Linking characteristic timescales and spatial scales for quasi-periodic pulsations in solar flares

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Quasi-periodic pulsations (QPPs)

- Time-variations of the intensity of light emitted by a flare
- First observed in solar flares by Parks & Winckler (1969)
- Example of QPPs in a solar flare: The Seven Sisters Flare, observed by Kane et al. (1983)
- Seem to be a fairly common feature of flares
Quasi-periodic pulsations

Two groups of possible mechanisms:

- Magnetohydrodynamic (MHD) oscillations ...
  ..of the flaring structure
  ..of a nearby structure

- Load/unload or ‘magnetic dripping’ mechanisms of energy release (periodically induced reconnection)
Solar flare QPP statistical study

- 181 GOES class flares from a single (very) active region
- 137 C-class, 38 M-class, 6 X-class
- Observations from GOES, EVE, Fermi, Vernov, NoRH
- Do QPP properties relate to properties of the flares or flaring region?

NOAA 12172, 12173, 12171

NOAA 12192

NOAA 12209
Detecting the QPPs

- Flare time series have power-law power spectra, due to trends and correlated noise.

- Need to account for this dependence when searching for peaks.

Detecting the QPPs

- Example solar flare observed by Nobeyama Radioheliograph
- Power spectrum confidence levels calculated according to Pugh et al. 2017a/b
- *Left:* Correlation time series of part of a flare
- *Right:* Periodogram with a peak above 99% confidence level, at a period of ~10 seconds
The set of flares with significant QPPs

- Out of 181 flares: 37 with periodic signal above 95% global confidence level (20% of sample)

- Right: histogram of QPP periods, with mean period of $20^{+16}_{-9}$ seconds

- Pugh et al. 2017b
The set of flares with significant QPPs

- Seven of these flares have the same QPP signal detected above the 95% confidence level in data from two different instruments.

- Right: 27 s period detected in both GOES/XRS and EVE/ESP light curves.
Relation to flare properties?

- QPP periods plotted against flare amplitude, flare duration (impulsive phase), and the duration of the QPP signal

- Period vs flare/QPP duration: can’t detect long-period short-duration QPP signals, but should be able to detect short-period long-duration signals
Relation to flare properties?

- Extension of Inglis et al. 2016 by Laura Hayes - includes all X, M, C class flares 2011-2016
- They also find no correlation with GOES class
- and a significant correlation with flare duration
Determining flare ribbon properties

- Only including flares where the AR was within +/- 60° of disk centre, so line of sight effects can be accounted for

- Follow approach of Toriumi et al. 2017 — combine AIA 1600Å and HMI data to determine spatial scales and magnetic field strength of flare ribbons
Relation to flare ribbon properties?

- QPP period correlates with flare ribbon area (left), separation distance (middle), and average magnetic field strength (right)
- Strongest correlation with ribbon separation distance

\[ \text{log Ribbon area (Mm}^2) \]
\[ \text{1.0} \quad 1.2 \quad 1.4 \quad 1.6 \quad 1.8 \quad 2.0 \]
\[ \text{log Period (s)} \]

\[ \text{GOES 0.1-0.8 nm} \]
\[ \text{GOES 0.05-0.4 nm} \]
\[ \text{GBM 25-50 keV} \]
\[ \text{NoRH 17 GHz} \]
\[ \text{DRGE 30+ keV} \]

\[ cc = 0.59 \]

\[ \text{log Ribbon separation (Mm)} \]
\[ \text{1.0} \quad 1.2 \quad 1.4 \quad 1.6 \quad 1.8 \quad 2.0 \]
\[ \text{log Period (s)} \]

\[ \text{GOES 0.1-0.8 nm} \]
\[ \text{GOES 0.05-0.4 nm} \]
\[ \text{GBM 25-50 keV} \]
\[ \text{NoRH 17 GHz} \]
\[ \text{DRGE 30+ keV} \]

\[ cc = 0.64 \]

\[ \text{log Average magnetic field (G)} \]
\[ \text{1.0} \quad 1.2 \quad 1.4 \quad 1.6 \quad 1.8 \quad 2.0 \]
\[ \text{log Period (s)} \]

\[ \text{GOES 0.1-0.8 nm} \]
\[ \text{GOES 0.05-0.4 nm} \]
\[ \text{GBM 25-50 keV} \]
\[ \text{NoRH 17 GHz} \]
\[ \text{DRGE 30+ keV} \]

\[ cc = 0.50 \]
Relation to flare ribbon properties?

- Toriumi et al. 2017 showed that these ribbon properties correlate with the flare duration.

![Graphs showing correlations between flare ribbon properties and flare duration.](image)
Relating to flare properties?

- Hayes et al. 2018 (in prep) shows a long-lasting QPP signal with an increasing period (~65-164 s).
- Could be linked to the expansion of the flare loop structure.

![Graph showing flare properties](image)
Summary

- Using a sample of solar flares from a single active region
- 20% of flares have a periodic signal above the 95% global confidence level in the power spectra
- Correlations between QPP period and flare ribbon properties
- Preliminary results of Hayes et al. 2018 (in prep) also suggest a link between the QPP period and the size of the flaring loop structure
- This could be used as a constraint for QPP models
- Further work: assessment of potential of observational bias to affect QPP period vs flare duration relationship, using simulated data