FLIPER: CHECKING THE RELIABILITY OF GLOBAL SEISMIC PARAMETERS FROM AUTOMATIC PIPELINES

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Abstract. Our understanding of stars through asteroseismic data analysis is limited by our ability to take advantage of the huge amount of observed stars provided by space missions such as CoRoT, *Kepler*, K2, and soon TESS and PLATO. Global seismic pipelines provide global stellar parameters such as mass and radius using the mean seismic parameters, as well as the effective temperature. These pipelines are commonly used automatically on thousands of stars observed by K2 for 3 months (and soon TESS for at least ~ 1 month). However, pipelines are not immune from misidentifying noise peaks and stellar oscillations. Therefore, new validation techniques are required to assess the quality of these results. We present a new metric called FliPer (Flicker in Power), which takes into account the average variability at all measured time scales. The proper calibration of FliPer enables us to obtain good estimations of global stellar parameters such as surface gravity that are robust against the influence of noise peaks and hence are an excellent way to find faults in asteroseismic pipelines.

Keywords: asteroseismology - methods: data analysis - stars: oscillations

1   Introduction

Surface gravity and global seismic parameters ($\Delta\nu$, ν_{max}) are related through the so-called global seismic scaling relations (Brown & Gilliland 1990; Kjeldsen et al. 1994): $\Delta\nu \propto M^{\frac{1}{2}} \times R^{\frac{-3}{2}}$ and $\nu_{max} \propto M \times R^{-2} \times T_{eff}^{-\frac{1}{2}}$. Hence, an accurate estimation of the seismic global parameters and the effective temperature can be used to provide an estimate of the surface gravity of stars with convective envelopes. However, most asteroseismic data obtained from *Kepler* and K2 are sampled with cadence of around 30 minutes (long cadence), leading to limited spectral information above the corresponding Nyquist frequency ($\sim 288~\mu$Hz). If a star pulsates at frequencies higher than the long cadence Nyquist frequency (for instance a main-sequence star, e.g. Davies et al. 2015) typical analysis methods cannot be applied to estimate seismic parameters. In some cases reliable information can be obtained (Chaplin et al. 2014) but typical automated asteroseismic pipelines are susceptible to providing unreliable estimates. Indeed, internal magnetic fields can inhibit the modes (e.g. Mosser et al. 2009; García et al. 2010; Chaplin et al. 2011), complicating the automatic characterization of seismic parameters.

Several methods have been developed to estimate the stellar parameters (e.g. surface gravity) from photometric data based on a simple measurement such as the variance of the time series (Hekker et al. 2012), the Flicker (Bastien et al. 2013, 2016), granulation characterization of the power spectrum (Mathur et al. 2011; Kallinger et al. 2014) or the autocorrelation as described in Kallinger et al. (2016). Some of these methods require the observation of acoustic modes of oscillation but those that rely on the information provided by just granulation do not. The Flicker technique is typically used for main-sequence stars, subgiants and giants down

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to a $\log_{10}(g) \sim 2.5$ dex. With FliPer we can reach the range of application to red giants to lower log(g) by taking into account the variability at all measured frequencies in the power spectrum (Bugnet et al. *in prep.*). Thus, with this simple metric it is possible to assess in a few seconds the reliability of results obtained from automatic global seismic pipelines.
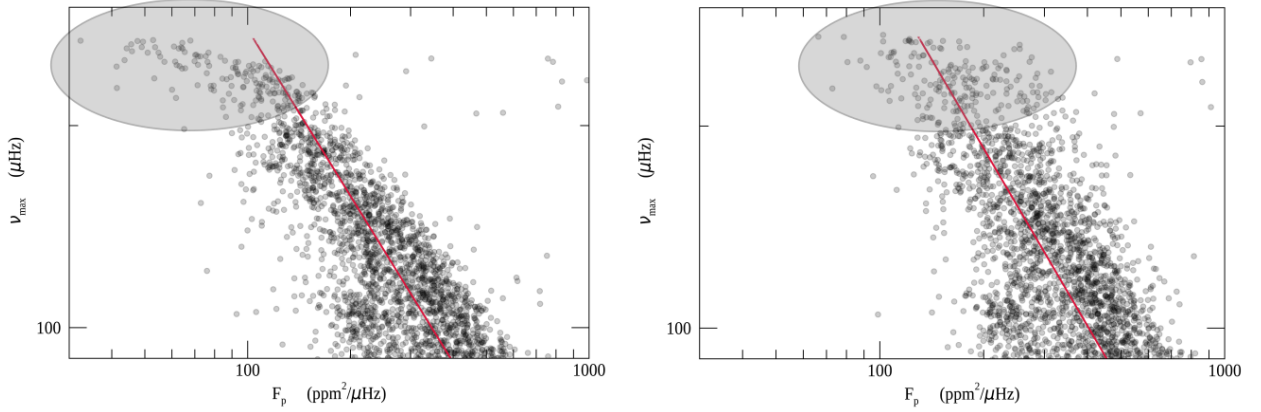
Fig. 1. $\nu_{\max}$ provided by the A2Z pipeline (Mathur et al. 2010) **vs** FliPer for stars with $\nu_{\max}$ from 90 to $300\mu Hz$ (It corresponds to a zoom on the rectangle on the left panel of Fig. 2). **Left:** Case where FliPer is computed using the mean of the high-frequency signal as the photon noise. **Right:** Case when the theoretical photon noise computed by Jenkins et al. (2010) is used. The grey-shaded circle is where the impact of the noise calculation on FliPer is important.

