Chapter
Quasi-periodic pulsations in solar and stellar flares
Observer's view

Ivan Zimovets

IKI RAS, Moscow, Russia

ISSI-Bj, Beijing, China

50th anniversary of Parks & Winckler (1969) discovery of QPPs in solar flares

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SIXTEEN-SECOND PERIODIC PULSATIONS OBSERVED IN THE CORRELATED MICROWAVE AND ENERGETIC X-RAY EMISSION FROM A SOLAR FLARE

G. K. PARKS AND J. R. WINCKLER
School of Physics and Astronomy, University of Minnesota, Minneapolis
Received December 30, 1968

ABSTRACT

The solar X-ray event of August 8, 1968, detected on a high-altitude balloon shows a 16-sec periodic modulation in the X-ray intensity–time profile. These periodic variations correlate well with the fine features in microwave radio-emission data. The X-ray energy spectrum as determined from a two-channel energy discriminator hardens during peaks of modulations.

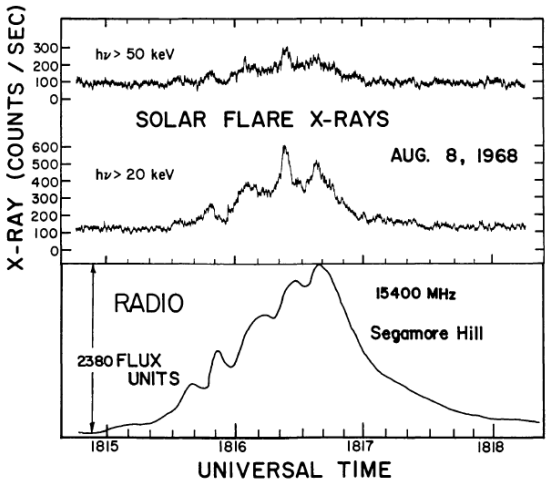


FIG. 1.—Time profiles of analogue X-ray count rate and original microwave-emission data are shown for the August 8, 1968, flare.

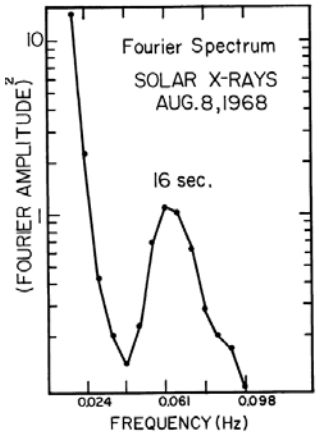


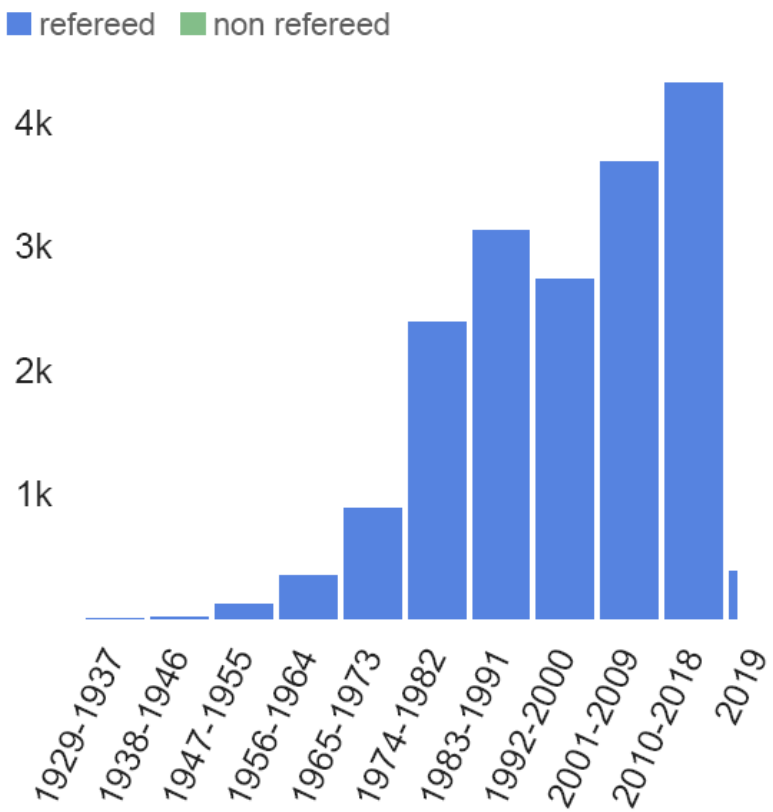
FIG. 2.—Result of Fourier analysis of X-ray data. Peak is centered about a 16-sec period

