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FliPer: A global measure of power density to estimate surface gravities of Solar-like stars

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ABSTRACT

Asteroseismology provides global stellar parameters such as masses, radii or surface gravities using the mean global seismic parameters as well as the effective temperature for thousands of low-mass stars ($0.8M_{\odot} < M < 3M_{\odot}$). This methodology can only be applied to stars in which acoustic modes excited by turbulent convection are measured. Other techniques such as the Flicker can also be used to determine stellar surface gravities, but this method only works for $\log g$ higher than 2.5 dex. In this work, we present a new metric called FliPer (Flicker in Power, in opposition to the standard Flicker measurement which is computed in the time domain) that is able to extend the range for which reliable surface gravities can be obtained ($0.1 < \log g < 4.6$ dex) without performing any seismic analysis. FliPer takes into account the average variability of a star measured in the power density spectrum in a given range of frequencies. However, FliPer values calculated on several ranges of frequency are required to better characterize a star. Using a large set of asteroseismic targets it is possible to calibrate the behavior of surface gravity with FliPer through machine learning. This calibration made with a random forest regressor covers a wide range of surface gravities from main-sequence stars to subgiants and red giants, with very small uncertainties from 0.04 to 0.1 dex. FliPer values can be inserted in automatic global seismic pipelines to either give estimation of the stellar surface gravity or to assess the quality of the seismic results by detecting any outliers in the obtained surface gravities. FliPer also constrain the surface gravities of main-sequence dwarfs using only long cadence data for which the Nyquist frequency is too low to measure the acoustic-mode properties. This is the first seismic-independent method that allows the estimation of surface gravities below 2.5 dex with good precision.

Key words. asteroseismology - methods: data analysis - stars: oscillations

1. Introduction

The precise knowledge of stellar parameters is crucial for a very broad range of fields in astrophysics. Indeed, while it helps us understanding stellar evolution, it also provides important information needed for planetary searches and for studying the chemical and dynamical evolution of our Galaxy. In the last decade, the NASA mission *Kepler* (Borucki et al. 2013) collected very high-quality photometric data for almost 200,000 stars (Mathur et al. 2017) continuously during ~ 4 years. These observations not only revolutionized the search for exoplanets but also opened a window into stellar physics. Asteroseismology proved to be a very powerful tool to better characterize the stars in terms of mass, radii, and age (Metcalfe et al. 2010; Mathur et al. 2012; Silva Aguirre et al. 2017; Serenelli et al. 2017) but also in terms of their rotation and magnetic activity (McQuillan et al. 2014; García et al. 2014a; Davies et al. 2015; Ceillier et al. 2017; Kiefer et al. 2017). However stellar oscillations have not been detected neither in all red giants ($\sim 16,000$ reported out of the $\sim 24,000$ in the latest *Kepler* star-properties catalog from Mathur et al. (2017)), nor in all the main-sequence Solar-like stars. Indeed, around 135,000 main-sequence dwarfs have only been observed in long cadence (LC, sampling time of 29.4 min) by *Kepler* preventing any direct asteroseismic analyses because their acoustic-mode frequencies are well above the Nyquist frequency and can only be seismically studied with short-cadence data (SC, sampling time of 58.85 s, (Chaplin et al. 2011b)).

To circumvent this, new techniques are being developed to extract precise surface gravities ($\log g$) directly from the photometric data. This is the case of the Flicker, i.e., the measurement of the brightness variations in timescales shorter than 8 hrs (Bastien et al. 2013, 2016), the variance of the flux (Hekker et al. 2012), the granulation (Mathur et al. 2011; Kallinger et al. 2014), and from the analysis of the time scales of convective-driven brightness variations (Kallinger et al. 2016). However all these techniques have limitations. Flicker is restricted by construction to stars with $4500 < T_{\rm eff} < 7150$ K and $2.5 < \log g < 4.6$ dex, preventing the study of high-luminosity red giant branch (RGB) and asymptotic red giant branch (AGB) stars. To obtain the granulation properties it is necessary to fit a complicated model including different scales of convection with many free parameters (for more details see the discussions in Mathur et al. 2011; Kallinger et al. 2014; Corsaro et al. 2017). The final method requires that the oscillation signal is temporally resolved preventing to extend the analysis to main-sequence dwarfs only observed in long-cadence data. It has also been shown that instead of using classic seismic methods it is possible to apply machine learning algorithms directly on the data. For instance, Hon et al. (2018) apply a convolutional neural network on spectra to classify stars. This method gives good results for about 99 % of their sample of red giants, including some stars that were not already characterized with seismic pipelines. A Random Forest regression model applied directly on the photometric light curves of variable stellar sources can also estimate their surface gravity with a 0.42 dex uncertainty (Miller et al. 2014).