## 2   Origin and definition of FliPer

It is well known that the shape and the amount of power in the power spectrum density (PSD) of a star changes with stellar evolution as discussed above. The shape of the PSD is dominated by photometric variability caused by star spots and stellar rotation at low frequencies, a convective continuum, and a hump of power due to the stellar oscillations. All of these stellar contributions are added to the constant photon noise. As a star evolves and surface gravity decreases, so $\nu_{\max}$ decreases. Because granulation properties are linked to $\nu_{\max}$ or surface gravity, as a star evolves so the total power from granulation increases (e.g. García & Stello 2015). To account for the total power in the PSD we define the new metric FliPer (F_p) as follows:

$$F_p = \overline{\mathrm{PSD}} - P_n \qquad (2.1)$$

where $\overline{\mathrm{PSD}}$ represents the mean value of the power spectrum density and P_n the photon noise. $\overline{\mathrm{PSD}}$ is computed from 0.7 μHz (corresponding to the 20 days high-pass filter used to calibrate the light curves following García et al. (2011)) to the Nyquist frequency ($\sim$288 μHz for long cadence *Kepler* data). The photon noise is estimated following Jenkins et al. (2010) and depends on the magnitude of the star. It could also be evaluated by taking the mean power at high frequency (see Fig. 1, left panel) instead of computing the expected noise by Jenkins et al. (2010) (see Fig. 1, right panel). A comparative study showed that for most stars, the values of FliPer obtained with both methods are similar. The only important difference appears for stars in which the high-frequency part of the spectrum is dominated by stellar signal and not by noise. This is typically the case for stars with $\nu_{\max}$ close to Nyquist or for super-Nyquist stars. For these stars, the power contained in the modes and in the granulation profile is partially taken into account in the noise calculation because there are still power at high frequencies. The resulting photon noise value is thus higher than expected. In this case, FliPer is artificially lowered when using the high-frequency noise calculation as shown for stars in the grey circle on Fig. 1.

3   Prediction of seismic parameters

From Fig. 2 left, we get in a first approximation a logarithmic law ($\log(F_{p,ppm^2/\mu Hz}) = -1.14 \times \log(\nu_{max,\mu Hz}) + 4.88$) between FliPer and $\nu_{\max}$ followed by more than 90% of the 16,000 red giants analyzed here. By calculating FliPer, we used this metric to determine those stars for which the resultant seismic parameters do not follow the
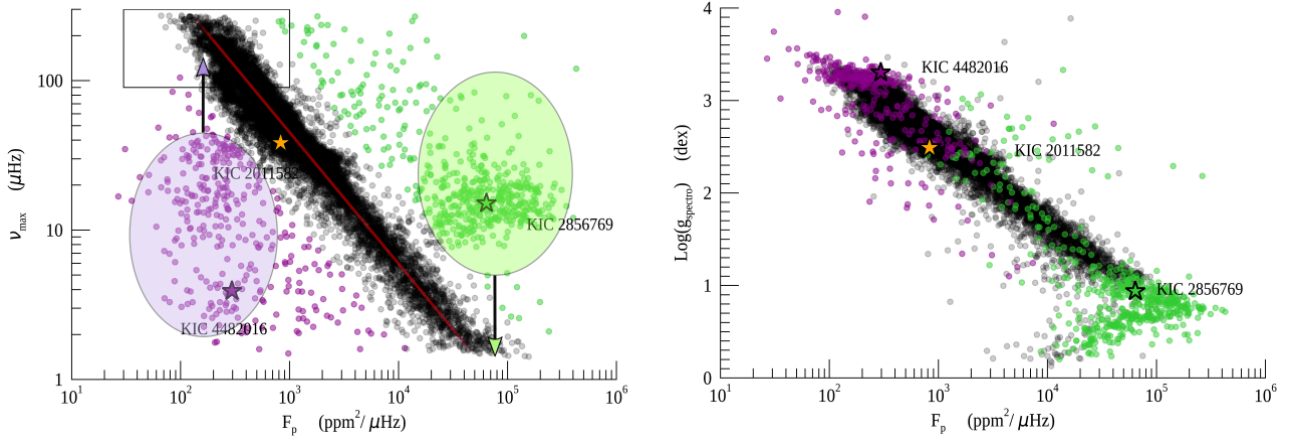
Fig. 2. Left: ν_{max} provided by the A2Z pipeline (Mathur et al. 2010) for $\sim 16,000$ red giants observed by *Kepler* (data corrected and interpolated following García et al. (2011, 2014c)) vs FliPer. The red line represents the best fitting to the data. Green stars have higher FliPer than the general trend and should be replaced at lower frequencies, while violet points have lower values of FliPerand should be replaced at higher frequencies (as indicated by ellipses and arrows). These limits are located at one standard deviation from the law. The black rectangle shows the location of the zoom of Fig. 1. **Right:** log(g) provided by photometric and spectroscopic measurements from the NASA *Kepler* catalog (Mathur et al. 2017) vs FliPer for the same stars than in the left panel.

