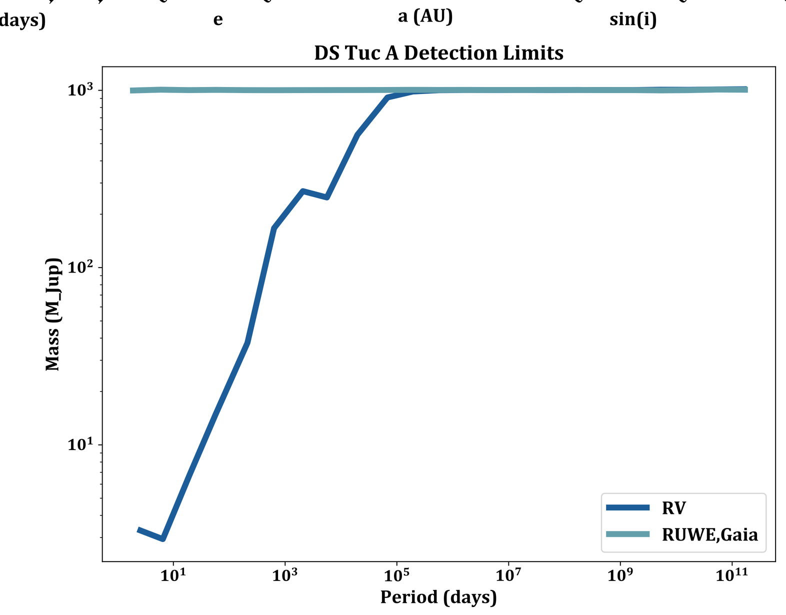

Figure 6: Companion detection limits for DS Tuc A demonstrating the usefulness of combining multiple tests. For these limits the generated binaries were all forced to have sin(i) ~1 to simulate only transiting objects.

Works Cited

Baraffe et al. (2015). *A & A*, *577*, A42.
Ziegler, C. et al. (2018) *AJ 156(6),* 259
Newton, E. et al. (2019)
Rizzuto, A. C. et al. (2018). *AJ*, *156*(5), 195.
Rizzuto A. C., et al.(in prep)

HIP 67522

HIP67522 is a star with a newly detected planet orbiting it at P~13. RV and AO data were combined to produce these limits. Plots of the surviving orbital parameters are below, as well as a plot showing the detection limits of a companion with the given data.

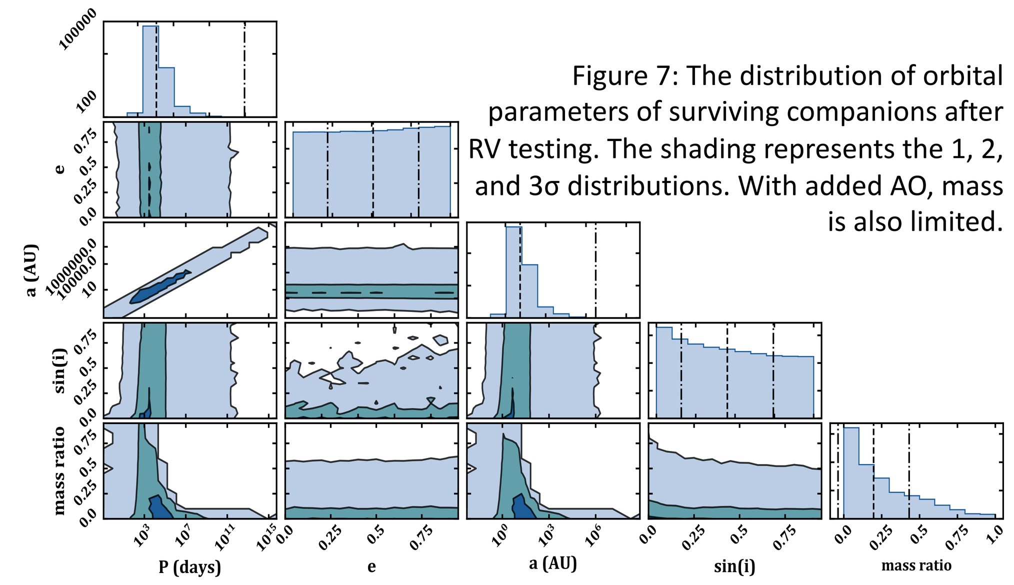

Figure 7: The distribution of orbital parameters of surviving companions after RV testing. The shading represents the 1, 2, and 3σ distributions. With added AO, mass is also limited.

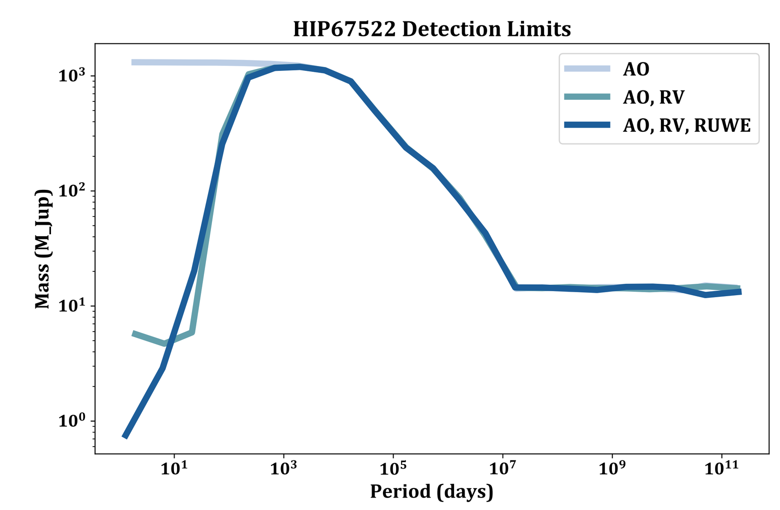

Figure 8: Companion detection limits around HIP67522 demonstrating the usefulness of combining multiple tests. For these limits the generated binaries were all forced to have sin(i) ~1 to simulate only transiting objects.

Future Prospects

- Color Magnitude Diagram position
- Transit Timing Variation constraints
- Running on Kepler volume limited sample to compute unseen binary occurrence rates
- More?

Acknowledgements

The authors would like to acknowledge contributions by A. Rizzuto