We present here a new metric called FliPer (Flicker in Power) –in opposition to the standard Flicker measurement which is computed in the time domain– that aims at linking the variability of a star to its surface gravity in a wider range than the Flicker, starting at a $\log g \sim 0.1$ and similar effective temperatures ($4500 < T_{\rm eff} < 7150$K) covering Solar-like pulsating stars. We are limited in the $0.1 < \log g < 4.6$ dex range of surface gravity because of the lack of information we have on extreme surface gravity Solar-like stars. There is no intrinsic limits of applicability to the FliPer calculation. We decide to combine powerful methods: we include FliPer values from different lower frequency boundaries into a supervised machine learning Random Forest algorithm in order to get even more accurate results on the surface gravity estimation. This way, we obtain information about the impact of the lower frequency boundaries and the effective temperature on the estimation of surface gravity.

2. Observations, data selection and preparation

In this work, long (29.4 minutes) cadence data (Gilliland et al. 2010) obtained by the NASA's *Kepler* main mission have been used. The light curves have been corrected and the different quarters concatenated following García et al. (2011). Two high-pass filters have been used with cut-off frequencies corresponding to 20 and 80 days. To minimize the effects of the gaps in the observations (García et al. 2014b) the missing observations have been interpolated using impainting techniques (Pires et al. 2015). Data are corrected from apodization following Chaplin et al. (2011a).

We selected $\sim 15,000$ red-giant stars (RG) among the ones in Mathur et al. (2017) showing stellar pulsations and characterized using the A2Z asteroseismic pipeline (Mathur et al. 2010). These stars have $0.1 < \log g < 3.4$ dex and $3285 < T_{\rm eff} < 7411$K. in addition, 254 main-sequence (MS) stars with $4951 < T_{\rm eff} < 6881$K are used to extend the study toward higher surface gravity range, reaching 4.5 dex.

3. The new metric: FliPer

The complete power spectrum contains contributions from the stellar variability at all time scales such as oscillation modes, surface granulation, and rotation. We define FliPer as:

$$\mathrm{F_p} = \overline{\mathrm{PSD}} - \mathrm{P_n}\ , \quad (1)$$

where $\overline{\textsc{psd}}$ represents the averaged value of the power spectrum density from a giving frequency (see Section 3.1) to the Nyquist frequency and $\mathrm{P_n}$ is the photon noise. This noise could be calculated by taking the average value of the PSD over a range of frequencies close to the Nyquist frequency, but this method leads to biased estimation of FliPer for stars that oscillate with a frequency close to the Nyquist frequency as explained in detail by Bugnet et al. (2017). Then, the photon noise has been theoretically computed by following Jenkins et al. (2010).

The value of FliPer is dominated by a combination of the granulation and the oscillation modes that both depend on the evolutionary stage of the star. The more evolved the star, the larger their oscillation and granulation amplitudes (e.g. Mosser et al. 2012; Garcıa & Stello 2015), while the frequency of maximum power $\nu_{\rm max}$ decreases (e.g. Bedding 2014).

It is important to notice that the signature of strong rotation (and its harmonics) would bias FliPer. This doesn't have a large impact for the case of red giants because a very small fraction of them shows signatures of the rotation in the PDS as shown by Ceillier et al. (2017) but needs to be studied in details for main-sequence Solar-like stars (see Section 3.3).

3.1. Computing FliPer from data

The observational frequency range used to compute $\overline{\textsc{psd}}$ is limited at high frequency by the Nyquist frequency. For most stars (those observed in LC) we cannot get information above $\sim 283\ \mu Hz$. Therefore, we select a first set of calibrator stars including red giant pulsating at a frequency lower than 300 μHz and for which asteroseismic parameters are available. A second set of known seismic main-sequence dwarfs is used to study FliPer with long cadence data only.

