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## The SpacInn SISMA archive

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**Abstract.** The *Spectroscopic Indicators in a SeisMic Archive* (SISMA) has been built in the framework of the FP7 SpaceInn project to contain the 7013 HARPS spectra observed during the CoRoT asteroseismic ground-based program, along with their variability and asteroseismic indicators. The spectra pertain to 261 stars spread around the whole Hertzsprung-Russell diagram: 72 of them were CoRoT targets while the others were observed in order to better characterize their variability classes. The Legacy Data lightcurves of the CoRoT targets are also stored in the archive.

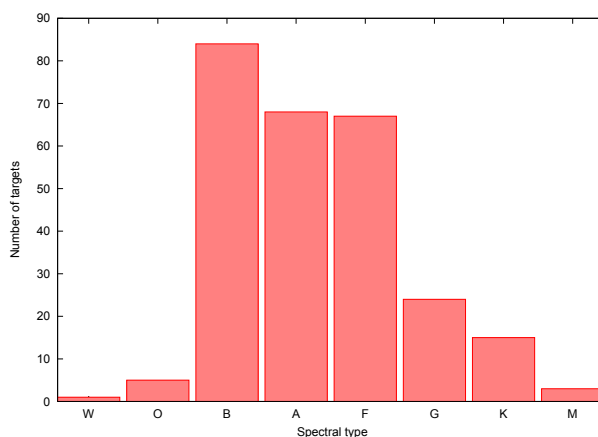
### 1 Introduction

A large number of high-resolution spectra have been taken in a six-year long ground-based observational campaign to complement the asteroseismic observations of the CoRoT satellite [1]. The main instrument used in this work was the HARPS spectrograph at the ESO-LaSilla Observatory [2], with which we collected 7103 good quality, high signal-to-noise ratio (S/N) spectra of 261 stars during the two Large Programmes LP 182.D-0356 and LP 185.D-0056, spanning 15 nights per semester from December 2008 to January 2013, for a total of 135 allocated nights. Seventy-two of the stars were CoRoT asteroseismic targets. Many other stars were observed to better define the variable classes of the CoRoT targets, in general by means of few spectra per star only. The coordination of the spectroscopic follow-up of the asteroseismic targets characterized the Italian participation to the scientific exploitation of the CoRoT mission [3], after the preparatory activities to select targets and fields [4, 5].

When the FP7-SPACE project *SpaceInn: Exploitation of Space Data for Innovative Helio-and Asteroseismology*<sup>1</sup> was set-up we took charge to create an online archive where not only the raw HARPS spectra could be found, but also the reduced ones. The goal was to make the HARPS spectra, in many cases already used in the first-analysis papers, directly exploitable for any further scientific study. To match this requirement we decided to compute specific spectral indicators, determine stellar parameters, and offer the possibility to compare straightly the spectroscopic timeseries with CoRoT ones. At the end of the *SpaceInn* project, we are proud to shortly present here the *Spectroscopic Indicators in a SeisMic Archive* (SISMA) database.

### 2 Observations and reduction

We used HARPS mostly in the high-efficiency mode EGGs, with resolving power  $R=80,000$ , because most of our targets are hot stars (Fig. 1) with large  $v \sin i$  values. As such, these targets are not suitable for the more precise radial velocities studies carried on using the high-accuracy mode HAM ( $R=115,000$ ): using the EGGs mode, we were able to reduce the exposure times, and to increase the signal-to-noise ratios, without losing precision on the radial velocity estimation, which is limited by the rotational broadening of the lines and not by the instrument resolving power. Only the cooler, slowly rotating targets were observed in the HAM mode.



**Figure 1:** Histogram of the spectral types of the stars in the SISMA database.

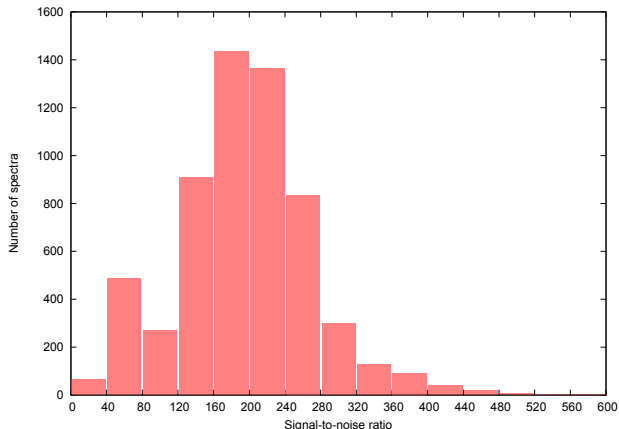
Most of the spectra observed with EGGs have S/N around 200 at about 5800 Å, while the HAM spectra usually have a S/N around 150 in the same region (Fig. 2), with the exception of HD 46375, whose 1160 spectra clus-

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ter around 50, high enough to detect the solar-like oscillations in the radial velocity time series. The high number of spectra on a single target were acquired as a pilot study to support one of the scientific goals of the CoRoT second extension, i.e., to have a full asteroseismic picture of the stars hosting exoplanets. Though granted, this second extension did not take place due to fatal satellite failure in November 2012.



