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High precision radial velocities: the case for NIR

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Abstract. In the context of the preparation for the high resolution spectrograph HIRES for E-ELT, we are studying the possibility to derive high-precision radial velocities (RV) on a prototype:GIANO, the near-infrared (NIR) echelle spectrograph now available at the Telescopio Nazionale Galileo. Radial velocities measured from near-infrared spectra are a potential tool to search for extrasolar planets around cool stars. High resolution infrared spectrographs now available are reaching the high precision of visible instruments, with a constant improvement over time. In particular, no other IR instruments have GIANO's capability to cover the entire NIR wavelength range. We have developed an ensemble of IDL procedures to measure high precision radial velocities on GIANO spectra. Taking into account the achieved precisions with GIANO, we constrain the sample of targets for which GIANO is better than HARPS-N, but with the advent of GIARPS (GIANO+HARPS-N), GIANO will improve its performances and include a much larger sample of stars. The NIR range is the future of RV measurements, especially because the jitter due to the star surface activities is reduced in the NIR. As a consequence, HIRES working in NIR range might be very useful, and for a wide range of cases, it will be more efficient than HIRES working in the visible range, for detection and characterization of planets using radial velocity technique.

Key words. Exoplanets – Radial velocity – GIANO – GIARPS – HIRES E-ELT – Infrared spectroscopy – CCF method

1. Introduction

Up to now about 600 planets have been discovered using RV technique. All of them have been discovered using instruments working in the visible; among these the most successful instruments, such as HARPS (High Accuracy Radial velocity Planet Searcher at the ESO La Silla 3.6m telescope), HARPS-N (High Accuracy Radial velocity Planet Searcher for the Northern Emisphere at TNG, La Palma, Spain) and HIRES (High Resolution Echelle Spectrometer at Keck Observatory, Hawaii) achieve 0.3 m s^{-1} precision. By comparison, NIR instruments are well behind: in fact the best instruments achieve $\sim$ 10 m s^{-1} accuracy, but RV measurements in the NIR seem to become the future for this technique. The Kepler mission has recently shown that terrestrial planets are more frequent around M dwarfs compared to solar-like FGK stars, so in the last years less massive stars, M-dwarfs, became more interesting targets for the search of planets, and the NIR RV measurements would appear to be advantageous for many reasons:

- M-dwarfs dominate the stellar population in our Galaxy (Henry et al. 2006);

- M-dwarfs are more likely to host rocky planetary companions (Bean et al. 2010);
- As the stellar mass decreases, the reflex motion of the host star due to the gravitational pull of the exoplanet is higher and more easily detectable than in the case of more massive stars;
- M-dwarfs have closer-in habitable zones than higher-mass stars (Kasting et al. 1993), as a consequence the small separation and shorter periods make the amplitude of the variation of RV large and therefore the temporal stability of the instrument is less constraining;
- Stellar jitter due to the rotational modulation of starspots is wavelength dependent and smaller in amplitude at longer (redder) wavelengths due to the lower flux contrast between star-spots and the stellar photosphere.

However these stars are challenging targets for optical spectroscopy even with 10-m telescopes, but accessible with IR spectroscopy. For these reasons interest in focussing efforts on IR instruments is rapidly intensifying.

2. Comparing IR and visible instruments

2.1. Some results with GIANO spectra

GIANO is the infrared echelle spectrograph at the Telescopio Nazionale Galileo (TNG) and it is a powerful tool to provide high resolution spectra for accurate RV measurements of exoplanets and for chemical and dynamical studies of stellar or extragalactic objects. No other IR instruments have GIANO's capability to cover the entire NIR wavelength range (0.95-2.45 μm) in a single exposure. We have developed an ensemble of IDL procedures to measure high precision radial velocities on GIANO spectra acquired during the Science Verification run, using the telluric lines as wavelength reference. We used the Cross Correlation Function (CCF) method to determine the velocity for both the star and the telluric lines. To this purpose, we constructed two suitable digital masks that include about 2000 stellar lines, and a similar number of telluric lines. The method is applied to various targets with different spectral type, from a K0V to an M8 star. Most of the scatter in RVs is due to non constant illumination of the slit. This was partly removed using the telluric line reference, that reduces the r.m.s. scatter of the stellar RVs. However, even once corrected for the telluric reference, the RVs show significant correlations between telluric lines' intensity or bisector velocity span (BVS) and stellar RVs (the Fig. 1 shows the correlation for a K2V object. The found correlations reflect an asymmetric slit illumination, that may arise due to disalignments between the fiber ends and the slit. Removing these correlations, the r.m.s. decreases, from an initial value of 28 m s^{-1} to 8 m s^{-1} for the first object, and from 131 m s^{-1} to 59 m s^{-1} for the M-type star.