Some statistics on refereed papers about solar flares and pulsations in solar flares

Adsabs / abstract words:

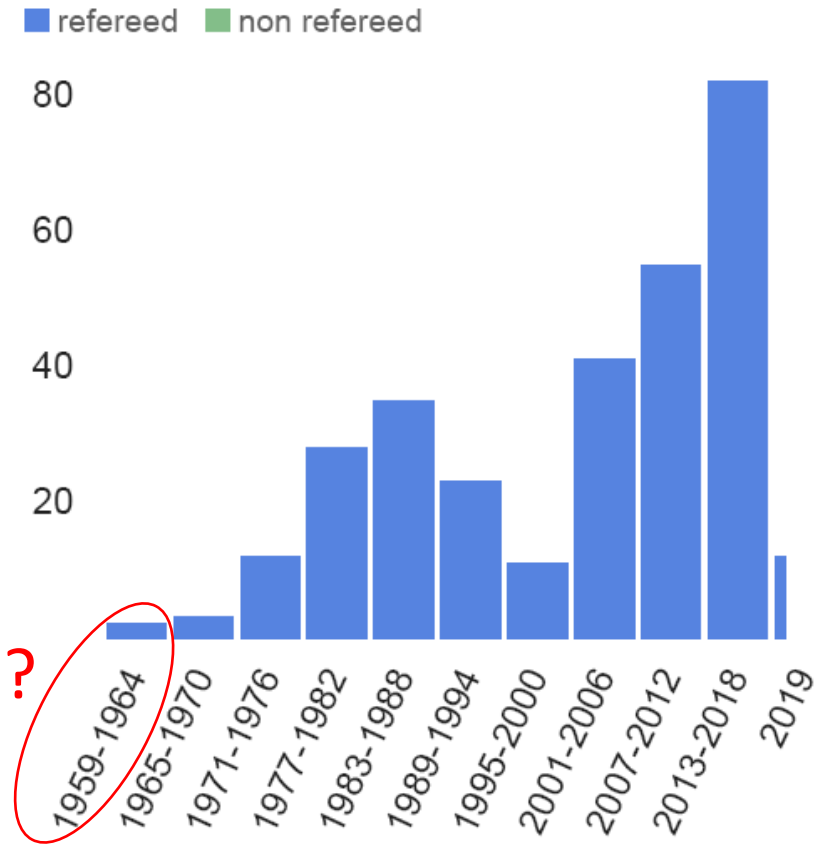
+solar+flare

18035 (100%)



+solar+flare+pulsation

304 (1.7%)



From: http://adsabs.harvard.edu/abstract_service.html

“+solar+flare+pulsation” before Parks & Winckler (1969)

301 1969ApJ...155L.117P 1969/02 cited: 134

Sixteen-Second Periodic Pulsations Observed in the Correlated Microwave and Energetic X-Ray Emission from a Solar Flare

Parks, G. K.; Winckler, J. R.

302 1968BAICz..19...97P 1968 cited: 1

Solar-flare X-ray emission producing geomagnetic pulsations

Pintér, Š .

303 1962ApJ...136..546T 1962/09 cited: 47

Spectral Observations of Solar Radio Bursts. III. Continuum Bursts.

Thompson, A. R.; Maxwell, A.