**Figure 2:** Histogram of the S/N values of the spectra in the SISMA database. The 1160 spectra of HD 46375 have been removed for easier reading.

The online ESO pipeline gave us as final outputs one-dimensional spectra with the echelle orders merged, which can be a problem when normalizing the whole spectrum because of the distorted continuum. In addition to that, we lose information on the pixel-by-pixel S/N and on the positions of the borders of the orders, which are important for detailed spectroscopic analysis: the S/N is very low on the borders of the orders and the merging may distort the spectral lines in these regions, particularly if the lines fall right on the border. In order to improve the quality of our spectra, we reduced them using a semi-automated pipeline developed at the Brera Astronomical Observatory. Our pipeline worked on the \*e2ds\* files given by the original DRS, i.e. the extracted, flat-field corrected spectra. For each observed spectrum, we obtain two output files: a five column ASCII file with wavelength, flux, normalized flux, S/N and number of the echelle orders, and a two column ASCII file with wavelength and normalized flux, with the echelle orders merged.

### 2.1 Instrumental problem in the spectra reduction

The intensive use of the HARPS instrument to study line-profile variations was very effective in detecting subtle instrumental effects. These effects could escape at the observer interested primarily at the value of the radial velocity. What happened in June 2009 was very instructive at this purpose. At that time the Be team noticed a strange

feature in the HARPS spectra collected in the December 2008-January 2009 runs. The mean profile of the  $\text{He I}$  line at 4921 Å showed some “oscillations” in the spectra of the Be star HD 51452, both on the line profile and on the continuum. The peak-to-peak amplitude was 0.5% of the continuum. The origin was not stellar since it was detected in the spectra of the other stars observed in the same runs. These oscillations resulted to be strongly enhanced in the spectra obtained later in June 2009 since the amplitude raised to 2%. After interaction with the ESO staff, the problem was identified in the misalignment of a filter on the path of the flat-field lamp. Indeed, the “oscillations” were visible in the raw images of the flat field, but not in those of the stars (or, at least, they are not so evident). The strong misalignment occurred few weeks before, at the end of May 2009. The ESO staff corrected such misalignment and produced new spectra re-reduced using the new flat-field. The spurious oscillation was reduced in strength so as to be cancelled in the mean LSD profile, but still noticeable in the mean profile of a given line. This subtle effect constituted a serious problem for our line-profile studies. Therefore, the Brera team and the ESO staff continued to investigate the problem. In late July 2009, we solved it by removing the filter from the optical path of the calibration lamp. The ESO staff re-ran the complete reduction of the HARPS spectra collected in the previous runs of our Large Programme (i.e., December 2008, January, June and July 2009) and delivered new ones free from the instrumental effect. We re-processed these corrected spectra with our pipeline, and made them available in the SISMA database.

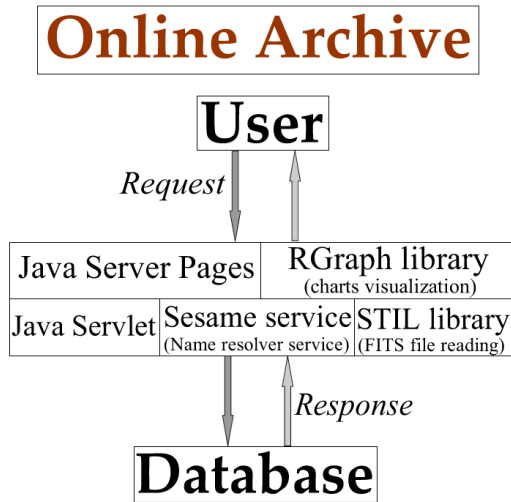
## 3 Variability indicators

In order to support the asteroseismic exploitation of the data, different kinds of indicators and secondary files have been computed to be provided alongside the spectra.

In particular, we used the LSD software [6] to compute mean line profiles for each spectrum. These profiles are stored in the archive and they were used to compute the radial velocities, the projected rotational velocities  $v \sin i$ , an indicator of the presence of differential rotation [7], and to amplify the effects of pulsation on the line profile variations. Just a quick look at the standard deviation between the mean line profiles and their average gives interesting information on the pulsational contents of the spectroscopic time series.