The low-frequency limit of $\overline{\textsc{psd}}$ is given by the cut-off frequency used in the calibration of the data. For most of the stars, a 20 days high-pass filter light curves is used. The associated cut-off frequency of the signal is 0.58 μHz. We thus establish a low-frequency limit for the analysis at 0.7 μHz. As main-sequence stars can rotate with a period shorter than 20 days, FliPer is computed with a low-frequency limit at 7 μHz (i.e. ∼1.6 days) avoiding most of the pollution induced by rotation signals (see Section 3.3). For stars showing rotation harmonics at higher frequencies, the low-frequency boundary should be taken even higher (e.g. 20 μHz) to avoid any additional impact on FliPer from the peaks associated with rotation. Finally, a small amount of red giants in our sample are either high-luminosity Red Giant Branch stars or AGB stars ($\log g < 1$ dex) pulsating at frequencies smaller than the 20 days cut-off frequency of the calibrated data. For these stars, an 80 days filter is used in the calibration process. It allows us to properly measure the stellar signal down to 0.2 μHz (which is the limit frequency utilized in this analysis) and to include oscillation-mode power into the FliPer value.

3.2. A first surface gravity estimator

For stars with Solar-like oscillations, seismic surface gravities are directly obtained from the frequency of maximum oscillation power ν_{max} computed with the A2Z pipeline (Mathur et al. 2010) and effective temperatures from the *Kepler* DR25 catalog (Mathur et al. 2017). Knowing seismic surface gravities with their uncertainties allows us to study the behavior of FliPer with

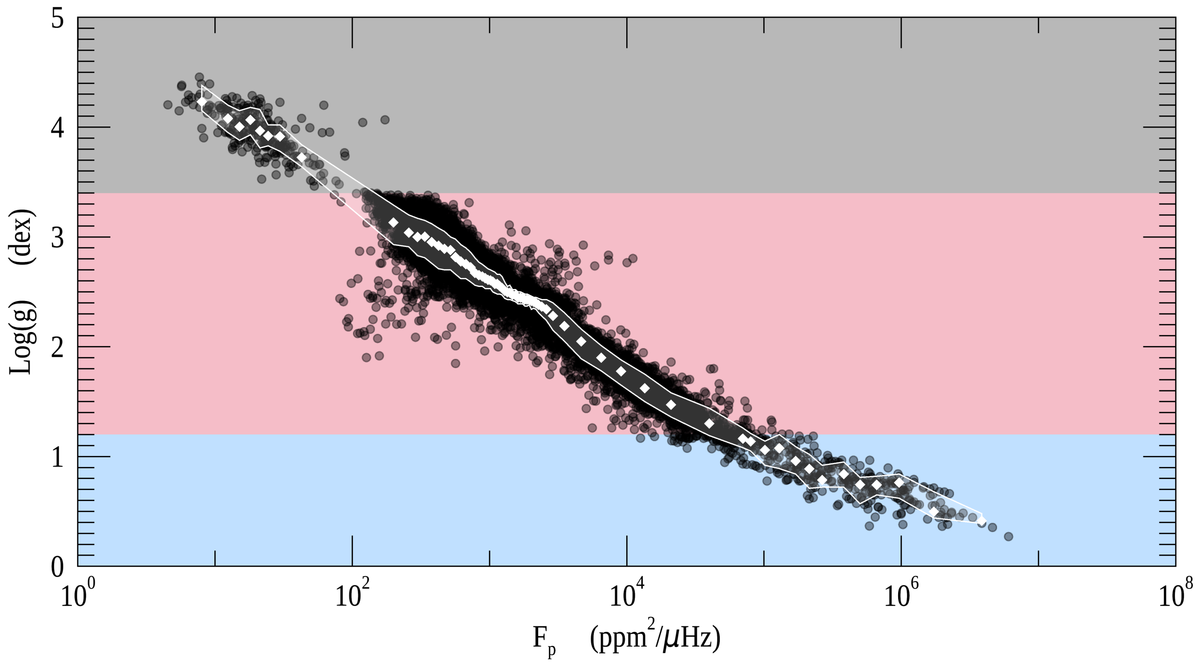

Fig. 1: Seismic $\log g$ vs FliPer for $\sim 15,000$ stars observed with *Kepler* long-cadence observational mode (black dots). The three shaded regions, grey, red and blue correspond to MS and sub-giant stars, RG, and high-luminosity RG stars or AGB respectively. White diamonds represent the weighted mean value of $\log g$ computed with 30 MS stars and 300 RGs each. The white area delimits the location where 68% of the stars in our sample are around the mean value. The white boundary represents the equivalent of a 1σ uncertainty (standard deviation) on the surface gravity obtained from FliPer.

