Searching and characterizing young planets with the GAPS2 project

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1. Introduction

Since 2012 the GAPS (Global Architecture of Planetary Systems; [1]) project at the *Telescopio Nazionale Galileo* (TNG) involves a large part of the Italian community working on exoplanetary science. In the first five years, the project was based on radial velocity (RV) surveys with the HARPS-N@TNG spectrograph and was focused on the search and characterization of planetary systems around stars with different properties. In 2017, thanks to the integration of GIARPS (GIANO-B & HARPS-N) at the TNG, the GAPS2 project started to explore the origin and the diversity of planetary systems adopting a twofold approach: the observation of planetary atmospheres and the detection/study of planets around young stars. The current literature suggests that we should expect a large fraction of hot Jupiters around very young stars with respect to the old ones, but the available statistic is poor and based on claimed detections still not confirmed by independent investigations. The observation of planets around young objects is therefore important because it allows us to study the ongoing planet formation, helping to investigate the role played by the formation sites, the migration mechanisms, and the orbit evolution.

2. The GAPS Young-Objects Program

The Young Objects (YOs) sub-program of the GAPS2 project performs a blind search for young planets by surveying members in young (e.g., Taurus, Upper Scorpius, Cepheus) and intermediate-age (e.g., Ursa Major, Coma Berenices, Hyades) associations, and carries out RV follow-up for planet candidates around young stars, mainly provided by the NASA-TESS satellite. We aim to determine the architectures and orbital parameters of hot and warm Jupiters and hot Neptunes around young (<100 Myr) and intermediate-age (<800 Myr) primaries, to clarify the prevailing migration mechanism, the dependence of formation site and orbit evolution of planetary mass and host properties, and to constrain the occurrence of evaporation for planets in close orbits around stars with large high-energy flux. Because of the difficulties introduced by the nature of young objects, we overcome the effects of the high level of the stellar activity through Gaussian Process regression techniques. Here, we will review some results of our survey around young objects.

4. The First Case Studies

HD285507 is a member of the Hyades cluster (~625 Myr). In 2014, a hot-Jupiter candidate around the star was claimed from TRES RVs [3]. Our analysis of high-precision RV data from GIARPS confirmed the Keplerian nature of the signal, and refined the measurement of the orbital eccentricity, which turned out to be close to zero, i.e. compatible with a disk migration scenario [4].

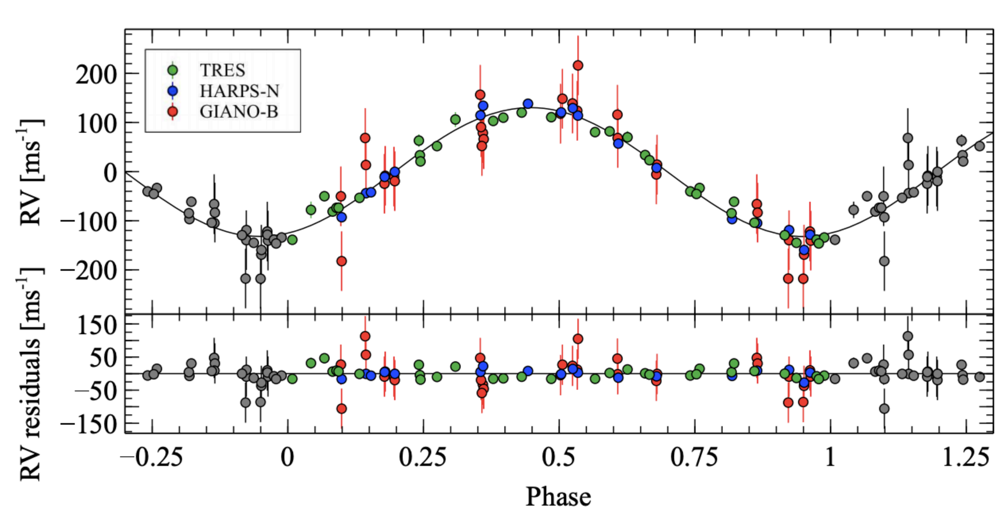

Fig. 1 – Keplerian fit (black line) at ~6.0 days obtaining combining the visible data from HARPS-N (blue diamonds) and TRES (green dots), and NIR data from GIANO-B (red dots).

AD Leo is a close active young star (~25-300 Myr) for which the presence of a planet in a spin-orbit resonance was proposed [5]. Our observations of this M star ruled out the claimed planet. The modulation of the RVs from HARPS-N is not reproduced by the RVs from GIANO-B, thus rejecting the Keplerian nature of the visible RV variations [4].