304 1959JGG....10..203K 1959 cited: 1

Geomagnetic Pulsation Accompanying with the intense Solar Flare

Kato, Yoshio; Tamao, Tsutomu; Saito, Takao

Recent (≤10 years) Reviews on/incl. QPPs

- Melnikov & Nakariakov (SSR, 149:119, 2009). Citations: 200 (CPY: 20.0)
  Quasi-Periodic Pulsations in Solar Flares

- Nakariakov, Inglis, Zimovets, et al (PPCF, 52, 124009 2010). Citations: 42 (CPY: 4.7)
  Oscillatory processes in solar flares

- Van Doorsselaere, Kupriyanova, Yuan (SSR, 291:3143, 2016). Citations: 51 (CPY: 17)
  Quasi-periodic Pulsations in Solar and Stellar Flares: An Overview of Recent Results (Invited Review)

- Nakariakov, Pilipenko, Heilig, et al (SSR, 200:75, 2016). Citations: 74 (CPY: 24.7)
  Magnetohydrodynamic Oscillations in the Solar Corona and Earth's Magnetosphere: Towards Consolidated Understanding

- McLaughlin, Nakariakov, Dominique, et al (SSR, 214:45, 2018). Citations: 34 (CPY: 34)
  Modelling Quasi-Periodic Pulsations in Solar and Stellar Flares

- Kupriyanova, Kolotkov, Nakariakov, et al (STP, 2019, submitted; in Rus). Citations: 0 (CPY: 0)
  Quasi-periodic pulsations in solar and stellar flares

What are QPPs?

McLaughlin et al (SSR, 2018):

- "Often the EM radiation generated in solar and stellar flares shows a pronounced oscillatory pattern, with characteristic periods ranging from a fraction of a second to several minutes. These oscillations are referred to as quasi-periodic pulsations (QPPs), to emphasise that they often contain apparent amplitude and period modulation."
- "… Thus, we usually intuitively consider a *quasi-periodic pulsation* (QPP) to be a quasi-repetitive pattern in the signal, which has at least three or four iterations—the QPP cycles."
- "Quasi-repetitive patterns have been detected in a variety of signals generated by flares. These are referred to as *quasi-periodic pulsations* (QPPs), and have been observed in radio, optical and X-ray emission of solar flares … and stellar flares"

Van Doorsselaere et al (SSR, 2016):

- "Quasi-periodic pulsations (or QPPs) are periodic intensity variations in the flare emission that occur across all wavelength bands."
- "In particular, the flare light curve shows periodic intensity increases and decreases. These are called *quasi-periodic pulsations* (*or QPPs*)."

No mathematically rigorous definition of QPPs exists

Why to study QPPs?

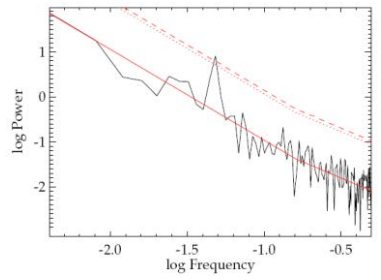
- It is attractive – various repetitive physical phenomena have always attracted people

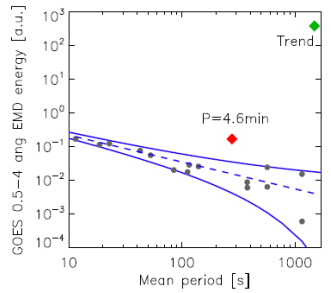
- Can help to understand solar/stellar flare mechanisms – since QPPs accompany many (all?) flares, adequate flare models must take QPPs into account

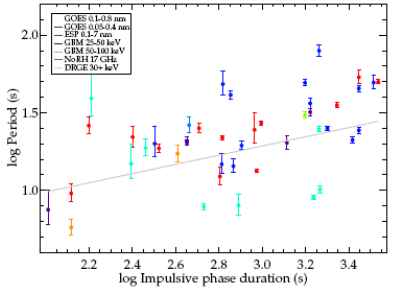
- Can help to diagnose physical parameters of solar/stellar flare regions – QPPs can contain information about many important parameters of flare regions (plasma density/temperature, magnetic field, electric currents, characteristic size of magnetic structures, …)

