iSTARMOD: a Python code to quantify the chromospheric activity of FGKM stars using the Spectral Subtraction Technique

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Abstract. The spectral subtraction technique has proven to be on to the best methods to quantify the chromospheric contribution of different optical and near-infrared features such as the Ca II H&K, Balmer, Paschen, Ca II IRT triplet, Na I D1&D2, He I D3 and He I 10830 lines that are the more important activity indicators in high-resolution spectra of FGKM stars. This method is based in the subtraction of a synthesized stellar spectrum constructed using artificially rotationally broadened, radial-velocity shifted, and weighted spectrum of an inactive star chosen to match the spectral type and luminosity class of the active star under consideration. Here it is described the Python code **iSTARMOD** implemented to apply the spectral subtraction technique. The code has been adapted to work with the particular features and formats of the spectra coming for different high-resolution spectrographs and include improvements from previous implementations, as the determination of the equivalent widths and automation, in order to perform time series analysis of large sets of spectra. We show here the results of appling **iSTARMOD** to a single star (K2.0V type PW And) to illustrate its applicability. The code will be made publicly available on GitHub when it was completely implemented and tested

Context

The stars presenting chromospheric activity have the remarkable feature that this activity can be detected through a limited series of lines. These lines, the activity indicators, can be seen in emission, in an otherwise quiescent (most of the times) spectrum, a phenomenon linked to the dynamo effect owed to stellar rotation of a cool star. A Spectral Subtraction Technique is thus, very well suited in order to quantify and characterize this chromospheric activity.
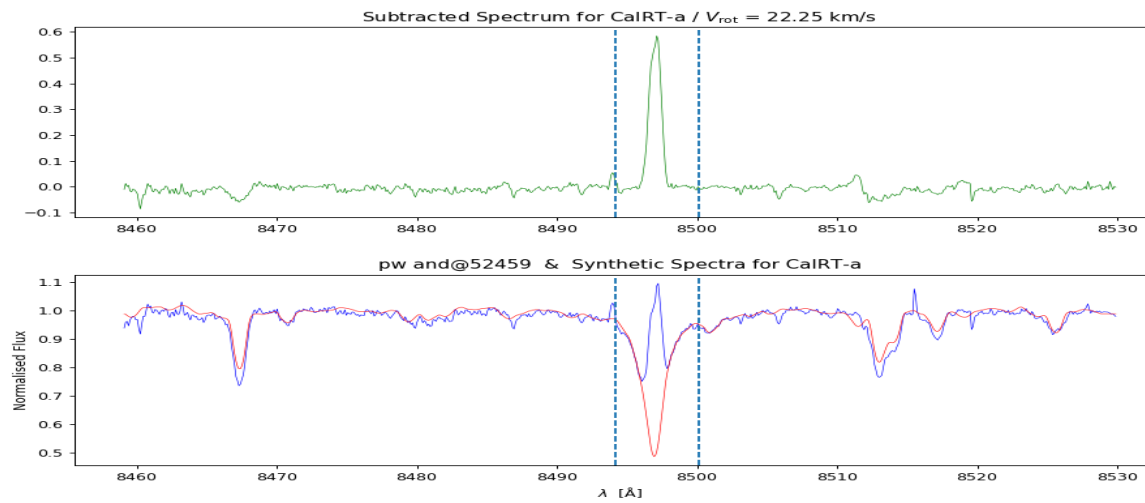