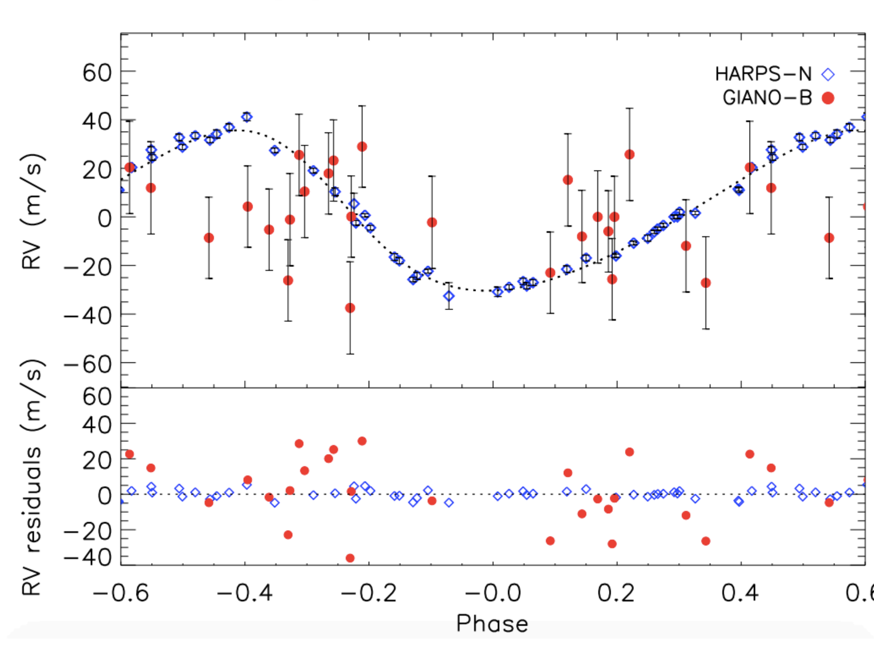

Fig. 2 – Orbital fit (black dotted line) at ~2.2 days obtained with the visible HARPS-N data (blue diamonds), with the GIANO-B NIR data (red dots) overplotted.

V830 Tau is a weak-line T-Tauri star (~2 Myr). A hot-Jupiter mass planet was announced in 2016 [6]. The host star shows a very high level of activity, at least an order of magnitude higher than the semi-amplitude of the detected planetary signal. We therefore followed-up V830 Tau for 2.5 yr with the aim to confirm the presence of the planet with a careful treatment of the RV activity through Gaussian Process regression techniques. Despite the different tests performed, we could not confirm the existence of the planet [7]. This result, supported by simulations, shows how challenging can be the blind detection of planets around very young active stars.

