Quasi-periodic pulsations in stellar flares

Chloe E. Pugh*, Anne-Marie Broomhall, and Valery Nakariakov

Centre for Fusion, Space and Astrophysics, Physics Department, University of Warwick, *e-mail: C.E.Pugh@warwick.ac.uk

Introduction

Flares that are orders of magnitude larger than the most energetic solar flares are routinely observed on Sun-like stars [1], raising the question as to whether the same physical processes are responsible for both solar and stellar flares. Quasi-periodic pulsations (QPPs) are time variations in the intensity of light emitted by a flare. QPPs are a common feature of solar flares (e.g. [2]) that are observed at many different wavelengths. Although QPPs appear not to be as abundant in white light Kepler flare light curves as they are in solar flares, albeit in different wavelengths, the structure of the pulsations are strikingly similar [3], hinting that the same underlying processes govern both solar and stellar flares. Here we consider a special case, observed on KIC9655129, which shows evidence of multiple periodicities. Multi-periodic QPPs are a rarity even in solar flares, while the physical mechanisms responsible for even single period QPPs remain uncertain (e.g. [4]). We speculate that the presence of multiple periodicities is a good indication that the QPPs were caused by magnetohydrodynamic oscillations, further strengthening the case that the physical processes in operation during stellar flares are at least analogous to those in solar flares.

KIC9655129

KIC9655129 is a K-type eclipsing binary star with a Kepler magnitude of 13.8. It's light curve shows evidence of flares (see Fig. 1).

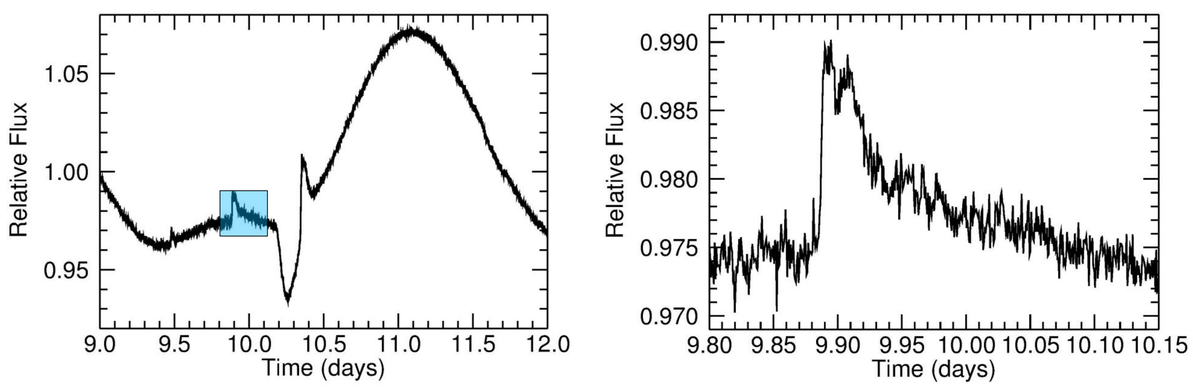

Fig. 1: Left: A section of the short cadence light curve of KIC9655129 from Quarter 14b, which contains three flares. Right: A shorter section of the light curve, showing the central flare in the plot on the left.

Wavelet analysis

To analyse the periodic component of the decay phase of the flare light curve an exponential decay function was removed and a wavelet analysis was performed (see Fig. 2).

- A feature at a period of **84^{+25}_{-19} min** is above the 99% confidence level (as defined by [5]).
- The feature appears to split into two bands, suggesting the presence of **two different periodicities**.
- A wavelet analysis of a detrended light curve shows that the second periodicity of **32±7min** is also significant at a 99% confidence level.

