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The GAPS Programme with HARPS-N at TNG:

XVII. Line profile indicators and kernel regression as diagnostics of radial-velocity variations due to stellar activity in solar-like stars.

Lanza A.F., Malavolta L., Benatti S., Desidera S., Bignamini A., Bonomo A.S., Esposito M., Figueira P., Gratton R., Scandariato G., Damasso M., Sozzetti A., Biazzo K., Claudi R.U., Cosentino R., Covino E., Maggio A., Masiero S., Micela G., Pagano I., Piotto G., Poretti E., Smareglia R., Affer L., Boccato C., Borsa F., Boschini W., Giacobbe P., Knapic C., Leto G., Maldonado J., Mancini L., Martinez Fiorenzano A., Messina S., Nascimbeni V., Pedani M., Rainer M.

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=[2018A&A...616A.155L](#) (SIMBAD/NED BibCode)

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**ADC\_Keywords:** Models ; Line Profiles

**Keywords:** planetary systems - stars: activity - stars: late-type - starspots - stars: atmospheres - techniques: radial velocities

**Abstract:**

Stellar activity is the ultimate source of radial-velocity (hereinafter RV) noise in the search for Earth-mass planets orbiting late-type main-sequence stars. We analyse the performance of four different indicators and the chromospheric index  $\log R'_{\text{HK}}$  in detecting RV variations induced by stellar activity in 15 slowly rotating  $v \sin i \leq 5 \text{ km/s}$ , weakly active ( $\log R'_{\text{HK}} \leq -4.95$ ) solar-like stars observed with the high-resolution spectrograph High Accuracy Radial velocity Planet Searcher for the Northern hemisphere (HARPS-N). We consider indicators of the asymmetry of the cross-correlation function (CCF) between the stellar spectrum and the binary weighted line mask used to compute the RV, that is the bisector inverse span (BIS),  $\Delta V$ , and a new indicator  $V_{\text{asy(mod)}}$  together with the full width at half maximum (FWHM) of the CCF. We present methods to evaluate the uncertainties of the CCF indicators and apply a kernel regression (KR) between the RV, the time, and each of the indicators to study their capability of reproducing the RV variations induced by stellar activity. The considered indicators together with the KR prove to be useful to detect activity-induced RV variations in  $\sim 47 \pm 18$  percent of the stars over a two-year time span when a significance (two-sided p-value) threshold of one percent is adopted. In those cases, KR reduces the standard deviation of the RV time series by a factor of approximately two. The BIS, the FWHM, and the newly introduced  $V_{\text{asy(mod)}}$  are the best indicators, being useful in  $27 \pm 13$ ,  $13 \pm 9$ , and  $13 \pm 9$  percent of the cases, respectively. The relatively limited performances of the activity indicators are related to the very low activity level and  $v \sin i$  of the considered stars. For the application of our approach to sun-like stars, a spectral resolution allowing  $\lambda/\Delta\lambda \geq 10^5$  and highly stabilized spectrographs are recommended.

**Description:**

A computer code (procedure) written in Interactive Data Language (IDL) to compute the spectral line profile indicators used in the above research article starting from the fits files provided by the data reduction software (DRS) of HARPS or HARPS-N. The procedure takes the cross-correlation function (CCF) files provided by the DRS as an input.

An example for the input files and the corresponding output file is provided with the sole purpose of allowing to test the proper

compilation and running of the procedure. Details on an auxiliary source file (mpfit.pro) required for compilation are provided in the header of the procedure file and in Appendix A of the above mentioned article. Interested users are warmly recommended to read them before compiling and running the procedure.

#### File Summary:

FileName	Lrecl	Records	Explanations
ReadMe	80	.	This file
asym_ind.pro	242	1697	IDL procedure
input/*	0	118	Directory containing example input FITS files
<a href="#">output.dat</a>	470	56	Example output file
mpfit.pro	95	3737	*Auxiliary IDL procedure for compilation

**Note on mpfit.pro:** The IDL procedure mpfit.pro was authored by Craig B. Markwardt, NASA/GSFC Code 662, Greenbelt, MD 20770 and is accessible at the URL <http://cow.physics.wisc.edu/~craigm/idl/fitting.html>

#### Description of file: input/\*

This directory contains the 116 FITS files used to produce the example output file by running the IDL procedure asym\_ind.pro. This procedure reads the input files, the names of which are listed in the auxiliary text files flistccf.lis and flistbis.lis, computes the line indicators for their CCFs and print the results in the output file. These FITS files were produced by the DRS running on HARPS-N observations of the star HD 108874. Details on the observations, the spectrograph, and the data reduction procedure are provided in Benatti et al. (2017A&A...599A..90B).