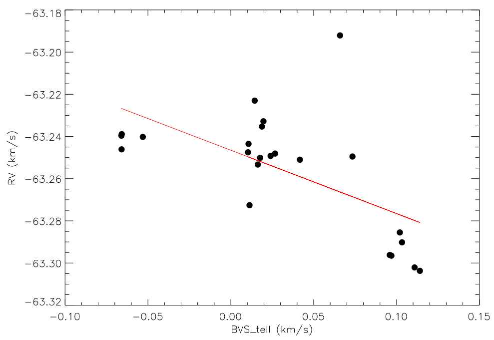

Fig. 1. Correlation between the telluric bisector velocity span and stellar radial velocities for a K2V star.

Mainly depending on H magnitude we reached different dispersions: for a H magnitude of about 5 we obtain an rms scatter of 10 m s^{-1}, while for a H magnitude of about 9 the standard deviation goes up to 100 m s^{-1}, as shown in Fig. 2.

2.2. HARPS-N vs GIANO

Starting from the results obtained with GIANO, as we described in the previous section, we can compare HARPS-N that works in the visible range and GIANO, an infrared

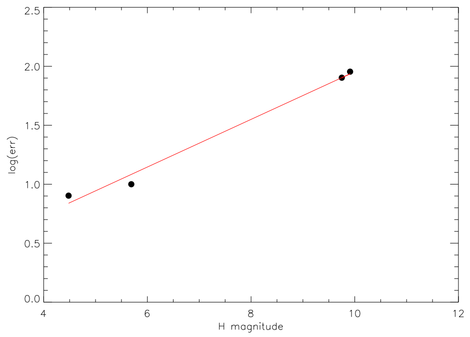

Fig. 2. The error in the RV measurements depending on the H magnitude. The best linear fit is represented by a red line.

instrument. The two instruments are mounted at the same telescope (TNG in La Palma): HARPS-N is fully optimized for RVs and it reaches internal errors of 0.3 m s^{-1} in the best cases, while GIANO has currently several limitations as showed in the previous section (low fiber efficiency, unstable slit illumination, lack of an accurate wavelength reference), and reaches internal errors of 10 m s^{-1} in the best cases. Considering the approximative error for HARPS-N $err_{HARPS-N}(km/s) = 10^{0.2V-4.5}$, and for GIANO $err_{GIANO}(km/s) = 10^{0.2H-3.05}$, we can state that GIANO is better than HARPS-N for stars with a colour of (V-H)>7.25, that means spectral types later than M6.5, as shown in Fig. 3. This information can be also translated in term of age (Fig. 4) and activity (Fig. 5) of the stars. The sample of targets for GIANO can grow if we consider GIARPS, a very interesting incoming project that predicts a common feeding for HARPS-N and GIANO. Figures 3 , 5 (Wright 2005), and 4 (Mamajek et al. 2008), show how with GIARPS, GIANO will include a greater number of targets. In this design GIANO will be fed by a train of optics rather fibers, and this will improve its performances. The main advantages are the higher efficiency that will reduce the internal erros, the elimination of modal noise due to the fibers and a stable slit illumination with a closed loop active tip/tilt mirror, that will reduce the systematic errors. Moreover, an absorbing cell for H and K band will be inserted, in order to have a wavelength reference much more stable than telluric lines. The expected accuracy with an ammonia cell is about 3 m s^{-1} in best cases. The project will be ready at mid-2016 and it will be possible to use GIANO and HARPS-N (IR and visible instruments) simultaneously. Within this context, GIARPS will be a forerunner for HIRES.