general trend. This could be a consequence of the presence of unexpected features in the PSD (e.g. pollution by spikes, etc) or because the resultant value obtained by the pipeline is incorrect.

The right panel of Fig. 2 represents the spectroscopic surface gravity from the NASA *Kepler* catalog (Mathur et al. 2017) against FliPer for the same sample of stars using the same color code than in the left panel. We observe that the purple outliers in the left panel follow the general trend with log(g), while the green data points appear to be reflected at some point. This change of slope around 0.7 dex comes from the cut in the PSD as a consequence of the high-pass filter used to calibrate the data (García et al. 2011). All stars with log(g) lower than this boundary have a biased estimation of FliPer and form a clump of green outliers stars on the left panel. This left panel show the same data from FliPer but with seismic ν_{max} on the y-axis. The log(g) measurements come from spectroscopic analysis that are independent of the seismic analysis. We thus demonstrate that most outliers stars in the left panel are due to a problem in the automatic seismic determination and not in FliPer, because FliPer values are consistent with surface gravity data.
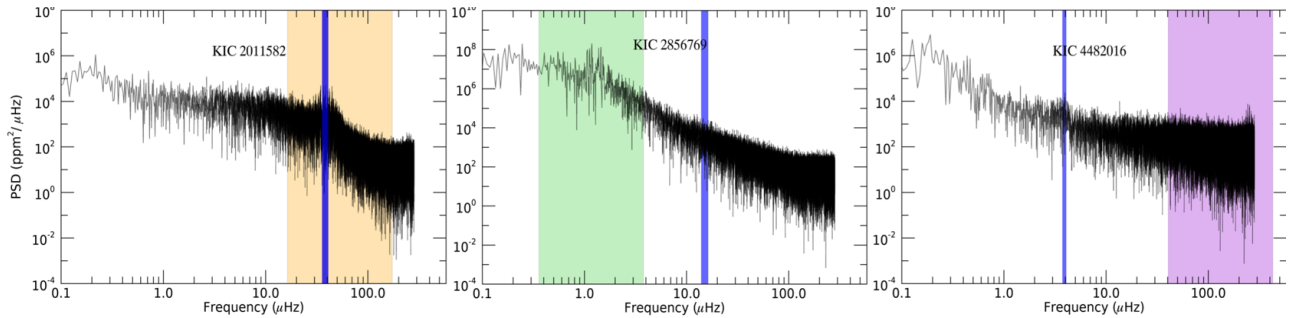
Fig. 3. PSD of the three stars represented with a star symbol on Fig. 2. The blue area corresponds to the ν_{max} returned by A2Z. The yellow, green, and purple shaded regions correspond to the range of accepted values of ν_{max} by FliPeras in Fig. 2. **Left:** KIC 2011582 for which the ν_{max} is well determined by A2Z. **Middle:** A high F_p star (KIC 2856769). This star has lower frequency modes than obtained by A2Z. **Right:** A low F_p star (KIC 4482016). This star has higher frequency modes than obtained by A2Z.

