Stellar Activity in Stars with Exoplanets: Presenting the SAITAMA pipeline

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Introduction

The characterization of stars is a crucial step for the detection and characterization of exoplanets and planetary systems. The method to derive stellar activity by measuring specific activity spectral indices, has already a tool implemented, in the form of ACTIN ([1], [2]).

The Stellar ActivITy AutoMatic cAlculator (SAITAMA) pipeline provides an easy way to characterize the stellar activity of stars with exoplanets using spectral data spread in a wide time range from different surveys. SAITAMA's ultimate goal is to complement SWEET-Cat ([3], [4]) with this relevant information for the planet-host stars for which we have good spectroscopic data and use it to find new correlations between this characteristic and the properties of the planets hosted by these stars.

Pipeline architecture

1. **spectral data acquisition:** queries, selects and downloads the spectra;
2. **data processing and analysis:** corrects spectra by RV, obtains activity indices and period of S_{CaII}, converts to literature indices and computes the chromospheric age and rotation period;
3. **data compilation and output:** computes statistical information, saves results for each instrument and combines the data into a FITS file once all instruments have been processed.

Input parameters:

- object and spectrograph identifiers;
- activity indices names;
- maximum number of spectra to be downloaded;
- minimum S/N of the spectra;
- ESO username;
- whether to download the spectra or not;
- specific spectra to be neglected;
- paths to store the products of the pipeline.