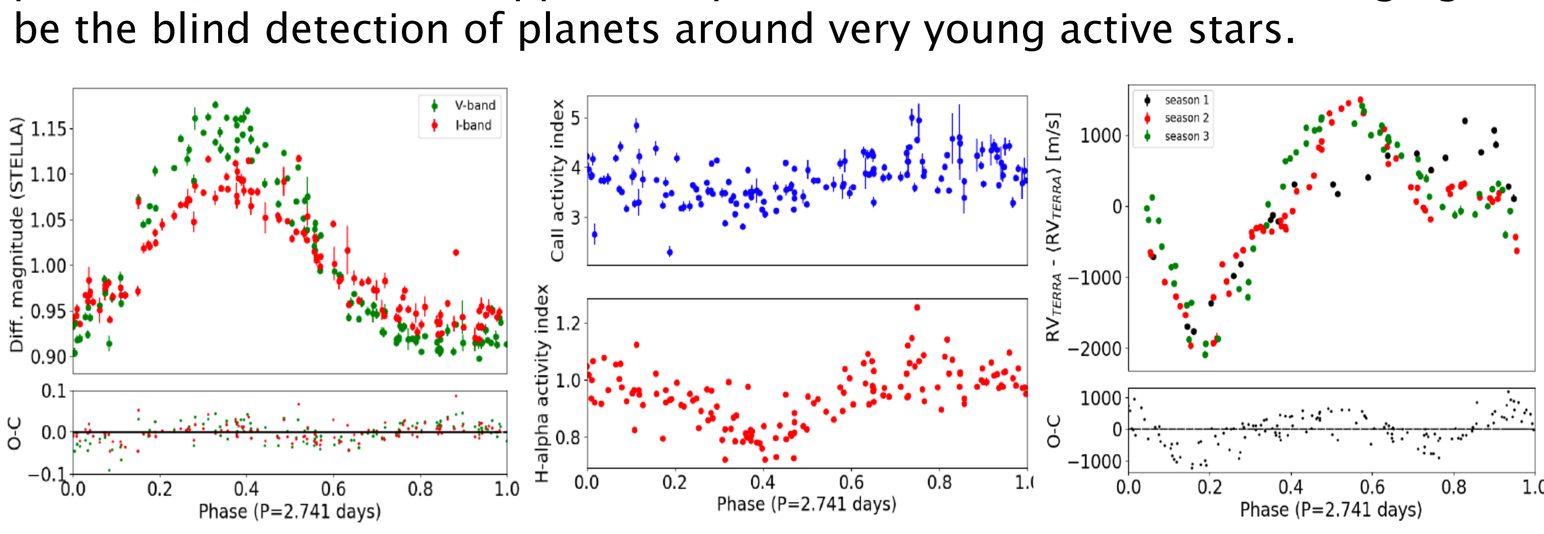

Fig. 3 – Light curves (*left panel*) and chromospheric activity indicators (*middle panel*) are anti-correlated, indicating a spot-dominated activity. This is also confirmed by the smaller amplitude of the I-band light curve when compared to the V-band amplitude. The ~0.2 phase shift between RVs (*right panel*) and light curves is typical of the effect related to the flux deficit due to spots affecting the CCF.

3. The GIARPS Spectrograph

To accomplish our final aims, we perform intensive RV monitoring taking advantage of the GIARPS configuration at the TNG. This observing mode is the combination of the HARPS-N and GIANO-B spectrographs [2], and offers the possibility for simultaneous high-precision RV measurements from the visual (~388 nm) to the near-infrared regime (NIR; ~2.42 μm). This approach is best suited for very active young stars, since the impact of the activity is less prominent in the red band. The simultaneous optical-NIR RV monitoring enables us to perform a better monitoring of stellar activity.

5. TESS Candidates

The NASA Transiting Exoplanet Survey Satellite (TESS) [8] is producing for the first time precise light curves for thousands of nearby young stars. It is also providing with a number of young transiting planetary candidates. Thanks to the assembled procedures and tools, we are able to identify targets of our interest among the TESS planets candidates, by exploiting TESS light curves, archives, and literature data. In the framework of a parallel program with HARPS@ESO, we started to monitor some young (50-800 Myr) TESS Objects of Interest (TOIs) aiming to validate the planet candidates and to obtain a measurement of their masses.

TOI-942 is an active young star (~50 Myr) observed by TESS. Thanks to a comprehensive stellar characterization, TESS light curve modelling, and precise RV measurements, we validated the planetary nature of the TESS candidate with a mass upper limit of ~16 $M_\oplus$ and detect an additional transiting planet with a mass upper limit of ~37 $M_\oplus$ on a longer orbit [9].