the evolutionary state of the stars using only LC light curves even for main-sequence stars. It is important to notice that for main-sequence stars, the seismic $\log g$ has been seismically inferred using SC data although FliPer has been computed using LC data.

In Fig. 1, the seismic $\log g$ is represented as a function of FliPer (black dots). Three different areas have been identified depending on the evolutionary state of the star: MS and sub-giant stars (grey shaded region), RG (red), and high-luminosity RG stars from the branch and from the asymptotic branch (blue). For each of these category of stars FliPer has been computed with a different low-frequency limit of 7 μHz (avoiding in most cases the region of possible pollution by rotation signatures present on data filtered with a high-pass filter at 20 μHz), 0.7 μHz (20 days filter), and 0.2 μHz (80 days filter) respectively. The color scheme is universal in the captions.

In order to characterize the relationship between FliPer and $\log g$ represented in Fig. 1, we calculate an averaged value of $\log g$ for each bin of n stars ($n = 300$ for RG and $n = 30$ for MS and sub-giant stars). These values are represented by the white diamonds, and are located at the averaged value of FliPer over each bin. To define the 1σ uncertainties, we compute the area containing 68% of the stars of the sample (marked by a white contour region in Fig. 1). Mean values and their corresponding $\pm 1\sigma$ uncertainties are reported in Table. A.1. By using these mean values it is possible to estimate the stellar surface gravity directly from the FliPer estimator. The uncertainties obtained on $\log g$ extend from 0.05 to 0.2 dex, depending on the evolutionary state of the star.

3.3. Disentangling Main-Sequence stars from Red Giants

As it is defined, FliPer is mostly dominated by a combination of the power coming from granulation and oscillation modes (when the latter are below the Nyquist frequency). The limitation in the use of the calibrated values from Table A.1 to directly estimate surface gravity of stars appears when the spectrum shows a specific behavior that strongly modifies the mean value of the power density. For instance, in stars showing large excess of power (e.g. due to spikes at thrusters frequency in K2 data, or to pollution from a background binary), the value of FliPer is biased towards high power density (Bugnet et al. 2017). On the contrary, in stars with a low signal-to-noise ratio the value of FliPer is biased towards lower values, because most of the spectrum is dominated by the instrumental noise. As a consequence, FliPer is higher than expected for fast rotating MS stars due to the rotation peaks and their harmonics, which can be particularly high for young main-sequence dwarfs. For these stars, the $\log g$ inferred from Table A.1 could be such that it corresponds to a RG and not to a MS star, even if we calculate FliPer with the 7μHz frequency limit.

To avoid this problem and to disentangle any MS stars from RGs, we need an additional parameter that takes into account the power due to rotation. The most simple solution is to combine different FliPer values, including some at higher frequencies than the 7μHz limit. For each star in our sample, we then calculate FliPer with several low-frequency limits (e.g. $F_{p_{0.2}}$ from 0.2, $F_{p_{0.7}}$ from 0.7, F_{p_7} from 7, $F_{p_{20}}$ from 20 and $F_{p_{50}}$ from 50 μHz). For MS stars with small rotation signatures the value of FliPer is almost the same for all the low-frequency boundaries