#### Byte-by-byte Description of file: [output.dat](#)

Bytes	Format	Units	Label	Explanations
2- 21	F20.8	<a href="#">d</a>	Time	Solar system barycentric JD (time) <a href="#">(1)</a>
22- 41	F20.8	<a href="#">km/s</a>	RV	Radial velocity (rv)
42- 61	F20.8	<a href="#">km/s</a>	e_RV	Error on radial velocity (e_rv)
62- 70	I9	---	maxcpp	Maximum number of counts per pixel (maxcpp)
71- 90	F20.8	<a href="#">km/s</a>	BIS	Line bisector slope (bis)
91-110	F20.8	<a href="#">km/s</a>	e_BIS	Error on line bisector slope (e_bis)
111-130	F20.8	<a href="#">km/s</a>	deltav	deltav indicator (delta_v)
131-150	F20.8	<a href="#">km/s</a>	e_deltav	Error on deltax indicator (e <sub>deltav</sub> )
151-170	F20.8	---	vasy	Vasy indicator of Figuera et al. <a href="#">(2013A&amp;A...557A..93F)</a> (vasy)
171-190	F20.8	---	e_vasy	Error on the vasy of Figueira et al. <a href="#">(2013A&amp;A...557A..93F)</a> (e_vasy)
191-210	F20.8	---	vasymod	Modified vasy indicator (present work) (vasymod)
211-230	F20.8	---	e_vasymod	Error of vasymod (e_vasymod)
231-250	F20.8	<a href="#">km/s</a>	FWHMdrs	FWHM as given by the DRS (fwhmdrs)
251-270	F20.8	<a href="#">km/s</a>	FWHMfit	FWHM as given by a Gaussian fit to CCF (fwhmfit)
271-290	F20.8	<a href="#">km/s</a>	e_FWHM	Error on FWHM computed by mpfit.pro (e_fwhm)
291-310	F20.8	---	cont-drs	CCF contrast given by the DRS (cont_drs)
311-330	F20.8	---	contrast	CCF contrast computed by mpfit.pro (contrast)

331-350	F20.8	---	e_contr	Error on the CCF contrast by mpfit.pro (e_contr)
351-370	F20.8	<a href="#">km/s</a>	FWHMs	Median FWHM of 200 CCF realizations (fwhm_s)
371-390	F20.8	<a href="#">km/s</a>	e_FWHMs	Error of fwhms (efwhms)
391-410	F20.8	<a href="#">km/s</a>	deltavs	Median delta_v of 200 CCF realizations (delta_vs)
411-430	F20.8	<a href="#">km/s</a>	e_deltavs	Error on deltavs (edeltavs)
431-450	F20.8	---	conts	Median contrast of 200 CCF realizations (cont_s)
451-470	F20.8	---	e_conts	Error on conts (econts)

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**Note (1):** For a full explanation of the various fields of the output file, see the header of the IDL procedure `asym_ind.pro`.

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#### Acknowledgements:

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#### References:

Covino et al.,	Paper I	<a href="#">2013A&amp;A...554A..28C</a> , Cat. <a href="#">J/A+A/554/A28</a>
Desidera et al.,	Paper II	<a href="#">2013A&amp;A...554A..29D</a>
Esposito et al.,	Paper III	<a href="#">2014A&amp;A...564L..13E</a>
Desidera et al.,	Paper IV	<a href="#">2014A&amp;A...567L...6D</a>
Damasso et al.,	Paper V	<a href="#">2015A&amp;A...575A.111D</a> , Cat. <a href="#">J/A+A/575/A111</a>
Sozzetti et al.,	Paper VI	<a href="#">2015A&amp;A...575L..15S</a> , Cat. <a href="#">J/A+A/575/L15</a>
Borsa et al.,	Paper VII	<a href="#">2015A&amp;A...578A..64B</a> , Cat. <a href="#">J/A+A/578/A64</a>
Mancini et al.,	Paper VIII	<a href="#">2015A&amp;A...579A.136M</a> , Cat. <a href="#">J/A+A/579/A136</a>
Damasso et al.,	Paper IX	<a href="#">2015A&amp;A...581L...6D</a> ,
Biazzo et al.,	Paper X	<a href="#">2015A&amp;A...583A.135B</a> , Cat. <a href="#">J/A+A/583/A135</a>
Malavolta et al.,	Paper XI	<a href="#">2016A&amp;A...588A.118M</a> , Cat. <a href="#">J/A+A/588/A118</a>
Benatti et al.,	Paper XII	<a href="#">2017A&amp;A...599A..90B</a> , Cat. <a href="#">J/A+A/599/A90</a>
Esposito et al.,	Paper XIII	<a href="#">2017A&amp;A...601A..53E</a>
Bonomo et al.,	Paper XIV	<a href="#">2017A&amp;A...602A.107B</a> , Cat. <a href="#">J/A+A/602/A107</a>
Gonzalez-Alvarez et al.,	Paper XV	<a href="#">2017A&amp;A...606A..51G</a>

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**(End)** Antonino F. Lanza [INAF, Italy], Patricia Vannier [CDS] 18-Apr-2018