A&A 586, A101 (2016)
DOI: 10.1051/0004-6361/201526900

Astronomy & Astrophysics

Radial velocity information content of M dwarf spectra in the near-infrared

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Received 6 July 2015 / Accepted 16 October 2015

ABSTRACT

Aims. We evaluate the radial velocity (RV) information content and achievable precision on M0-M9 spectra covering the *ZYJHK* bands. We do so while considering both a perfect atmospheric transmission correction and discarding areas polluted by deep telluric features, as done in previous works.

Methods. To simulate the M-dwarf spectra, PHOENIX-ACES model spectra were employed; they were convolved with rotational kernels and instrumental profiles to reproduce stars with a $v \sin i$ of 1.0, 5.0, and 10.0 km s^{-1} when observed at resolutions of 60 000, 80 000, and 100 000. We considered the RV precision as calculated on the whole spectra, after discarding strongly polluted areas, and after applying a perfect telluric correction. In the latter option, we took into account the reduction in the number of recorded photons due to a transmittance lower than unity and considered its effect on the noise of the recorded spectra. In our simulations we paid particular attention to the details of the convolution and sampling of the spectra, and we discuss their impact on the final spectra.

Results. Our simulations show that the most important parameter ruling the difference in attainable precision between the considered bands is the spectral type. For M0-M3 stars, the bands that deliver the most precise RV measurements are the *Z*, *Y*, and *H* band, with relative merits depending on the parameters of the simulation. For M6-M9 stars, the bands show a difference in precision that is within a factor of ~2 and does not clearly depend on the band; this difference is reduced to a factor smaller than ~1.5 if we consider a non-rotating star seen at high resolution. We also show that an M6-M9 spectrum will deliver a precision about two times better as an M0-M3 spectra with the same signal-to-noise ratio. Finally, we note that the details of modeling the Earth atmosphere and interpreting the results have a significant impact on which wavelength regions are discarded when setting a limit threshold at 2−3%. The resolution element sampling on the observed spectra plays an important role in the atmospheric transmission characterization. As a result of the multiparameter nature of the problem, it is very difficult to precisely quantify the impact of absorption by the telluric lines on the RV precision, but it is an important limiting factor to the achievable RV precision.

Key words. techniques: radial velocities – instrumentation: spectrographs – methods: data analysis – stars: low-mass

1. Introduction

The technique of spectroscopy is central to the study of stars and has allowed astronomy to gather a significant body of knowledge from the few photons a star provides us. During the past 20 years, spectroscopy was extensively applied in an emerging field in astronomy: the study of extrasolar planets. Following the discovery of 51 Peg b in 1995 (Mayor & Queloz 1995), more than 1900 planets were discovered, with masses and radii down to those of Earth (e.g., Dumusque et al. 2012; Barclay et al. 2013; Pepe et al. 2013). The radial velocity (RV) technique, with which the very first planet around a solar-type star was found, is still one of the most widely used detection methods; it is the main contributor to our knowledge of the mass of known exoplanets. The hunt for the exoplanet with the lowest mass pushed the RV precision down to the subm/s domain and motivated the construction of instruments such as ESPRESSO, which aims at a precision of 10 cm/s (Mégevand et al. 2012; Pepe et al. 2014b).

The RV signature of a planet scales with the mass of the star with $M_*^{-2/3}$ and with the planetary orbital period with $P_{\rm orb}^{-1/3}$. For an Earth-mass planet orbiting inside the habitable zone around a solar-type star, the RV amplitude is 10 cm/s, while for a planet with the same characteristics but orbiting an M7 dwarf, the RV amplitude is larger than 1 m/s. This is due to both a lower host mass and a closer habitable zone (a consequence of the lower luminosity output of these hosts). This relatively high amplitude contributed to an increased interest in the search for exoplanets around the low-mass M-dwarf (0.5−0.08 $M_\odot$) and led to the first estimates of the fraction of M dwarfs hosting Earth-mass planets inside the habitable zone (Bonfils et al. 2013). The intrinsic faintness of the stars in the visible domain limited these surveys to the brightest one hundred stars of our neighborhood and, along with activity, photon noise contribution to the noise budget proved to be the limiting factor. Spurred by the abundance of exoplanets, the exoplanet hunters did not rest in their efforts, and in the last several years, a new research direction