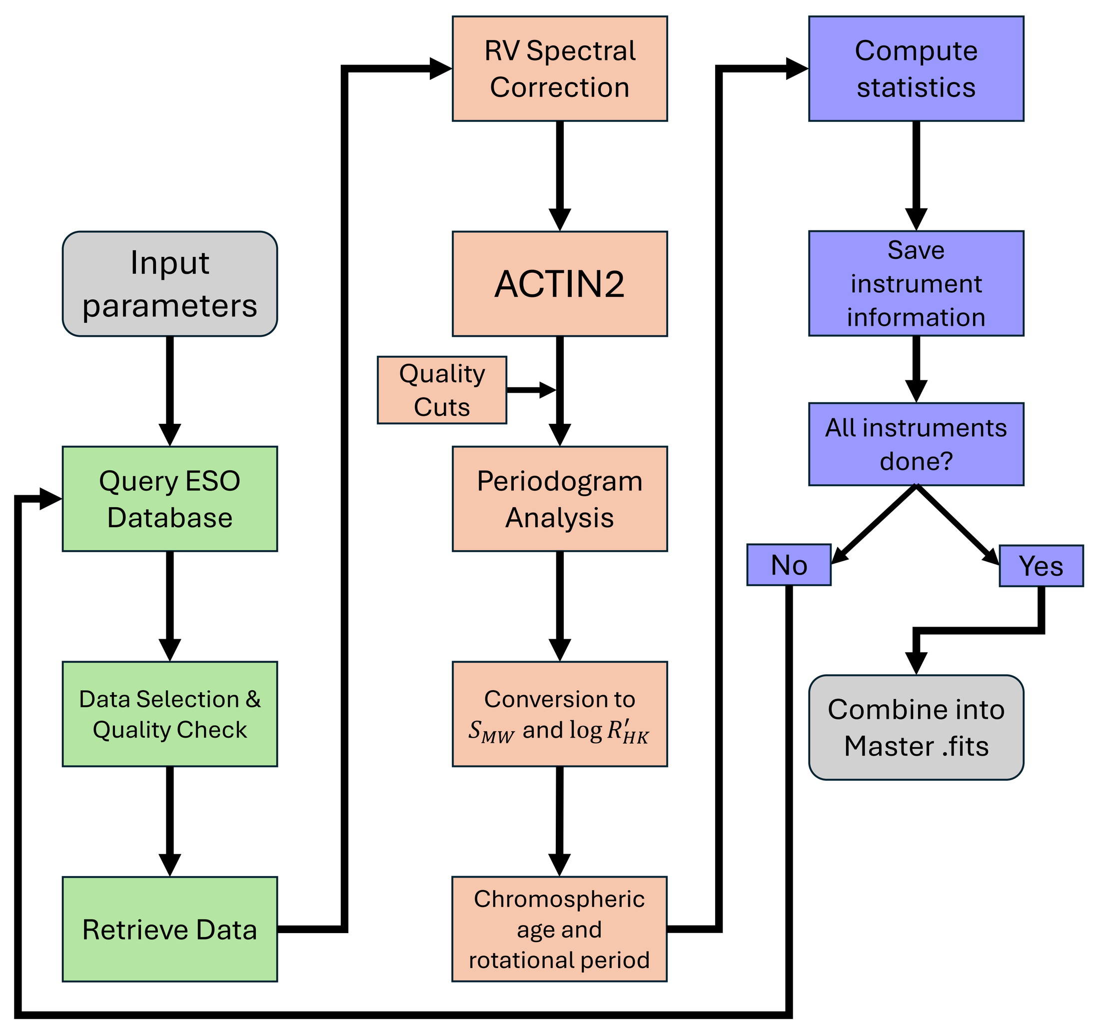

Figure 1. SAITAMA flowchart. Green: spectral data acquisition step. Orange: data processing and analysis. Violet: data compilation and output step.

Spectral data acquisition

- **Search in the ESO archive** using Gaia DR3 identifier, as well as the instrument;
- **Initial quality checks:** ignores spectra with S/N < 15 due to low-quality individual exposures, and with S/N too high to avoid saturation of the individual exposures;
- **Quality - time span trade-off check:** group the observations in months per year and orders each group by descending S/N. Then iterates for each group, adding to the list of spectra to be downloaded the best S/N spectra, until the maximum number of spectra is achieved.

Data Processing and Analysis

RV correction by Doppler shift

- RV obtained through a **CCF** with a template spectrum;
- Uses only two 250 Å intervals for computational optimization.

Is the spectrum well corrected?

- Based on reference line (Ca I):

$$\alpha_{RV} = \frac{\mathrm{Mdn}\, F_{\mathrm{continuum}}}{\mathrm{Mdn}\, F_{\mathrm{core}}}$$

- Induce different λ offsets and

$$\gamma_{RV} = \begin{cases} 0, & \text{if } \lambda_{\min(\alpha_{RV})} \notin [-0.03, 0.03]\ \text{Å} \\ 1, & \text{otherwise} \end{cases}$$

- β_{RV}: overall quality indicator of RV correction

$$\beta_{RV} = \frac{\#\ \text{spectra with}\ \gamma_{RV} = 0}{\text{total}\ \#\ \text{spectra}}$$

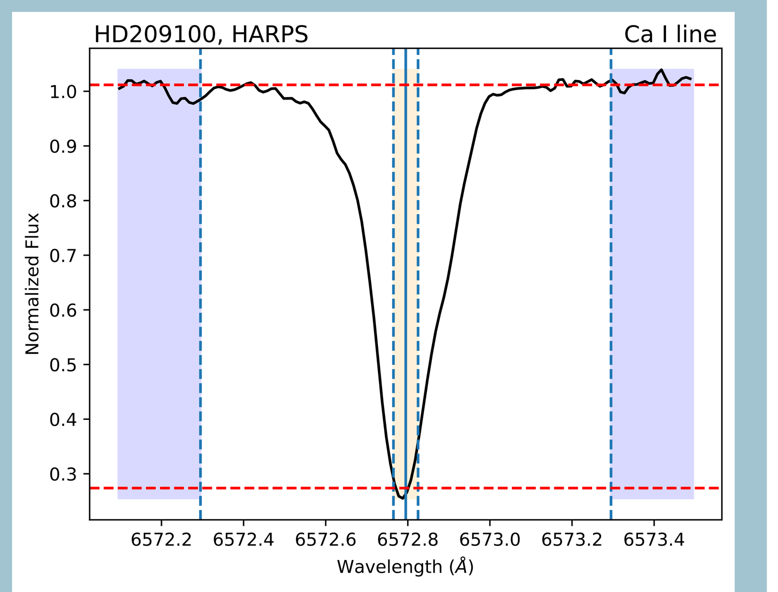

Figure 2. HD209100 spectrum. $\alpha_{RV} = 0.27$. Blue: continuum regions. Orange: core region.

Activity indices and quality cuts

- SAITAMA builds data frame with the activity indices and related information;
- Plots of known important lines: Hα, Ca II H&K, Fe II, Na I D1, Na I D2, He I and Ca I;
- Cuts spectra with Rneg > 0.01 and $\gamma_{RV} = 1$, and 3σ-clip on activity indices (care needed).