In the below images it can be seen the subtracted spectra in each upper panel, as well as the input and synthetic spectra (in the lower panels). Each image corresponds with an activity indicator, from left to right, **CaII H** (3968 Å), H Balmer beta **Hβ** (4861,32 Å), Sodium doublet **NaD$_{1,2}$** (5895.92/5889.95 Å), H Balmer alpha **Hα** (6562.80 Å), and one of the Calcium infrared triplet **CaII IRT** 8498.1 Å. The spectra, from the chromospherically active star **PW And**, of type K2 V, were obtained using FOCES spectrograph (López-Santiago, et al. 2003)
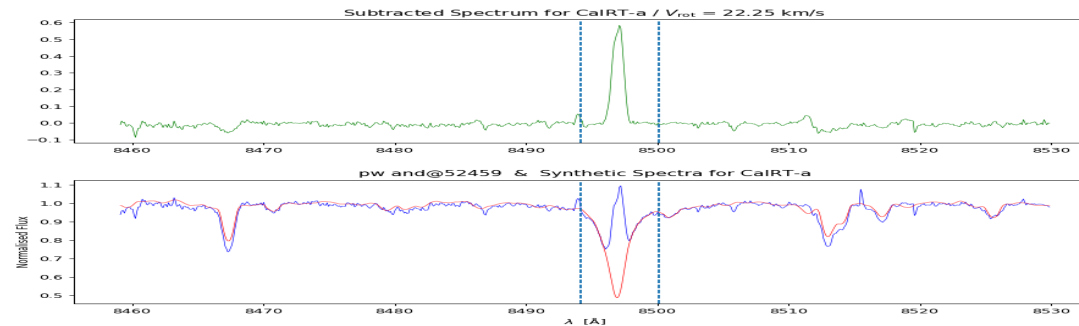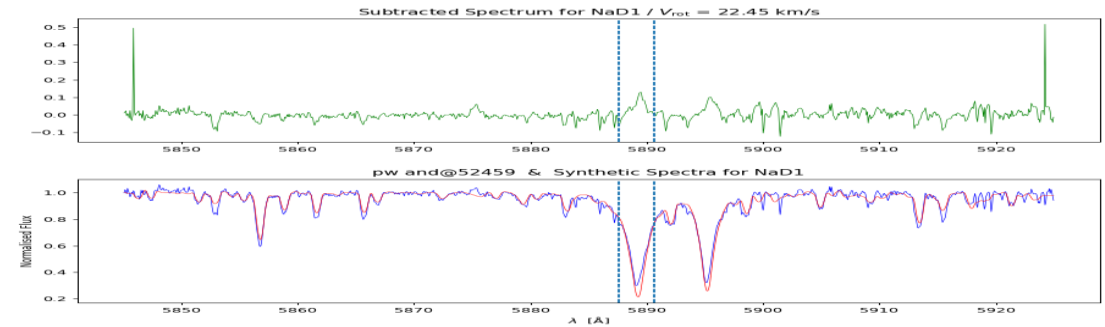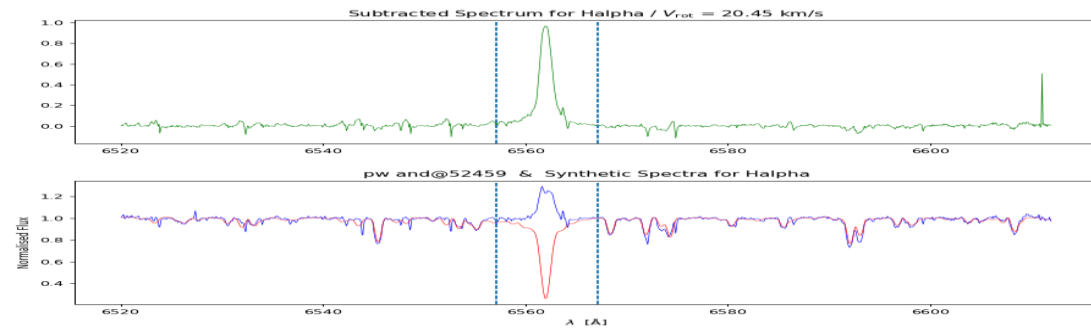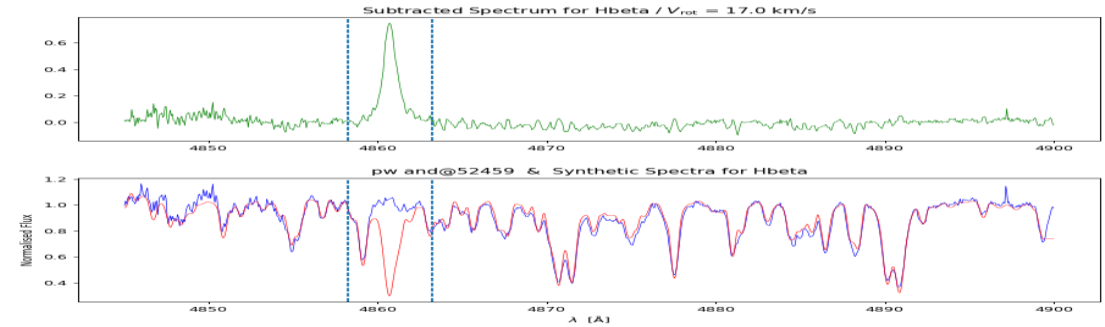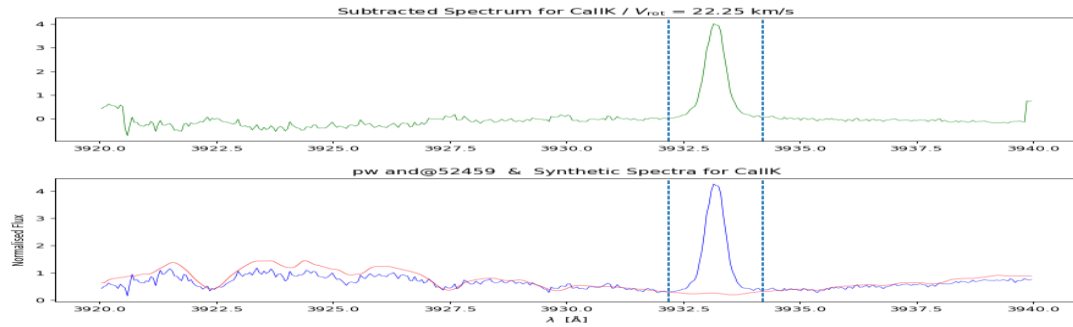
To apply spectral subtraction we use iSTARMOD, a modified and upgraded version of the code STARMOD developed at Penn State University (Barden 1985). The algorithm was modified later by Montes et al. (2000) and López-Santiago et al. (2010). We have