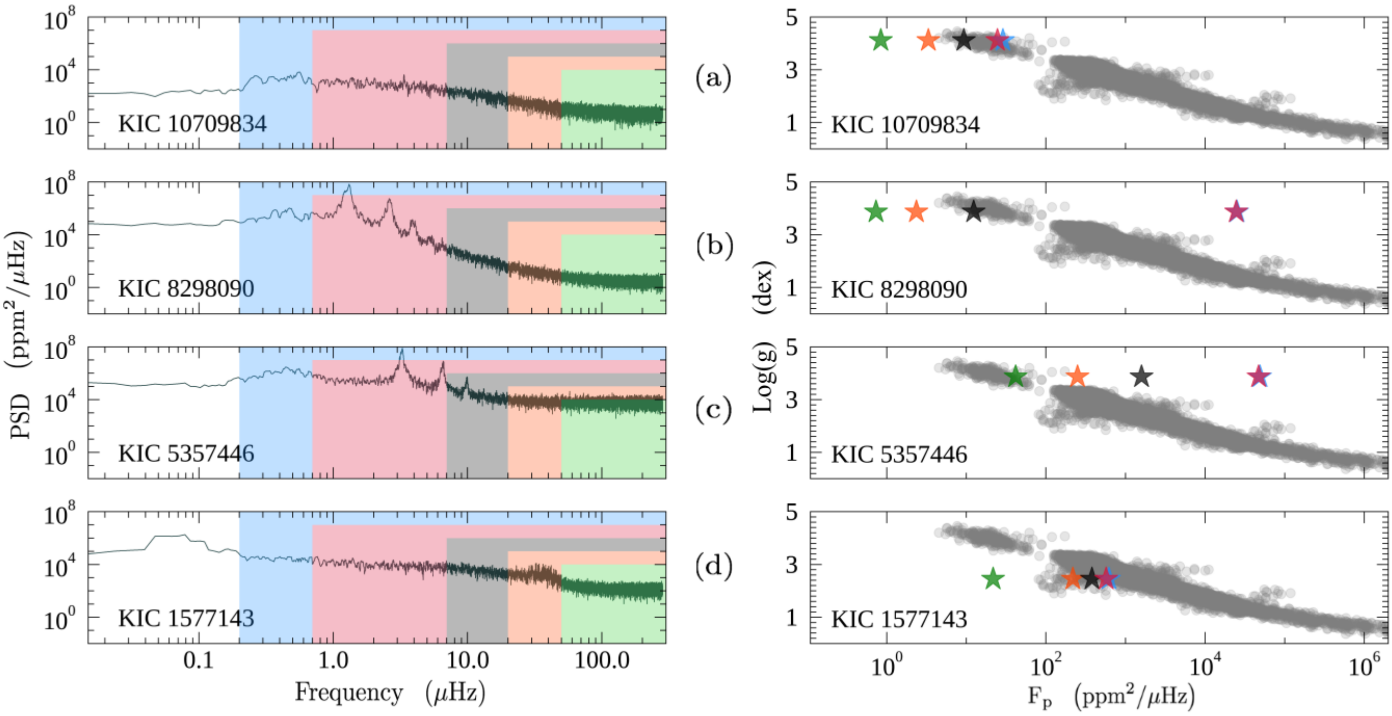

Fig. 2: Impact of the lower frequency limit in the FliPer calculation on the estimation of surface gravity for different type of star. **Left panels:** Power density spectra of four *Kepler* targets. Colored areas (resp. blue, red, black, orange and green) represent the different ranges of frequency used for FliPer calculation (from resp. 0.2, 0.7, 7, 20 and 50 μHz to the Nyquist frequency). The color scheme is universal in the captions. **Right panels:** All studied *Kepler* stars from Fig. 1 are represented in grey in the log(g) V.S FliPer diagram. Colored stars (blue, red, black, orange and green) show the position in the diagram of the four stars from left panels with their color corresponding to the low-frequency boundaries used to compute the FliPer value. Panel (a) represents a MS star without any visible rotation component, panel (b) a MS star showing rotation, panel (c) a high frequency rotating MS star, and panel (d) a RG star.

(see panel (a) on Fig. 2). However, when rotation peaks are present, there is a large difference between the FliPer parameters, depending on the frequency of the rotational peaks (See Fig. 2). This is the case for both stars KIC 8298090 and KIC 5357446 represented on panels (b) and (c). On panel (b) all the rotational components are below the 0.7μHz boundary, meaning that parameters $F_{p_{20}}$ and $F_{p_{50}}$ were not necessary to classify this star as a main-sequence star. However on panel (c) the rotation peaks reach higher frequencies: in order to estimate the surface gravity of this star the two new high-frequency parameters are needed. Panel (d) shows a RG star for comparison. In the regime of RG stars ($0.1 < \log(g) < 3.4$ dex), all the FliPer values are very similar - except the lowest ones coming from the calculation with high-pass filter that doesn't include the range of frequency of oscillation modes. By comparing the values of FliPer computed with different low-frequency limits, it is then possible to disentangle MS stars with a high rotation signature from RG stars.

