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Telluric correction in the near-infrared: standard star or synthetic transmission?

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ABSTRACT

Context. The Earth's atmospheric absorption is an important limiting factor for ground-based spectroscopic observations, with the near-infrared and infrared regions being the most affected. Several software packages, that produce a synthetic atmospheric transmission spectrum, have been developed to correct for the telluric absorption, namely *Molecfit*, TelFit, and TAPAS.

Aims. Our goal is to compare the correction achieved using these three telluric correction packages and the division by a telluric standard star. We want to evaluate the best method to correct near-infrared high-resolution spectra as well as the limitations of each software package and methodology.

Methods. We apply the telluric correction methods to CRIRES archival data taken in the J and K bands. We explore how the achieved correction level varies depending on the atmospheric T-P profile used in the modeling, the depth of the atmospheric lines, and the molecules creating the absorption.

Results. We found that the *Molecfit* and TelFit corrections lead to smaller residuals for the water lines. The standard star method corrects best the oxygen lines. *Molecfit* and the standard star method corrections result in global offsets always below 0.5% for all lines; the offset is similar with TelFit and TAPAS for the H_2O lines and around 1% for the O_2 lines. All methods and software packages result in a scatter between 3% and 7% inside the telluric lines. The use of a tailored atmospheric profile for the observatory leads to a scatter two times smaller, and the correction level improves with lower values of precipitable water vapor.

Conclusions. The synthetic transmission methods lead to an improved correction compared to the standard star method for the water lines in the J band, with no loss of telescope time but the oxygen lines were better corrected by the standard star method.

Key words. atmospheric effects – radiative transfer – instrumentation: spectrographs – methods: data analysis – techniques: spectroscopic

1. Introduction

In ground-based observations, the light coming from a celestial object is partly or totally absorbed by the Earth's atmosphere, a phenomenon that is strongly wavelength-dependent. Even if the position of an observatory is carefully chosen to minimize the impact of the atmosphere, there is still a need to correct for telluric absorption. In spectroscopic studies, the species present in the atmosphere imprint absorption or emission lines on top of the spectra of the target. In absorption, the telluric lines create what is called the transmission spectrum of the Earth's atmosphere. The volume mixing ratio of the different molecules as function of height (that can be understood in terms of density profile) present in the atmosphere and the atmospheric conditions (pressure, temperature) affect the telluric lines in their shape, depth, and position in wavelengths. **High winds can shift the telluric features, and Figueira et al. (2012) showed that an horizontal wind model can account for some of these shifts and is in agreement with radiosonde measurements.** Thus, the transmission spectrum depends strongly in the time and location of the observations. Every molecule contributes differently to the final transmission. For example, H_2O leads to an absorption over a very wide wavelength range, spanning the optical, the near infrared, and the infrared. This absorption defines the near infrared bands over which photometry and spectroscopy was done for many years. The water vapor shows hourly to seasonal variations which are challenging to correct (Adelman et al. 2003; Wood 2003). O_2 absorption might be easier to correct, because it provides sharp, deep and well-defined features and the O_2 volume mixing ratio is more stable in the atmosphere. O_2 bands and individual lines in the optical have been studied for a long time (Wark & Mercer 1965; Caccin et al. 1985). When observations are done through cirrus clouds, the atmospheric transmission is not impacted. Cirrus clouds are thin clouds made of ice crystals and usually found at altitudes higher than 6 km (Wylie et al. 1994). The ice crystals transmit most of the incoming stellar light and do not introduce water features in the transmission spectrum.

A correction of telluric absorption is required when the studies aim at high spectral fidelity; for example it is an essential step to characterize planetary and exoplanetary atmospheres (e.g. Bailey et al. (2007); Cotton et al. (2014); Brogi et al. (2014)). Telluric correction has also been studied in the context of exoplanet search through radial velocity (RV) measurements.

Earlier on, the telluric lines started to be used as a wavelength calibration to measure precise radial velocities (Griffin & Griffin 1973). The atmosphere can be considered as a gas cell which imposes its absorption features on the target spectrum. Smith (1982) and Balthasar et al. (1982) used O_2 lines as wave-