In addition to this, an activity index has been computed for each spectrum using the Ca II H and K lines, and the violet-to-red peak intensity ratio of the  $H_\alpha$  is given in case of emission line stars.

The physical parameter  $T_{\text{eff}}$ ,  $\log g$  and [Fe/H] of all the stars have been computed using the SME software [8] in the wavelength region 5160-5190 Å of an average spectrum in order to lessen the effects of pulsations on the parameters determination.



**Figure 3:** The software used in the interaction between user and database.

## 4 Structure of the spectroscopic Archive

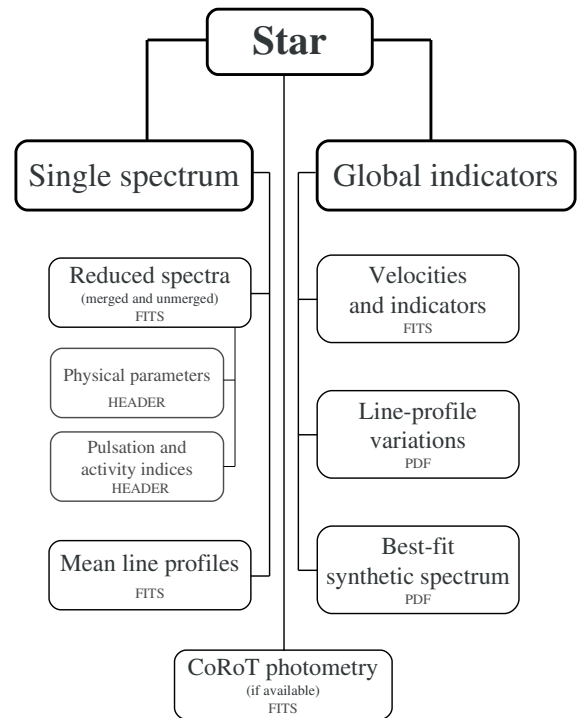
All the reduced spectra, indicators and lightcurves are stored in the online SISMA archive (<http://sisma.brera.inaf.it/>) and they can also be accessed through the Seismic Plus portal<sup>2</sup>. This portal is another product of the *SpaceInn* project and it was designed with the goal to coordinate the use of different helio- and asteroseismic databases.

### 4.1 Database infrastructure

The SISMA archive is hosted on a dedicated Linux server at the Brera Astronomical Observatory. The database management system used is the open-source PostgreSQL, while the web user interface is written in the Java/Servlet/JSP language. SISMA uses the name resolver service Sesame<sup>3</sup> in order to allow the user to query the database by target name. Otherwise it is possible to query the archive by variability class. The results can either be downloaded or displayed online using the Javascript library RGraph<sup>4</sup> in order to quickly create and plot inside the user browser all the required data (spectra, lightcurves or indicators). The archived FITS files are read using STIL (Starlink Tables Infrastructure Library)<sup>5</sup>. A schema of the software used in the interaction between the database and the user is shown in Fig. 3.

### 4.2 Scientific data

The SISMA archive contains several different kinds of data. For each of the observed 261 stars it is possible to find both single observations and time series and global data, as:



**Figure 4:** Structure of the HARPS archive, with the content and format of the available files.

- the reduced spectra, which are the backbone of the archive. They are available in two format: unmerged with both normalized and non-normalized flux, and merged with normalized flux;
- the mean line profiles obtained by means of the LSD software;
- the time series of several spectroscopic indicators and quantities, i.e. the activity index, H $\alpha$  violet-to-red peak-intensity ratio, the differential rotation indicator, the radial velocities and the projected rotational velocities  $v \sin i$  with their relative errors;
- the estimated physical parameters  $T_{\text{eff}}$ ,  $\log g$  and  $[\text{Fe}/\text{H}]$ , which are stored in the header of all the FITS files;
- a PDF file with the best-fit synthetic and observed spectrum in the 5160-5190 Å region used to compute the physical parameters;
- a PDF with a quick look of the pulsational content of the mean-line profile time series;
- the CoRoT Legacy Data lightcurves (only for the 72 CoRoT targets stored in the archive).

Figure 4 summarizes how the data have been stored in the archive and how we structured the output of our reduction and analysis. Note that parameters and indices are properly stored in the FITS headers of all the reduced spectra. The graphical interface of the SISMA archive is shown in Fig. 5.