4. Seismic independent surface gravity prediction from 0.1 to 4.5 dex

The direct estimation of surface gravity from Table A.1 gives good results only when the evolutionary state of the star is already known, and when the spectrum does not show a specific behavior that strongly modifies the mean value of the power density. The reason is that we only use one value of FliPer computed from one lower frequency limit. Estimating surface gravities of unclassified or complex stars requires a different use of the FliPer method.

As explained above, combining different FliPer values is powerful to detect MS stars showing high rotation signal among RGs. It also means that by using different high-pass filters in the calculation of FliPer we are sensitive to different physical signatures in the PSD. Combining them in the study thus improves the characterization of the star, and we intend to use this wisely to predict surface gravities. To do so, we train a Random Forest regressor algorithm on a random subsample representing 20% of our set of stars. The Random forest method is based on the aggregation of a large number of decision trees. The trees are constructed from a training data set and internally validated to give prediction given the predictor for future observations. The random forest method not only allows the use of a large number of parameters but also the estimation of their individual impact on the regression. The parameters used are $F_{p_{0.2}}$, $F_{p_{0.7}}$, F_{p_7}, $F_{p_{20}}$, $F_{p_{50}}$ and $T_{\rm eff}$. They represent the values of FliPer calculated from a low frequency limit of 0.2, 0.7, 7, 20, 50 μHz and the effective temperature. Their impacts on the training process are represented on Fig. 3 A.

A predictable result is that the $F_{p_{0.7}}$ parameter largely dominates the training. It comes from the fact that this is the most suitable parameter to study RG, representing more than 90% of the total amount of stars. Other relevant values of the filtering appear to be 7 and 0.2 μ Hz. Indeed, F_{p_7} plays an important role

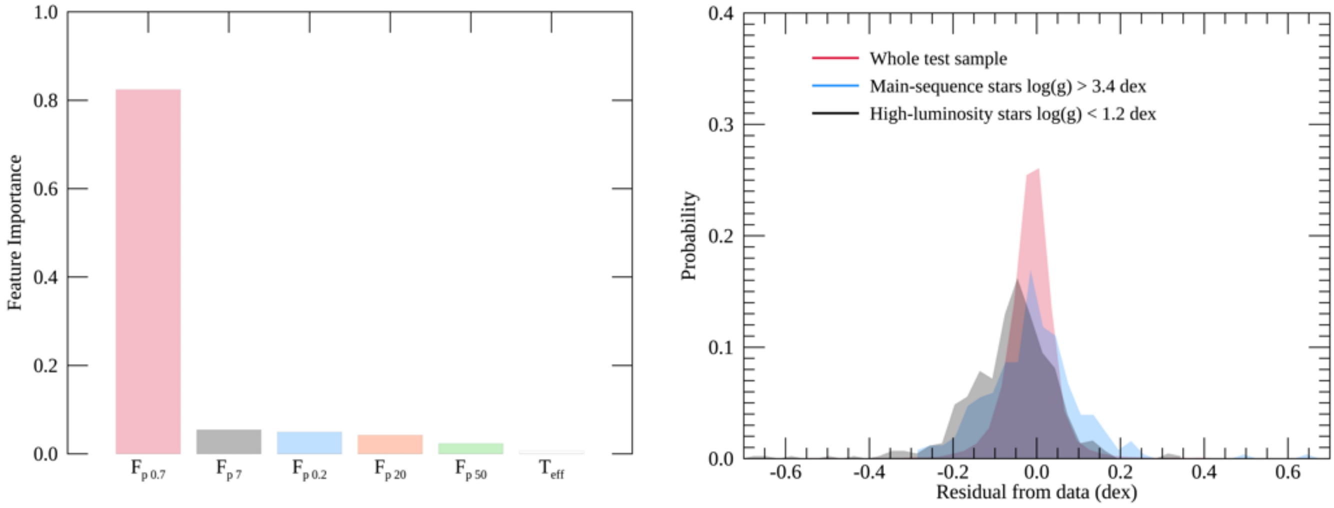

Fig. 3: **Left panel:** Importances of the different parameters $F_{p_{0.2}}$, $F_{p_{0.7}}$, F_{p_7}, $F_{p_{20}}$, $F_{p_{50}}$ and T_{eff} on the training process. The color scheme is universal in the captions. **Right panel:** Histogram of the residuals from the expected $\log(g)$ value ($\log(g)_{A2Z} - \log(g)_{RF}$) for all the test set (red), main-sequence test stars only (blue), and high-luminosity stars only (black).