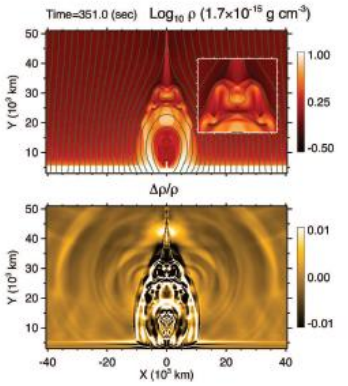
Recent results in QPPs

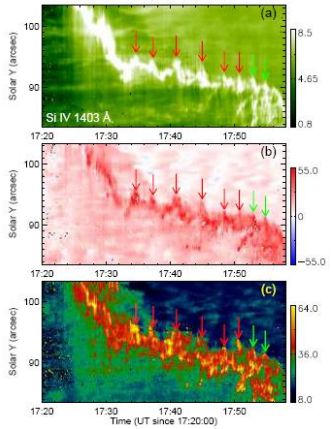
- **Progress in QPP searching methods:** *EMD* (Kolotkov et al., 2016), *red-noise accounting* (Gruber et al., 2011; Inglis et al., 2015; 2016; Pugh et al., 2017)
- **Large-scale searches for solar QPPs** (Simoes et al., 2015; Inglis et al., 2016; Pugh et al., 2017)
- **Recognition of QPP commonality in solar flares** (Kupriyanova et al., 2010; Simoes et al., 2015; Pugh et al., 2017)
- **Some scaling laws for solar flare QPPs** (Kuznetsov et., 2016; Pugh et al., 2019; Szaforz & Tomczak, 2019)
- **Classification of QPP mechanisms** (McLaughlin et al., 2018)
- **Several new QPP models** (Takasao et al., 2016; Ledentsov & Somov, 2016; Parker & Longcope, 2019)
- **Forward modelling of QPPs in solar flares** (Ruan et al., 2019; Zhao et al., 2019)
- **New spatially and spectrally resolved observations** (Brosius & Daw, 2015; Kuznetsov et al., 2016; Li et al., Zhang et al., 2016; Tian et al., Zimovets et al., 2018)
- **Intriguing QPP observations difficult for explanation by available models** (Tan et al., 2016; Li et al., 2017; Hayes et al., 2019)
- **New similarities of solar & stellar flares** (Pugh et al., 2016; Cho et al., 2016; Broomhall et al., 2019)

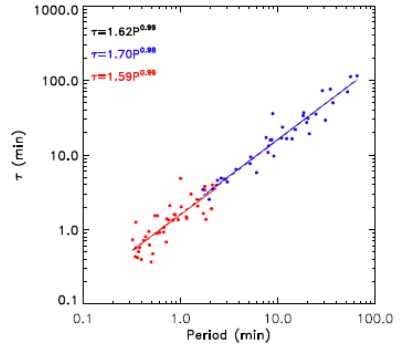












(V): Van Doorsselaere, Kupriyanova, Yuan (SSR, 291:3143, 2016)

"The current article aims to give an overview of recent theoretical and modelling results. Even though many new results have been obtained, there is still no consensus reached on what physical mechanism is responsible for the generation of QPPs."

(M): McLaughlin, Nakariakov, Dominique, et al (SSR, 214:45, 2018)

- "**We review the current understanding of quasi-periodic pulsations in solar and stellar flares.** In particular, we focus on the possible physical mechanisms, with an emphasis on the underlying physics that generates the resultant range of periodicities. These physical mechanisms include MHD oscillations, self-oscillatory mechanisms, oscillatory reconnection/reconnection reversal, wave-driven reconnection, two loop coalescence, MHD flow over-stability, the equivalent LCR-contour mechanism, and thermal-dynamical cycles. We also provide a histogram of all QPP events published in the literature at this time."

