1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title:

Exoplanets around evolved stars.

1.1. Project goals

This project aims at detection of extrasolar planetary systems around solar-mass evolved stars from the sample defined within Pennsylvania-Toruń Planet Search (PTPS), and a statistical study of a larger sample of stars from several radial velocity searches for exoplanets around evolved stars. Within PTPS sample of 885 evolved stars 30 planetary systems were already detected. Several new candidates were recently identified in the sample that show radial velocity variations consistent with planetary-mass companions ($m_p \sin i < 13\ M_J$). We propose to explore the sample (in which we accumulated multiple epoch data for all stars) in depth and search for more low-mass companions. Detection of several new exoplanets is expected within this part of the project.

In parallel to planet search a statistical analysis of a large sample of all evolved stars searched for exoplanets by several teams is planned. The questions that will be addressed with this study include planet occurrence rate in evolved planetary systems, planet occurrence rate versus stellar metallicity relation for evolved solar-mass stars, high stellar mass limit of planetary systems, Jupiter analogs occurrence rate versus evolutionary stage of the host star and impact of stellar evolution on planetary systems architecture.

1.2. Outline

The first planets orbiting other stars were discovered over 30 years ago. Massive exoplanet searches launched since then resulted in detections of nearly six thousands of such objects. These research projects revealed a vast variety of exoplanetary system architectures and a multitude of exoplanet types, including unobserved in our Solar System Hot Jupiters, Super Earths, Hot Neptunes. Vast majority of known exoplanetary systems are hosted by stable Main Sequence stars of solar- or low-mass. Relatively only a small number (146 substellar companions in 129 systems) of evolved planetary systems is known (33 companions in 30 systems were detected by our PTPS and Tracking Advanced Planetary Systems with Harps-N, TAPAS projects). Certainly searches for exoplanets around evolved stars deserve more attention as they allow us to reach otherwise unavailable to current techniques planetary systems of stars significantly more massive than the Sun. They also give us an insight into evolved planetary systems, affected by billions of years of planet-planet dynamical interactions and stellar evolution of their hosts.

Proposed project is based on existing high precision radial velocity data obtained with the Hobby-Eberly Telescope within PTPS and with Harps-N within TAPAS. For some stars additional observations will be required. The collected data will be modelled with state-of-art Keplerian orbit fitting algorithms, like Markov chain Monte Carlo (MCMC). More complicated multi-planetary

systems will require dynamical modeling. Collected high resolution spectra will also be searched for evidence of stellar activity to exclude false detections. The statistical properties of evolved planetary systems will be studied based on published data from existing projects with dedicated software tool prepared by the student.

It is expected that the resulting PhD Thesis will be based on at least three refereed journal publications.

1.3. Work plan

The planet search part of this project will require modelling of already collected data, application for more observations for identified planetary system candidates, collection of new data and final modeling of all gathered data. Detailed analysis of stellar activity of observed stars will also be required. The statistical analysis will be based on a compilation of all available data on all evolved stars searched for exoplanets, including detected exoplanets. New dedicated software prepared by the student will be required to manage the resulting database and for statistical analysis of collected data.

1.4. Literature *(max. 7 listed, as a suggestion for a PhD candidate preliminary study)*

Maciejewski, G., Niedzielski, A. et al. (2024) **Tracking Advanced Planetary Systems (TAPAS) with HARPS-N. VIII. A wide-orbit planetary companion in the hot-Jupiter system HD 118203**, Astronomy & Astrophysics, Volume 688, id.A172, 13 pp.

Wolthoff, V. et al. (2022) **Precise radial velocities of giant stars. XVI. Planet occurrence rates from the combined analysis of the Lick, EXPRESS, and PPPS giant star surveys**, Astronomy & Astrophysics, Volume 661, id.A63, 17 pp.

Niedzielski, A., Villaver E., et al (2021) **Tracking Advanced Planetary Systems (TAPAS) with HARPS-N. VII. Elder suns with low-mass companions**, Astronomy & Astrophysics, Volume 648, id.A58, 14 pp.

Döllinger, M. P. and Hartmann, M. (2021) **A Sanity Check for Planets around Evolved Stars, The Astrophysical Journal Supplement Series**, Volume 256, Issue 1, id.10, 12 pp.

Deka-Szymankiewicz, B., Niedzielski, A. Et al. (2018) **The Penn State - Toruń Centre for Astronomy Planet Search stars. IV. Dwarfs and the complete sample**, Astronomy & Astrophysics, Volume 615, id.A31, 11 pp.

1.5. Required initial knowledge and skills of the PhD candidate

Knowledge: MSc in astronomy. English level B2 minimum.
Skills: Unix/Linux/MacOS system, Python programming.

1.6. Expected development of the PhD candidate's knowledge and skills

The PhD candidate is expected to become an expert in the field of radial velocity based searches for exoplanets and statistical analysis of data.