Table 2: Summary statistical results on the test set. MAD is the mean averaged deviation.

Parameters	MAD (dex)
$\log(g)_{ALL}$	0.04
$\log(g)_{MS}$	0.10
$\log(g)_{HL}$	0.08

in the training because of its ability to distinguish MS stars from RGs, and the $F_{p_{0.2}}$ parameter helps in the prediction of surface gravity for high luminosity stars. The other parameters $F_{p_{20}}$ and $F_{p_{50}}$ have lower impacts on the training, but still help the learning for high rotating MS stars. Even the effective temperature that only has a 0.46 % importance plays a significant role considering the large amount of stars we are characterizing. We confirm from Fig. 3 that combining different lower frequency boundaries in the FliPer calculation makes a great difference for the estimation of a robust surface gravity.

To evaluate the performance of the algorithm, the estimate of surface gravity from the test sample (representing the total set of stars) is compared to the corresponding A2Z estimation of surface gravity. The mean averaged deviation (MAD) of the Random Forest surface gravities from reference values is reported in Table 2. This estimator of the deviation is chosen to be robust against outliers to avoid any issue coming from an eventual remaining error in the A2Z estimation of surface gravity.

The estimation of surface gravity resulting from the machine learning on the test sample has an averaged deviation of ~ 0.04 dex from our reference values (see Table 2). This uncertainty is small compared to the typical spectroscopic error bars obtained on surface gravities (0.2-0.4 dex). We also get surface gravity uncertainties for the different Solar-like star classes (RGs, Clump stars, high luminosity, MS) on Table 2. We conclude that for all our stars, the new method gives a very good precision on surface gravity. The Flicker method in the range of $\log g$ of $2.5 - 4.6$ dex have typical errors between 0.1 and 0.2 dex. Here, errors lies from 0.04 dex for RGs to 0.1 dex for MS stars.

5. Discussion & Conclusion

In this work we present a new method to estimate surface gravity of Solar-like stars that extracts information from global power in their spectra. The sample of $\sim 15,000$ stars is constituted of main-sequence and sub-giant stars, stars on the red giant branch (RGB) and clump stars, and also high luminosity stars on the asymptotic giant branch (AGB). This way, we study stars with $0.1 < \log g < 4.5$ dex in which mode oscillations are expected to arise from surface convection. Power spectra should then present patterns of granulation power, rotation components, and oscillation-mode power.

FliPer values are calculated by taking the average power density normalized by the photon noise of the star from different lower frequency limits to the Nyquist frequency. Our first method consists of calibrating surface gravity of stars from their FliPer value with a 1σ uncertainty (see Table A.1). We explained how these values can be used directly to give a first estimate of surface gravity, however it works well only on stars that are already characterized. Indeed, the evolutionary state has to be known or the star must have a weak rotational signature in order to distinguish main-sequence stars from red giants. To give estimations of surface gravities for any star, we introduce a second method. A Random Forest regressor algorithm is trained to estimate surface gravity on a sample of our stars. We use FliPer values computed with different frequency ranges, spectroscopic effective temperatures and seismic surface gravities. This way, stars are better characterized during the process, and no additional information is needed to provide accurate estimation of surface gravity, even for highly rotating MS stars. By testing the algorithm on the rest of our sample, we obtain estimates of surface gravity with a mean averaged deviation of 0.04 dex from seismic $\log g$. The training relies on seismic observations of Solar-like stars representing 80 % of our sample. However, there is no need for additional seismic measurements to obtain precise estimations of surface gravities on the test set of stars.