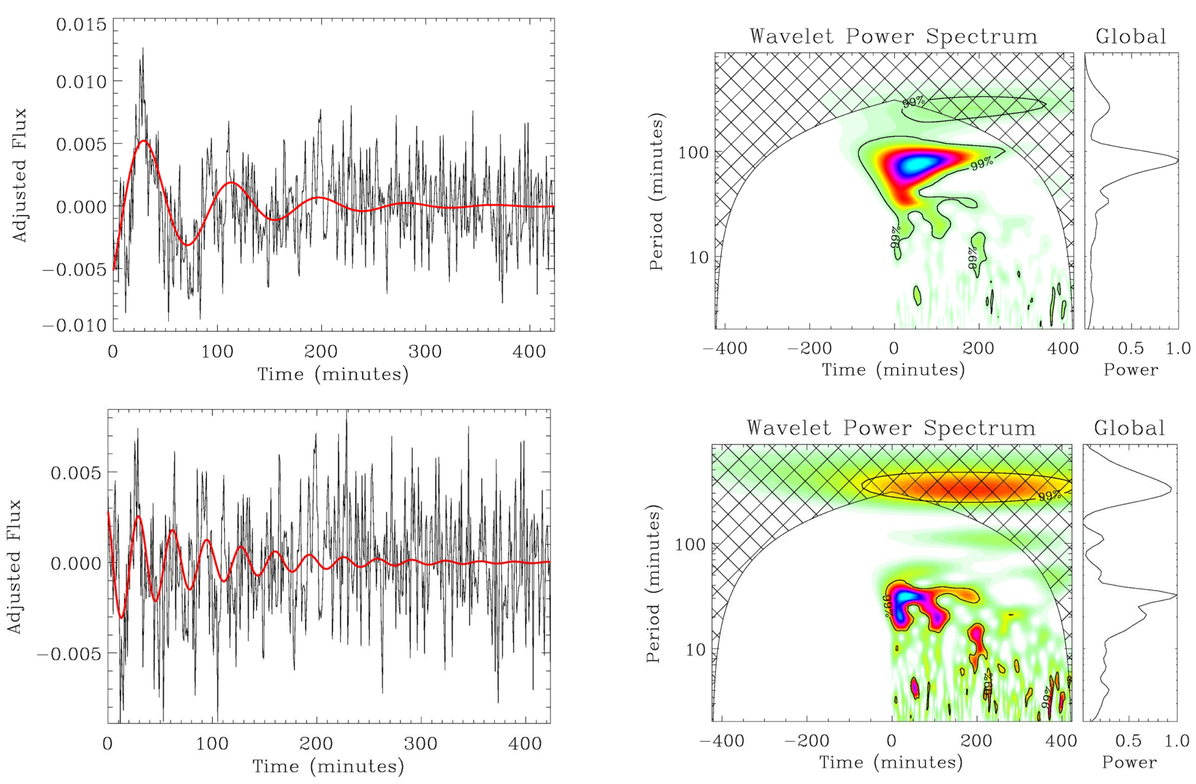

Fig 2: Top left: Flare light curve once exponential decay term has been removed. A decaying sinusoid has been fitted to the signal (red). Top right: Wavelet spectrum of flare light curve shown in top left hand panel. Bottom left: Flare light curve once exponential decay term and main periodicity have been removed. A decaying sinusoid has been fitted to the signal (red). Bottom right: Wavelet spectrum of flare light curve shown in bottom left panel.

Global fit to light curve

Fig. 3 shows the result of fitting the decaying part of the light curve, with a function containing the exponential decay and 2 decaying sinusoids simultaneously, after performing 10,000 Monte Carlo simulations.

- The two periodicities were found to be **78±12** and **32±2min** (see Fig. 4).
- **No strong correlations** were found between
  - the periods (8% Pearson's correlation),
  - the periods and their corresponding decay times (Pearson's correlation of 19% for the longer periodicity and 29% for the shorter periodicity).
- The longer periodicity was found to be slightly correlated with the decay time of the flare itself, with a Pearson's correlation of 50%. However, over 99% of the fitted values were within the range indicated by the wavelet analysis.
- The decay time of the shorter periodicity is 77±29 min, compared to 80±12 min for the longer periodicity implying **the shorter periodicity is not higher harmonic of a non-linear signal.**
- The observed phases of the signals suggest that the **QPPs are linear** and that the **shorter periodicity is a spatial harmonic of the longer periodicity**, or the result of a different mode.
- There is no evidence of periodicities less than several hours in the rest of the light curve, implying the signals are flare related.