Ca II H&K activity periods

$\#\,\text{spectra} > 50$ and $t_{\text{span}} > 2\,\text{yrs} \Longrightarrow$ GLS periodogram ([5])

- **Is the peak significant?** $\Longrightarrow$ False Alarm Probability (FAP) > 1%, not close to Window Function periodogram peaks and exclude harmonics that include best period peak
- **Error of period** $\Longrightarrow$ curvature in power peak by fitting a parabola $y = aa \times x^2$
- **Color based quality indicator of period** - acceptable colors: green or yellow

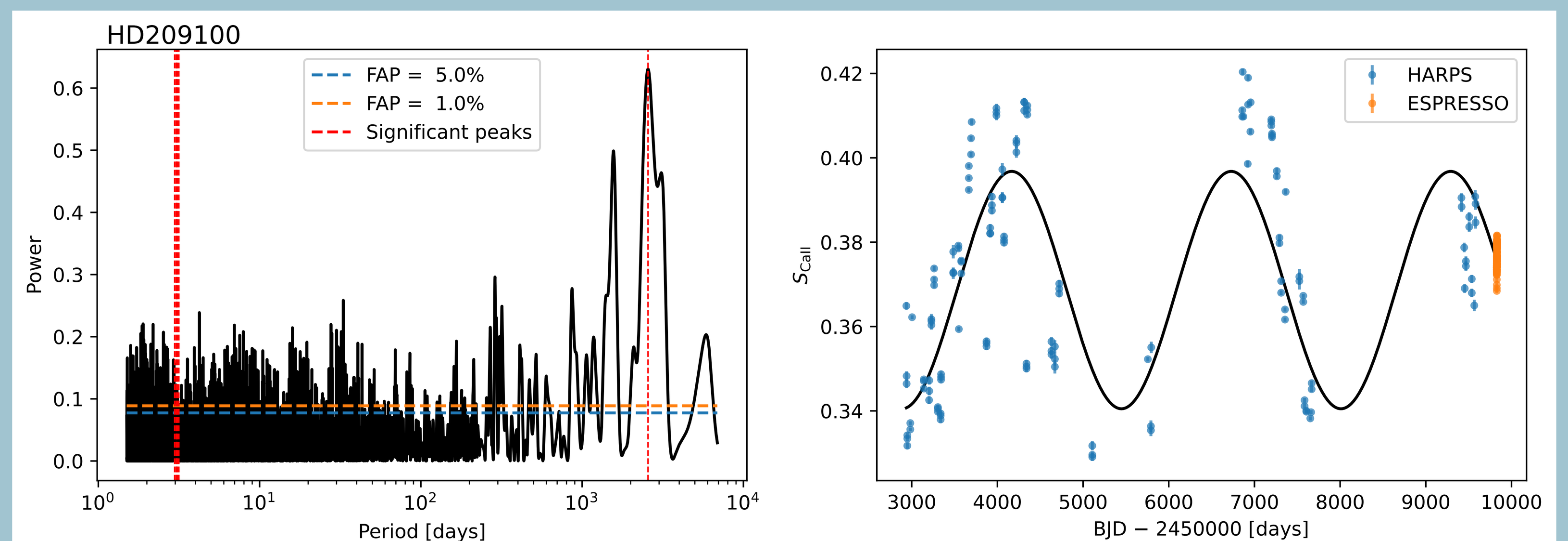

Figure 3. GLS periodogram for HD209100 using data from HARPS and ESPRESSO and fit to data.

S_{MW}, $\log R'_{\mathrm{HK}}$, chromospheric age and rotational period

- S_{MW} through calibrations for HARPS and ESPRESSO;
- $\log R'_{\mathrm{HK}}$ through 2 calibrations including B-V color depending on spectral type of star;
- P_{rot} through 2 different calibrations - one computes chromospheric age (gyrochronology).