<sup>2</sup><http://voparis-spaceinn.obspm.fr/seismic-plus/>

<sup>3</sup><http://cdsweb.u-strasbg.fr/doc/sesame.htm>

<sup>4</sup><http://www.rgraph.net/>

<sup>5</sup><http://www.star.bristol.ac.uk/~mbt/stil/>

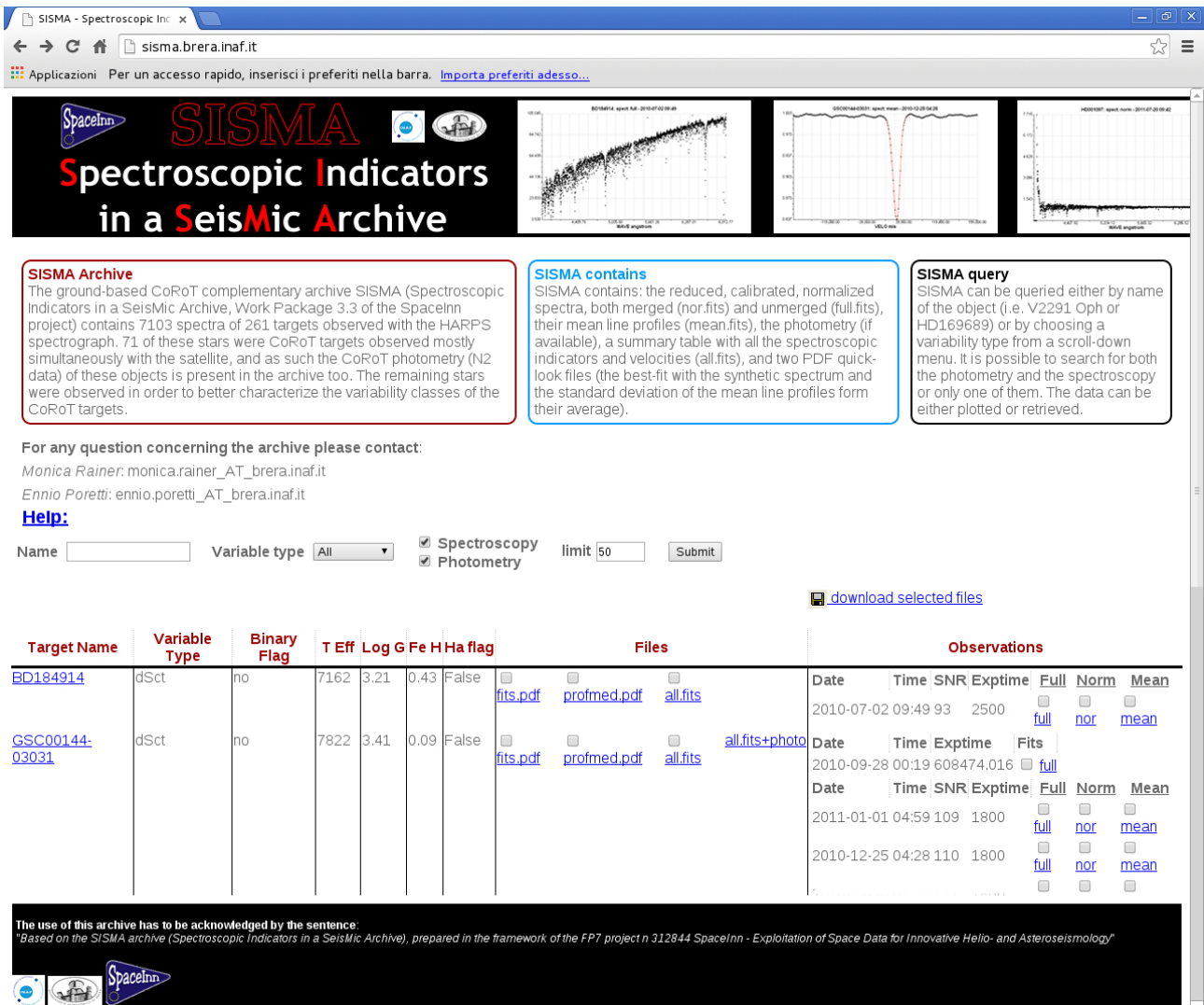


Figure 5: Screenshot of the SISMA web page.

## 5 Conclusions

The *SpaceInn* project aimed at coordinating several archives of helio- and astero-seismological data. We collected a large number of high-resolution HARPS spectra of the targets observed, often simultaneously, with the CoRoT satellite. Therefore, we considered very appropriate to make them available to the whole community. We strongly encourage more in-depth and statistical studies, since the reduced archival spectra are complemented with many indicators of variability and activity. Moreover, we suggest to look at the SISMA database as an opportunity to test new methods to extract physical information from high quality, high S/N spectra.

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