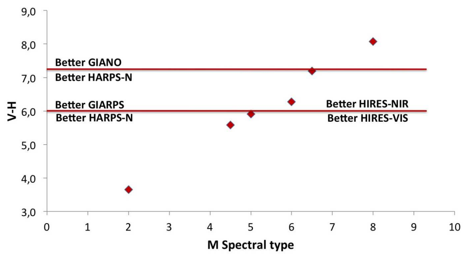

Fig. 3. Colour (V-H) vs M spectral type. Considering GIANO compared with HARPS-N, the first one is better than the second one for targets with a colour > 7.25; with GIARPS, that means GIANO without fibers and with an absorbing cell, the sample of target increases, including stars with colour > 6.

2.3. HIRES-vis vs HIRES-IR

In the same way, considering the approximative errors for HIRES working in the visible

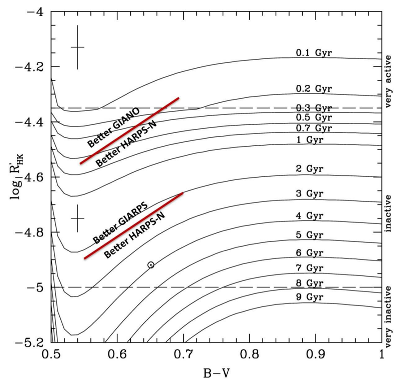

Fig. 4. GIANO is better than HARPS-N for targets with age smaller than 0.2 Gyr. GIARPS enlarges the sample to ages of about 2 Gyr.

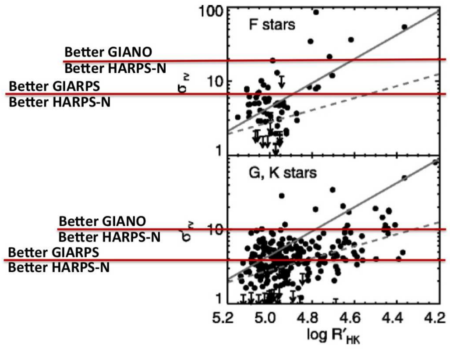

Fig. 5. RV errors vs Stellar Activity. With GIARPS the RV internal error is expected to decrease from 10 m s^{-1} to 3 m s^{-1} for G and K stars.

range, $err_{HIRES-vis}(km/s) = 10^{0.2V-5.55}$, and HIRES working in the IR range, $err_{HIRES-nir}(km/s) = 10^{0.2H-4.35}$, HIRES-NIR is better than HIRES-vis for stars with a colour of (V-H)>6 (spectral types later than M5). However this only concerns internal errors. The stellar jitter is considered the major source of noise in the RV measurements; it is about 1.5 m s^{-1} for inactive stars,but it is expected to be about 1/3 in the NIR with respect to optical range (Dumusque et al. 2011), so while for HARPS-N, considering inactive stars, RV jitter dominates over photon noise for V<8.4, for all HIRES targets it dominates for V<13.6. If a good reference (e.g. laser comb) will be available, there could be three regimes for HIRES:

– For bright targets (~ V<11), the lower jitter in the NIR implies that we need ~ 1/10 as many observations with HIRES-NIR than with HIRES-VIS to get similar confidence levels;
– For very faint sources (~ V>13), HIRES-VIS leads to more accurate results unless the source is very red;
– For intermediate magnitudes, to be examined case-by-case (depends on activity/colour).

3. Conclusions

The search for extrasolar planets around low mass stars is becoming more and more intense for various reasons, in particular because this type of stars is more likely to host rocky companions. Infrared spectroscopy is a crucial tool, being M-dwarfs brightest at wavelength larger than 1 μm and the jitter activity reduced with respect to the visible range. Comparing GIANO and HARPS-N, we can state that GIANO is better than HARPS-N for targets with spectral type later than M6.5, but the incoming project GIARPS will make GIANO a much better RV instrument. GIARPS is a very interesting forerunner for HIRES. Likewise, comparing HIRES working in NIR and HIRES working in the visible range, the first one is better than the second one for stars with a spectral type later than M5. Finally, for a wide range of cases, HIRES-NIR will be more efficient than HIRES-VIS for detection and characterization of planets using RVs. This obviously requires accurate wavelength reference for NIR.

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