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Editorial: The Effect of Stellar Multiplicity on Exoplanetary Systems

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Editorial on the Research Topic

The Effect of Stellar Multiplicity on Exoplanetary Systems

Exoplanet discovery is a recent endeavor, being only about a generation old. Characterization of exoplanetary systems is well underway and one of the most exciting findings is that planets can form and survive in binary star systems. Binary systems provide unique environments and planetary architectures, as well as presenting special observational challenges and research opportunities. Current work on observation, formation, dynamics and evolution of exoplanets residing in binary star systems forms a large research arena. Planning for future exoplanet studies, both from large aperture ground-based telescopes and focused "search for life" 6-m space telescopes, requires both insight into the nature of such complex systems as well as a full understanding of the best exoplanet candidates. Additionally, proper telescope and instrument design need to build on such information in order to deliver successful future observations.

Given that about half of all exoplanet systems exist in multiple star systems, it seems timely and appropriate to put together this Research Topic. Observational as well as theoretical work on the formation and evolution of exoplanetary systems and their stars, current and future searches for habitable worlds, and near-future work on direct imaging and terrestrial planet atmospheric spectra, will need to take multiple stellar hosts into account. Furthermore, to infer the true distribution of planetary properties and exoplanetary occurrence rates, a proper treatment of multiple stellar hosts is required.

Many bright and nearby stars, some visible to the naked eye, are now known to host exoplanets, leading to a stronger connection of the night sky to the age-old question "Are we alone?". In this Research Topic, the above ideas and current investigations from theory modeling, and observation are collected together to provide insights into this field of study. Transit searches, especially those being conducted from space (e.g., Kepler, TESS, CHEOPS), are finding thousands of candidate exoplanets all in need to detailed follow-up, characterization, theoretical modelling and study.

Observational Studies and High-Resolution Imaging: High-resolution imaging in both the IR and the optical band-passes has matured into one of the mainstays of exoplanet validation and characterization. Large ground-based programs, such as those undertaken by NASA, observe and provide to the exoplanet community many hundreds of observations each year. These surveys contribute to the Exoplanet Follow-up Observing Program (ExoFOP) archive which includes a broad range of follow-up studies of targets observed by TESS, K2, and Kepler plus a number of other exoplanet search programs. High-resolution imaging allows the elimination of possible contamination from blends, such as bound and background sources, in the near vicinity ($<$ a few arcsec) of the exoplanet host star. This is an important step to assess host star multiplicity and increase the statistics of exoplanet occurrence rates in multiple systems. High-resolution imaging also yields a more precise determination of the planet radius yielding confirmation of small planets beyond the reach of PRV (Precise Radial Velocity) measurements (such as those terrestrial planets in

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the habitable zone) as well as planets that orbit fainter stars. The precise knowledge of the physical parameters of exoplanets, and their hosts stars, are an important step to give robust information about the planet formation process and possible differences between formation and evolution of planetary systems in binary and single stars.

In their paper, Schlieder et al. discuss some results of their multi-year campaign to observe candidate exoplanet host stars using Keck NIRC2 AO imaging. In the optical, Howell et al. and Ziegler et al. use ROBO-AO and speckle interferometric techniques to perform surveys of exoplanet host stars in order to assess their multiplicity fraction and provide needed "third-light" corrections to both the stellar and planetary parameters. Observations of many hundreds of exoplanet host stars have allowed studies of the statistical properties of binary exoplanet host stars, revealing a number of intriguing properties. Binary hosts have, in general, wider spatial separations, possible planer alignment between the binary plane and the known planetary orbits, and serious observational biases in the detection of small, Earth-size planets. Theoretical work is needed to refine the current models of binary and exoplanet formation and to reconcile them with the recently available observational results.

Gaia Contributions: While observational evidence has shown close stellar companions, such as those detected with high-resolution imaging, affect planet formation, the role of companions at intermediate separations ($\sim 100 - 300$ AU) is still uncertain. At angular separations greater than about one arcsecond stellar companions can be resolved as individual point sources, however, as the separation between the stars increases it becomes increasingly difficult to distinguishing between physically bound stars and optical alignments. The position, proper motion, and parallax data of more than a billion stars provided by Gaia has enabled the detection of stellar companions consistent with being gravitationally bound over a wide range of separations.