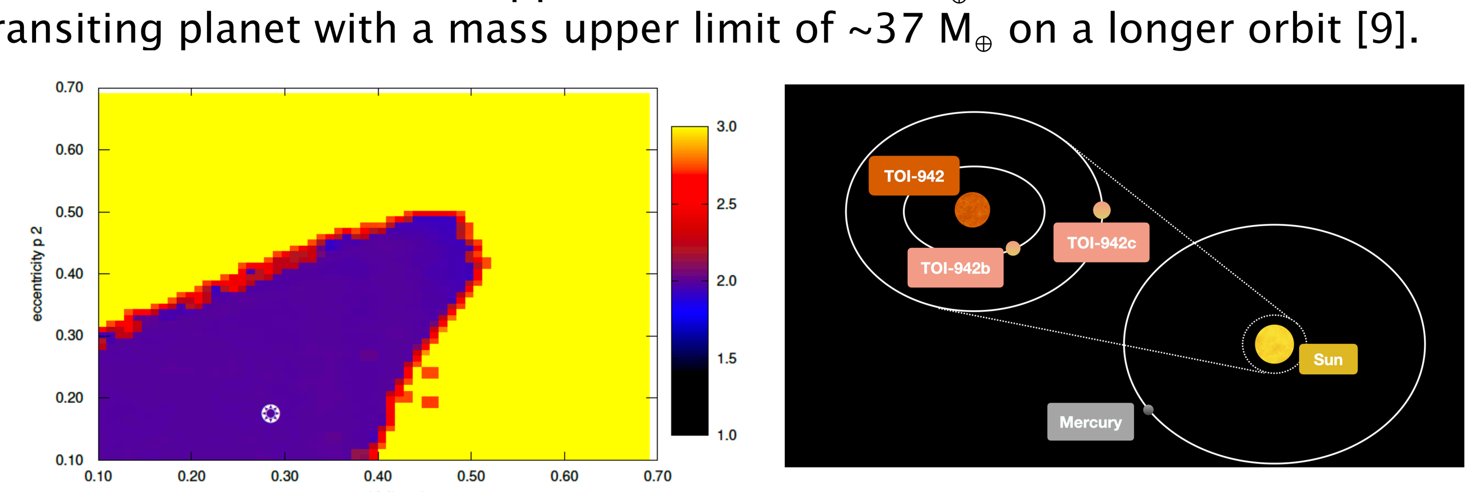

Fig. 4 – *Left panel:* Stability map of the system, where the star symbol shows the nominal eccentricities values. The value of ~2 (as indicated in the color bar) indicates a stable area; larger values (the yellow region) point to chaotic evolution. *Right panel:* Schematic representation of the planetary system around TOI-942 compared to the orbit of Mercury around the Sun (Credits: INAF).

5. Chemical Analysis of GAPS-YOs

To exploit all the information from our GIARPS spectra, we analyzed a sample of GAPS-YOs to derive their atmospheric parameters and chemical composition [10]. To overcome issues related to the young ages of the stars, we applied a new spectroscopic method that uses Ti lines in the optical spectra to derive the atmospheric parameters. We also derived abundances of several elements (C, Na, Mg, Al, Si, Ca, Ti, Cr, Fe, Ni, and Zn) both in optical and NIR ranges. We found that the abundances of C from high-excitation line increase at decreasing T_{eff} and increasing activity index $\log R'_{HK}$. Instead, we found no correlations between the C abundances obtained from a CH molecular band and T_{eff} or $\log R'_{HK}$. We also found an indication of an increasing abundance ratio [X/H] with the condensation temperature for a target in the Ursa Major group (i.e. HD167389), suggesting possible episodes of planet engulfment.

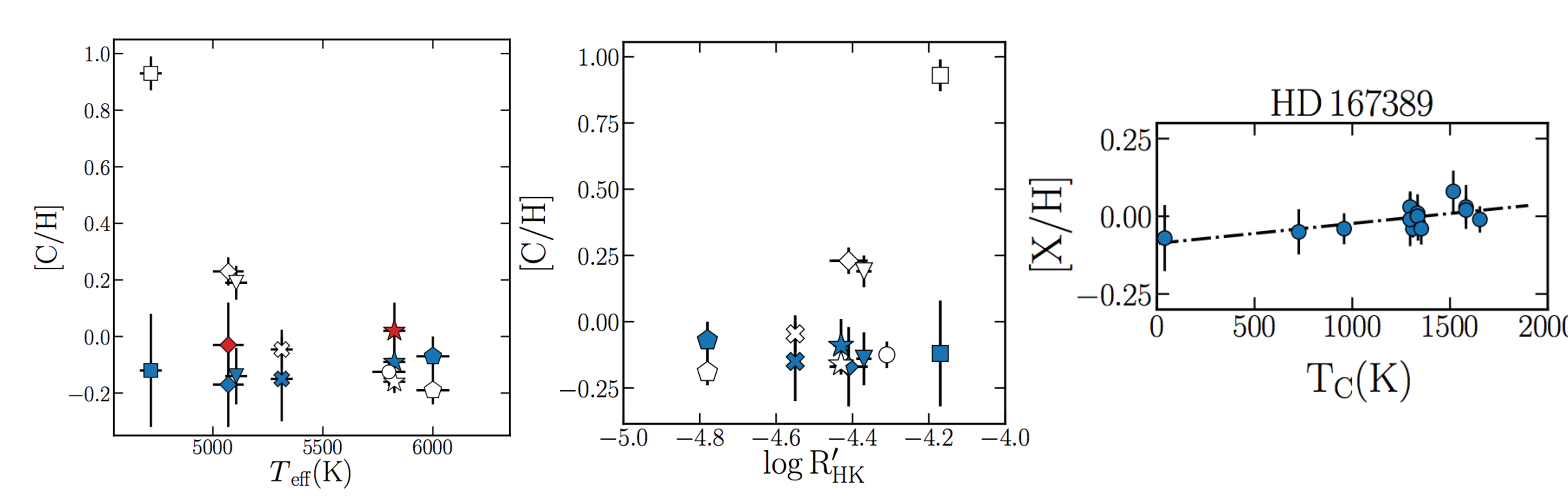

Fig. 5 – *Left panel:* Abundances of CI vs Teff, derived from optical analysis (empty symbols), from the NIR line (red), and from the CH band (blue). *Middle panel:* C abundance vs $\log R'_{HK}$. Symbols as in the left panel. *Right panel:* [X/H] values as a function of the condensation temperature for a member of the UMa group.

6. References

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