Data compilation and output

- **Statistics:** maximum, minimum, mean, median, standard deviation and weighted mean of $S_{\mathrm{Ca\,II}}$, $I_{\mathrm{H}\alpha}$, $I_{\mathrm{Na\,I}}$, RV, S_{MW}, $\log R'_{HK}$, rotation periods and chromospheric age, and N_{spectra}.
- **Files saved per instrument:** raw data table, plots of spectral lines, activity indices and periodogram, FITS file with processed data table and important information in the header;
- **Master (final) files:** table and header for each instrument and combined table and header, as well as plots of the periodogram analysis.

Test stars results

We tested SAITAMA with 18 stars from SWEET-Cat with **V mag < 8, declination < +30° and SWFlag = 1**. We ordered them by T_{eff} and chose the stars with several spectra with 15 < S/N < 550 from HARPS and UVES. We computed activity indices for Ca II H&K, Hα and Na I lines.

Table 1. 18 test stars partial results using combined data. Instruments: HARPS - 1, ESPRESSO - 2, UVES - 3. Activity period $P_{S_{\mathrm{CaII}}}$ and mean rotation period from [6] in days. N_{CaII} is number of spectra including Ca II H&K lines.

HD	Instruments	$P_{S_{\mathrm{Ca\,II}}}$	P_{Flag}	$\langle S_{\mathrm{Ca\,II}}\rangle$	N_{CaII}	$\langle I_{\mathrm{H}\alpha}\rangle$	$\langle I_{\mathrm{Na\,I}}\rangle$	$N_{H_\alpha,\mathrm{Na\,I}}$	$\langle S_{\mathrm{MW}}\rangle$	$\langle \log R'_{HK}\rangle$	$\langle P_{\mathrm{rot,\,M08}}\rangle$	$\langle \mathrm{Age}_{\mathrm{M08}}\rangle$
142A	1,3	–	white	0.12	32	0.10	0.52	39	0.15	-4.95	12.27	2.44
1461	1,3	3770 ± 143	**green**	0.13	142	0.10	0.28	142	0.16	-5.03	31.73	5.80
10647	1,3	3027 ± 78	**green**	0.16	134	0.11	0.42	134	0.20	-4.71	7.42	1.16
13445	1,3	–	red	0.22	122	0.13	0.23	122	0.27	-4.75	30.14	3.78
16141	1,3	–	white	0.12	45	0.10	0.35	54	0.15	-5.13	40.29	8.11
16417	1,3	–	black	0.12	149	0.10	0.33	149	0.15	-5.06	30.37	5.73
20794	1,3	–	black	0.14	137	0.11	0.28	137	0.17	-4.99	33.95	6.00
22049	1,2,3	–	red	0.39	148	0.17	0.22	188	0.48	-4.49	15.50	1.10
46375	1,2	–	black	0.15	91	0.12	0.19	91	0.19	-4.98	45.55	7.45
47536	1,3	–	white	0.09	16	0.10	0.29	22	0.12	-5.50	90.00	–
85512	1	3674 ± 53	**green**	0.36	141	0.16	0.12	141	0.44	-4.93	49.18	–
102365	1,2,3	–	black	0.14	145	0.10	0.33	145	0.17	-4.95	27.27	4.58
108147	1,3	–	white	0.15	43	0.11	0.42	49	0.18	-4.79	9.35	1.55
115617	1,2,3	2798 ± 180	**green**	0.13	141	0.10	0.28	142	0.17	-5.00	33.20	5.92
160691	1,2,3	–	black	0.12	143	0.10	0.28	143	0.15	-5.11	37.78	7.44
179949	1,3	–	white	0.17	17	0.11	0.43	51	0.21	-4.68	7.22	1.02
192310	1,3	3417 ± 81	**green**	0.17	147	0.12	0.19	147	0.21	-4.95	45.91	–
209100	1,2,3	2562 ± 25	**green**	0.37	276	0.15	0.14	322	0.46	-4.73	33.52	–

Conclusions

Caveats

- **Low spectral resolution** may warp the results (UVES spectra mainly);
- Discrepancies in spectra taken with **different instruments** due to specific characteristics.

Future Work

- More thorough analysis on discrepancy between instruments.
- Tests with stars of different types (A, M): all of the 18 test stars were FGK type.

We hope that SAITAMA can be used without reservation in the studies about stellar activity, aiming to find correlations between it and properties of the planets hosted by these stars.

References

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[6] E. E. Mamajek and L. A. Hillenbrand. *The Astrophysical Journal*, 687:1264, 2008.