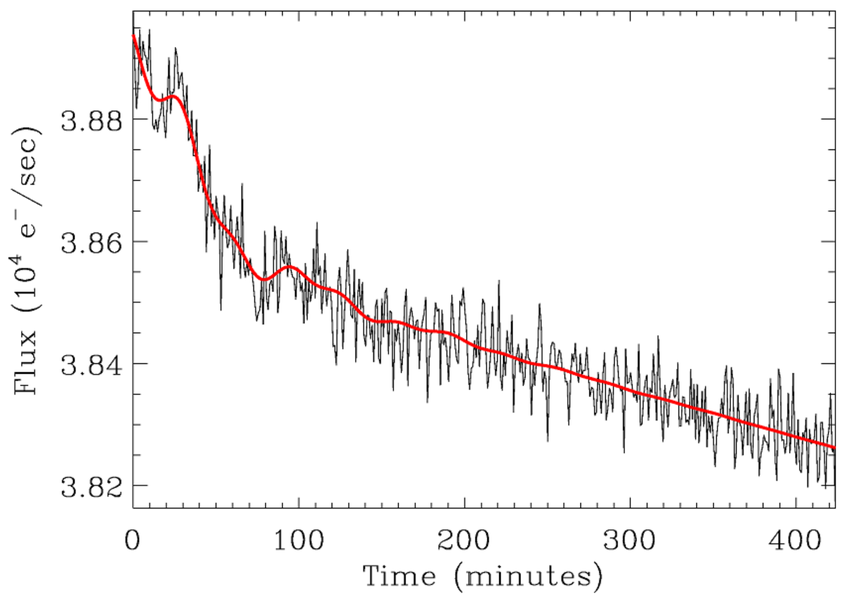

Fig. 3: The flare decay light curve with the result of a least-squares fit to the flare decay, along with the two periodicities (red).

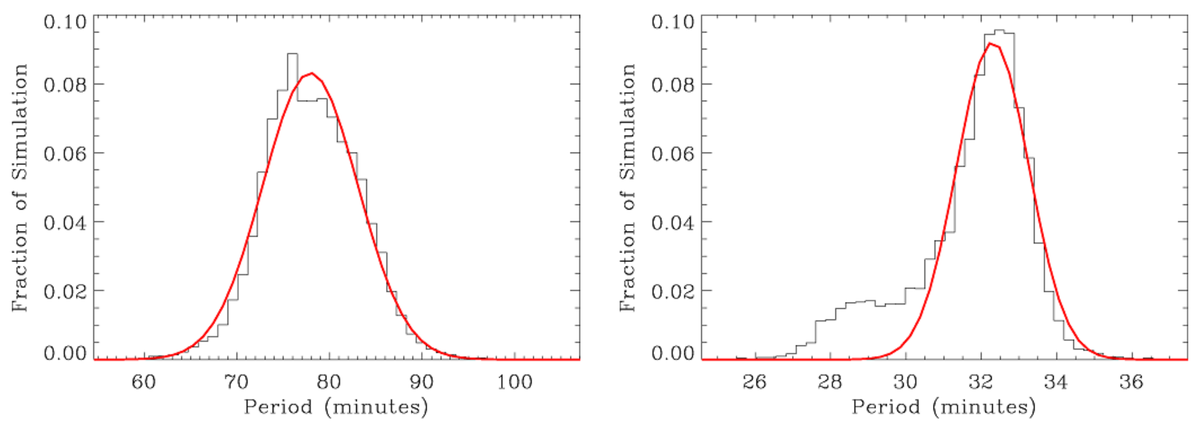

Fig. 4: Histograms showing the results of Monte Carlo simulations for the main (left) and secondary (right) periods. The red overplotted curves show Gaussian fits, which have been used to estimate the periods.

Discussion

Two significant quasi-periodic pulsations (QPPs) in the light curve of a flare on KIC9655129 with periods of **78±12min** and **32±2min**.

- These are consistent with the presence of **two spatial harmonics** due to the dispersive nature of guided magnetohydrodynamic (MHD) waves.
- Multiple periods are much more likely to be associated with **MHD wave mechanisms of QPPs**, rather than load/unload mechanisms.
  - It is also possible that one periodicity is due to a load/unload mechanism, and the other due to an MHD oscillation.
- Crucially this result suggests that the **underlying physics in solar and stellar flares could be similar.**

References

[1] Maehara, H., et al. 2012, Nature, 485, 478

[2] Kupriyanova, E. G., Melnikov, V. F., Nakariakov, V. M., & Shibasaki, K. 2010, Sol. Phys., 267, 329

[3] Nakariakov, V. M., & Melnikov, V. F. 2009, Space Sci. Rev., 149, 119

[4] Balona, L. A., et al. 2015, MNRAS, 450, 956

[4] Torrence, C., & Compo, G. P. 1998, Bulletin of the American Meteorological Society, 79, 61