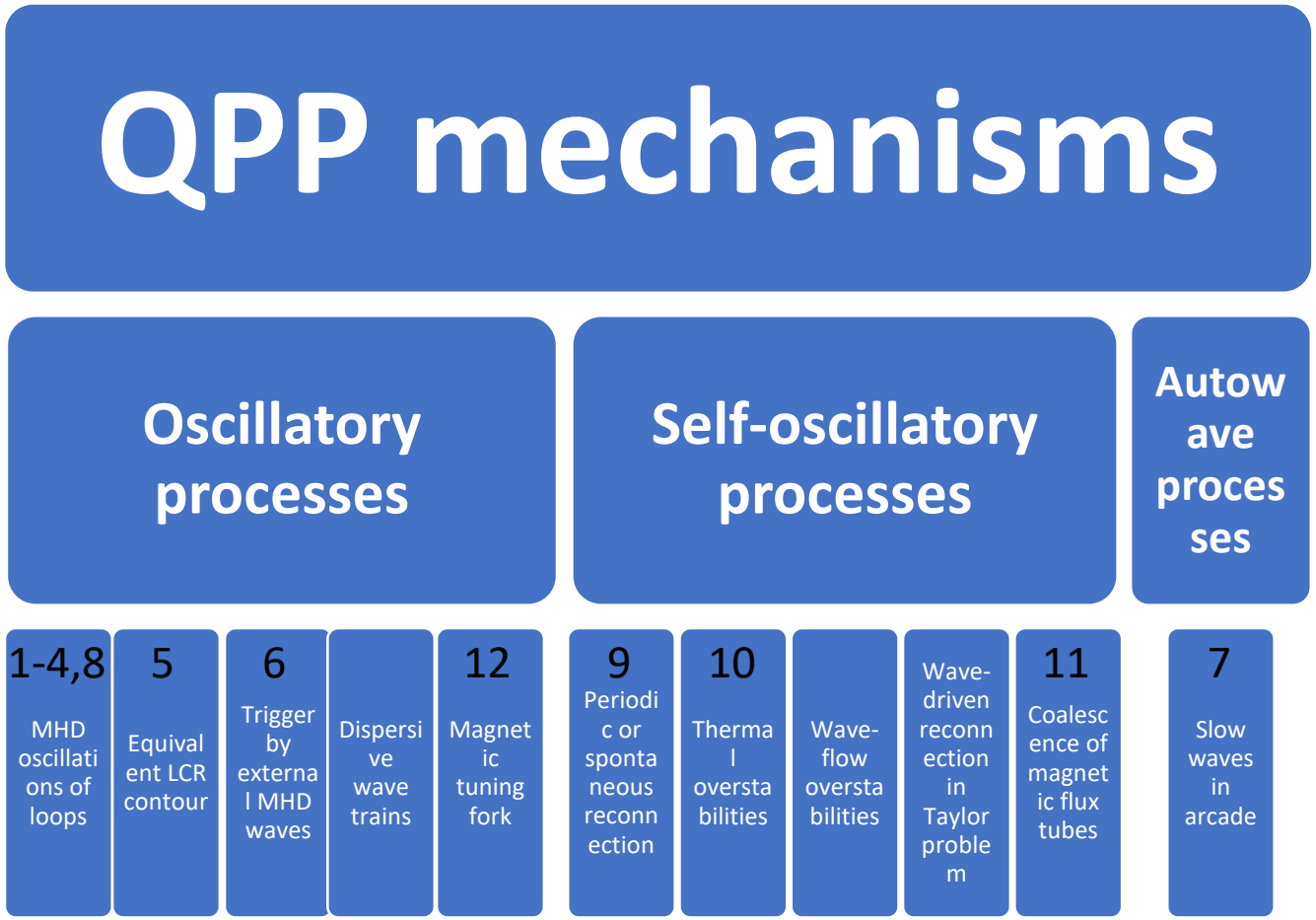
- "**This review paper considers one of these three key components: the modelling of waves and pulsations in solar and stellar flares.** Specifically, we focus on quasi-periodic pulsations (QPPs)—see Sect. 1.3—but also briefly review other important wave processes in the Appendices A and B."

(K): Kupriyanova, Kolotkov, Nakariakov, et al (STP, 2019, submitted; in Rus)

- "**This paper provides an overview of the state-of-art studies of oscillatory processes in solar and stellar flares, based on modern observational data of ground-based and spaceborne instruments with high temporal, spatial and spectral resolution in different ranges of the electromagnetic spectrum. The mechanisms generating the flare radiation and its quasi-periodic modulation are considered.** The similarities and differences of solar and stellar flares are discussed together with the associated problems of superflares on the Sun and the problems of space weather. It is shown that quasiperiodic pulsations (QPPs) of the flare radiation are an effective tool for diagnosing both the flare processes themselves and the parameters of the flare plasma and accelerated particles. We consider the types of QPPs, their statistical properties and methods of analysis, taking into account the non-stationarity of the QPPs' parameters. Separate sections are devoted to the review of the proposed mechanisms of the QPPs and to open questions."