Our method, once calibrated, is then independent from any traditional seismic study. The uncertainty on our results largely improves upon previous non-seismic estimations of surface gravity. Indeed, spectroscopic estimations are known to have 0.2-0.4 dex error bars and recent methods such as the Flicker (Bastien et al. 2016) or the study of time-scale of granulation (Kallinger et al. 2016) gives estimates with errors higher than 0.1 dex. In addition, FliPer is extended to a wider range of surface gravities, reaching $\log g$ as small as 0.1 dex with a mean averaged deviation of 0.04 dex comparable to the other RGs.

For main-sequence stars that oscillate at high frequency (above the *Kepler* LC Nyquist frequency), FliPer computed from LC data does not contain mode power, but only granulation-related power (Corsaro et al. 2017) and rotation signals. However, Fig. 1 clearly shows that FliPer values for main-sequence stars are still correlated with surface gravity although the mean averaged deviation is degraded to 0.07 dex. This is a new evidence of the link between granulation and asteroseismic properties (Mathur et al. 2011; Kallinger et al. 2014), allowing us to estimate ν_{max} or rather surface gravities on LC data for which high-frequency modes are not measured. Thus, proper surface gravities can be precisely inferred for any *Kepler* LC solar-like target, from main-sequence to high-luminosity stars, without using direct seismic analysis.

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Appendix A:

Table A.1: Weighted mean value of $\log g$ from diamonds on Fig. 1 with their 1σ uncertainties for each bin of 30 (for MS and HL stars) or 300 (for RGs) stars.

log(F_P)	$\log g$ (dex)	-1σ (dex)	+1σ (dex)
0.90	4.23	0.08	0.15
1.09	4.08	0.13	0.13
1.18	4.00	0.12	0.14
1.26	4.07	0.14	0.11
1.33	3.97	0.16	0.19
1.39	3.92	0.09	0.10
1.47	3.91	0.13	0.11
1.63	3.72	0.08	0.11
2.30	3.13	0.21	0.15
2.41	3.04	0.13	0.16
2.47	3.00	0.17	0.17
2.53	3.00	0.19	0.14
2.58	2.95	0.19	0.17
2.63	2.92	0.21	0.16
2.67	2.89	0.19	0.16
2.72	2.88	0.18	0.12
2.75	2.82	0.16	0.16
2.79	2.78	0.15	0.15
2.83	2.75	0.14	0.15
2.86	2.72	0.14	0.13
2.89	2.67	0.12	0.14
2.92	2.65	0.10	0.12
2.95	2.64	0.09	0.11
2.97	2.62	0.09	0.10
2.99	2.61	0.08	0.10
3.01	2.60	0.08	0.09
3.02	2.59	0.10	0.10
3.04	2.57	0.08	0.11
3.06	2.57	0.09	0.09
3.07	2.55	0.07	0.11
3.09	2.53	0.07	0.10
3.11	2.51	0.07	0.08
3.13	2.50	0.06	0.05
3.15	2.49	0.06	0.06
3.17	2.47	0.06	0.05
3.19	2.47	0.06	0.05
3.21	2.45	0.06	0.05
3.23	2.45	0.05	0.05
3.24	2.44	0.05	0.05
3.26	2.43	0.06	0.05
3.27	2.43	0.05	0.05
3.29	2.43	0.05	0.04
3.30	2.42	0.07	0.05
3.32	2.41	0.06	0.04
3.34	2.40	0.06	0.05
3.36	2.38	0.07	0.06
3.38	2.37	0.08	0.06
3.41	2.34	0.10	0.09
3.46	2.28	0.13	0.12
3.55	2.19	0.14	0.13
...	...	...	...
3.67	2.05	0.16	0.11
3.81	1.90	0.12	0.11
3.96	1.78	0.13	0.10
4.13	1.62	0.12	0.13
4.32	1.47	0.11	0.11
4.60	1.30	0.11	0.14
4.85	1.16	0.08	0.10
4.90	1.14	0.08	0.08
5.01	1.06	0.14	0.08
5.11	1.08	0.19	0.13
5.23	0.96	0.12	0.13
5.33	0.89	0.18	0.14
5.42	0.79	0.07	0.13
5.58	0.84	0.12	0.11
5.70	0.74	0.17	0.07
5.82	0.74	0.09	0.08
5.99	0.76	0.14	0.08
6.24	0.50	0.05	0.18
6.59	0.41	0.02	0.07