The papers by Michel and Mugrauer and Fontanive and Bardalez Gagliuffi use Gaia DR2 to search for co-moving stellar companions to exoplanet host stars. As part of an ongoing multiplicity survey, Michel & Mugrauer detected 61 companions (47 stars, 1 white dwarf, and 13 brown dwarfs) to 289 exoplanet host stars within 500pc of the Sun for a multiplicity rate of 16%. The detected companions have masses of $0.06 - 1.66 M_{\odot}$ with projected separations of $52 - 10,000$ AU.

Fontanive and Bardalez Gagliuffi use Gaia DR2 and existing literature to find 218 companions to 938 exoplanet (and brown dwarf) host stars within 200pc, yielding a multiplicity rate of 23%. The detected companions have masses between $\sim 0.07 - 2.37 M_{\odot}$ and projected separations of $0.5 - 20,000$ AU. However, they find that small planets ($< 0.1 M_{\rm Jup}$) have a lower binary rate than more massive Jovian planets. Fontanive and Bardalez Gagliuffi also explore trends between multiplicity and the properties of the planetary companions in their sample, finding that high-mass ($> 0.1 M_{\rm Jup}$), small-separation planets have a different distribution of planet properties than planets in single star systems.

Such studies of wide companions to exoplanet host stars confirm the wider binary separations seen in high-resolution studies, as compared to field stars, with the Fontanive and Bardalez Gagliuffi paper finding a peak around 600 AU. While stellar companions at separations of thousands of AU appear to have no impact on planetary populations, the different trends for high-mass, small-separation planets as a function of multiplicity found by Fontanive and Bardalez Gagliuffi suggest that stellar binary companions likely affect the formation and/or migration of such objects. Further studies of exoplanet host stars with stellar companions within tens to hundreds of AU will be key to unraveling the impact stellar binaries have on planet formation.

Circumbinary Planets and Habitability: A challanging problem in binaries is assessing the habitability of terrestrial planets either on circumstellar (S–type) or circumbinary orbits (P–type). The scenario may be further complicated by the presence of a giant planet on an outer orbit. The combination of the binary and exterior planet perturbations may destabilize the habitable zone or produce large variations in the orbital elements which may jeopardize the habitability of an Earth–size planet. Giant planets on outer orbits have indeed been found in a significant fractions of exoplanets in S–type orbits (like 94 Cet or HD 169 885) and in P–type orbits (Kepler–35 or Kepler–39). When dealing with P–type configurations it is necessary to account also for the two close sources of radiation, possibly of different spectral type which may also affect the habitability of a planet.

In their paper, Georgakarakos et al. compute the location of the habitable zones for circumbinary terrestrial planets perturbed by an external giant planet. In this study, they adopt the concept of "dynamically informed habitable zones" (DIHZ) which accounts not only for the orbital evolution of the planet, which affects its distance from the binary, but also for the climate inertia defined as the time it takes climate parameters, such as the mean surface temperature, to react to radiative forcing.

In order to calculate DIHZ borders for circumbinary systems it is necessary to determine whether or not the dynamical configuration is stable, how the orbital evolution of the system affects the amount of radiation the planet receives, and how the star light influences the climate of a potentially habitable world.

Georgakarakos et al. apply their analytical formulations for the computation of the limits of the DIHZ to a sample of circumbinary systems where a known giant planet is on a circumbinary orbit. By applying their methodology, they prove that the presence of the additional known planet in the majority of cases does not prevent the existence of habitable words such as in the case of Kepler-35, Kepler-38, and Kepler-64.

For planets in S–type orbits, the combined perturbations of the binary companion and an external giant planet are more complex due to the presence of secular resonances. Pilat-Lohinger and Bazsó in their paper explore this peculiar dynamical environment and they describe the main features of the algorithm SHaDoS (Secular perturbations in Habitable zones of Double Stars), accessible at https://www.univie.ac.at/adg/shados/index.html, which determines the location of secular resonances in the habitable zone around the primary star. This algorithm allows, for given initial conditions concerning the binary and exterior planet orbital elements and masses, to compute the stable areas within the habitable zone of the system for putative terrestrial planets. Applications of SHaDoS to the wide binary star HD106515 AB and the tight system HD41004 AB reveal a quiet HZ for both systems.

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