migrated the FORTRAN code to Python and adapted it to work with several FITS formats of spectra coming from high-resolution spectrographs (such as FOCES, HERMES and CARMENES). Additional improvements have been implemented in order to calculate the EW of the subtracted spectra as well as performing automated processing of them.
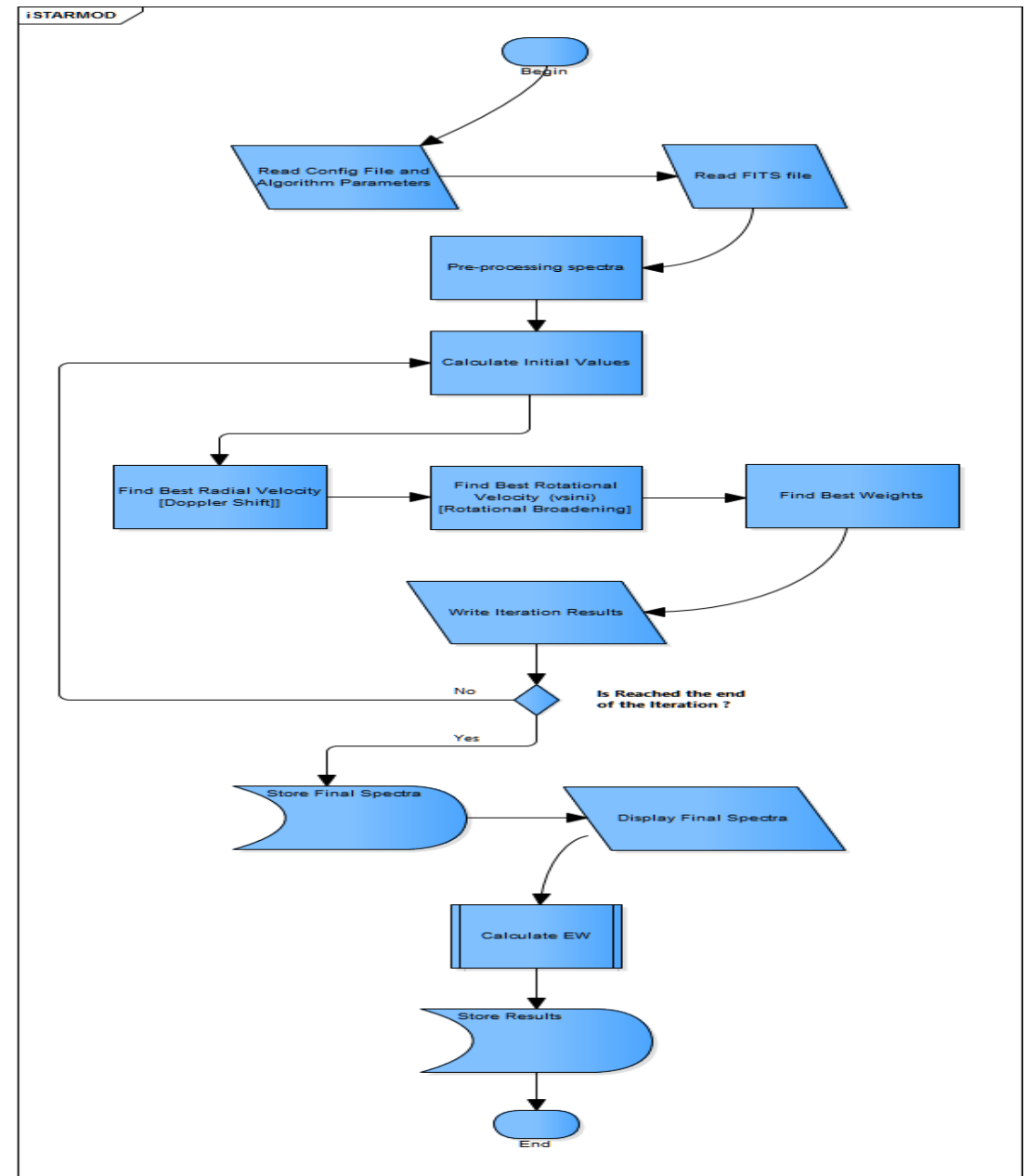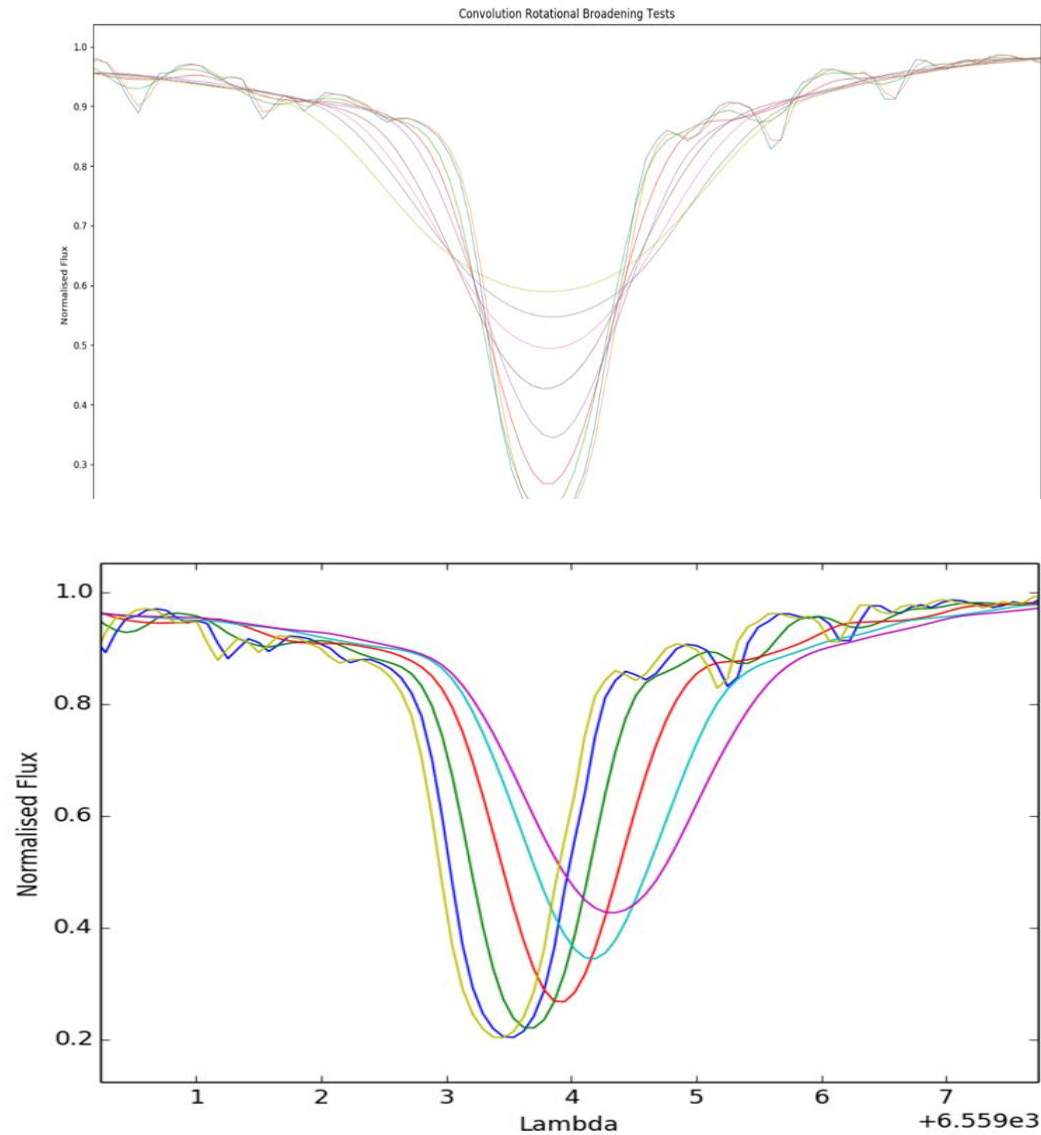
The algorithm implemented is depicted as a flow chart in the leftmost panel. There, an iterative procedure is implemented in order to obtain a synthetic spectrum, from a reference inactive star, to be subtracted to our input spectrum. There are two main processes, showed in the left panels:

- A Doppler shift in order to overlap the line positions of input and synthetic spectra.
- A rotational broadening, using a convoluted Gray Profile, in order to account for the effect of rotation in the synthetic spectrum.

Spectroscopic binaries can also be analyzed in this way using one weighted inactive star spectra for each component of the system, producing the resultant spectrum.

These processes are put together by means of the iteration obtaining a least-squares best fit of the synthetic spectrum with respect to the input one

Impact and prospects for the future

iSTARMOD is being used as a set of tool by the Department, in several lines of research and Master and PhD Theses

It is intended to complete the suite of tools in order to adapt to very disparate sources of data in different programs and lines of research.

The code will also be completed with a series of automated routines to process the data an perform needed calibrations.

Additionally the aim is to provide a friendly Graphical User Interface, in order to ease the application of the code and algorithms by future users.

References:
Barden 1985, ApJ, 295, 162
López-Santiago, et al. 2003, A&A, 411, 489
López-Santiago, et al. 2010, A&A, 514, A97
Montes, et al. 1995, A&A, 294, 165
Montes, et al. 2000, A&AS, 146, 103