Figure 3 represents the PSD of three stars represented with a star symbol in Fig. 2. Left panel corresponds to KIC 2011582 well characterized both by A2Z and FliPer. Stars with a higher FliPer value than

expected (green stars on Fig. 2) have low surface gravities, meaning that they are highly evolved RGB stars. The $\nu_{\max}$ is too close to the frequency cut-off of 20 days used to calibrate the series. As a result, the A2Z pipeline cannot properly estimate $\nu_{\max}$ (a lower filter is needed to properly analyze these stars). An example, KIC 2856769, is presented in the middle panel in Fig. 3. Most outliers stars with a low value of FliPer (purple stars on Fig. 2) have a high $\log(g)$: they are probably main-sequence or sub-giants stars and should have a much higher $\nu_{\max}$ than the value returned automatically by A2Z. An example is KIC 4482016 represented on the right panel of Fig. 3. These stars needs to be treated independently by A2Z and FliPer helps to flag them up.

There are however about 1% of the stars that remain outliers on the right panel of Fig. 2. Among these outliers that could present however a good estimation of $\nu_{\max}$, we observe stars that present high rotation power (e.g. García et al. 2014b; Ceillier et al. 2017), spikes, pollution by another star, binaries systems, low signal-to-noise ratio stars (Mathur et al. 2016), low-amplitude dipole mode stars (e.g. Mosser et al. 2012; García et al. 2014a), etc. Not only does the FliPer metric allows to estimate surface gravity, but also to detect stars that present a particular signal in their power spectra. For example, the detection of spikes is important in the study of K2 observations which are affected by spikes at the Thrusters frequency and its harmonics.

4 Conclusions

We demonstrate that the FliPer follows a quasi-logarithmic trend with the global seismic parameters and, therefore, it is related to surface gravity. It allows us to quickly estimate the reliability of seismic parameters estimated from global pipelines. The FliPer method can be used to identify stars without detected modes, stars dominated by the harmonics of the K2 Thrusters seen as spikes in the spectrum, highly evolved stars, and super-Nyquist stars (i.e., stars for which the p-mode excess power is above the observational Nyquist frequency).

References

Bastien, F. A., Stassun, K. G., Basri, G. et al. 2016, ApJ, 818, 43

Bastien, F. A., Stassun, K G., Basri, G. et al. 2013, Nature, 500, 427

Brown, T. M. & Gilliland, R. L. 1990, ApJ, 350, 939

Ceillier, T., Tayar, J. and Mathur, S. et al. 2017, A&A, 605, 111

Chaplin, W. J., Bedding, T. R., Bonanno, A. et al. 2011, ApJ, 732, 5

Chaplin, W. J., Elsworth, Y., Davies, G. R et al. 2014, MNRAS, 445, 946

Davies, G. R., Chaplin, W. J., Farr, W. M. et al. 2015, MNRAS, 446, 2959

García, R. A., Mathur, S., Salabert, D. et al. 2010, Science, 329, 1032

García, R. A., Hekker, S., Stello, D. et al. 2011, MNRAS, 414, L6

García, R. A., Pérez Hernández, F., Benomar, O. et al. 2014a, A&A, 563, 84

García, R. A., Ceillier, T., Salabert, D. et al. 2014b, A&A, 572, 34

García, R. A., Mathur, S., Pires, S. et al. 2014c, A&A, 568, 10

García R. A. & Stello, D. 2015, Asteroseismology of red giant stars in Extraterrestrial Seismology, ed. V. Tong & R. García (Cambridge University Press) (pp. 159-169)

Hekker, S., Elsworth, Y., Mosser, B. et al. 2012, A&A, 544, 90

Jenkins, J. M., Caldwell, D. A., Chandrasekaran, H. et al. 2010, ApJl, 713, L120

Kallinger, T., De Ridder, J., Hekker, S. et al. 2014, A&A, 570, A41

Kallinger, T., Hekker, S., Garcia, R. A. et al. 2016, Science Advances, 2, 1500654

Kjeldsen, H. and Bedding, T. R. 1994, A&A, 293, 87-106

Mathur, S., García, R. A., Regulo, C. et al. 2010, A&A, 511, A46

Mathur, S., Hekker, S., Trampedach, R. et al. 2011, ApJ, 741, 119

Mathur, S., García, R. A., Huber, D. et al. 2016, ApJ, 827, 50

Mathur, S., Huber, D., Batalha, N. M. et al. 2017, ApJS, 229, 30

Mosser, B., Michel, E., Appourchaux, T. et al. 2009, A&A, 506, 33

Mosser, B., Elsworth, Y., Hekker, S. et al. 2012, A&A, 537, 30