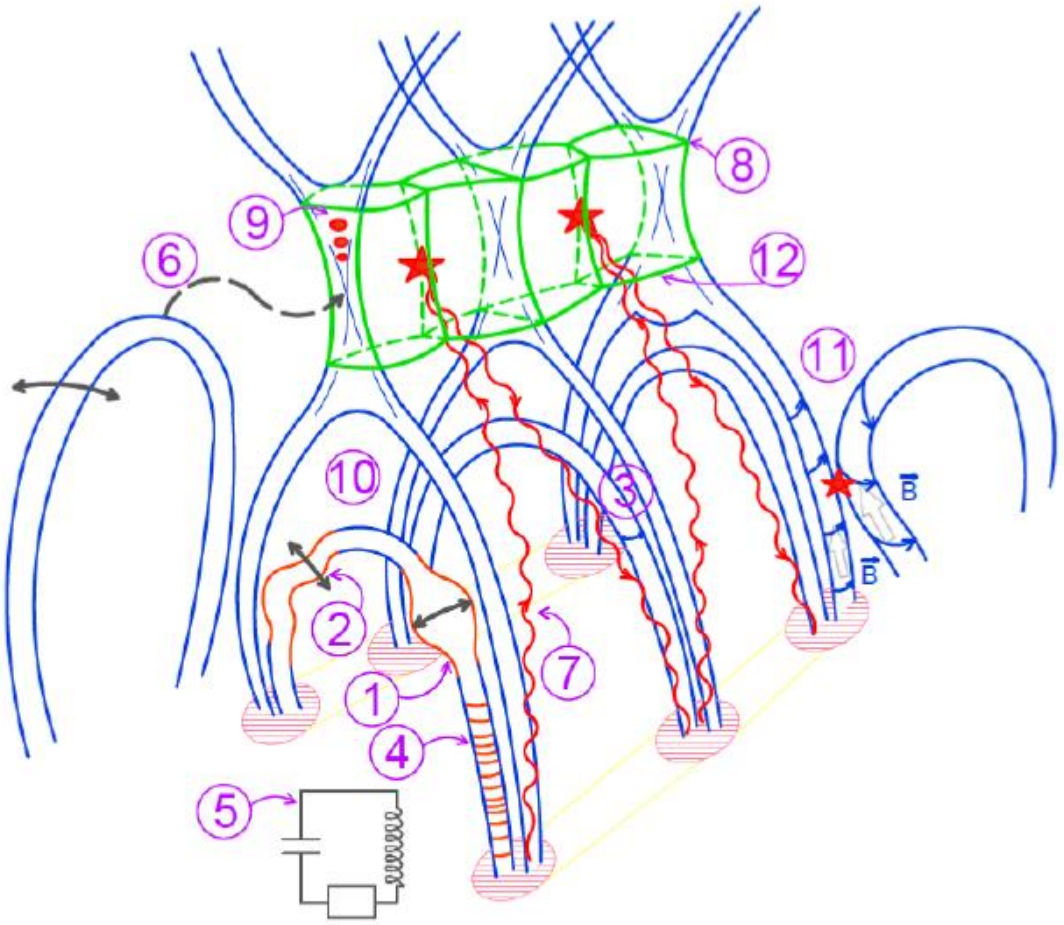
QPP mechanisms classification

according to McLaughlin et al. (2018)



QPP mechanisms cartoon

according to Kupriyanova et al. (2019, submitted)



Do we really need another review on QPPs now?

- The majority of QPP theories/models are covered in K,M,V-reviews
- However, observational signs of the models were not structurized

- 225 refereed papers [ADS: *(pulsation or oscillation) and (solar or stellar) and flare*] in 2016-2019
- 112 are related to QPPs in solar/stellar flares
- Less than 50% are referred in K,M,V-2016-2018-QPP-reviews
- ~70% of papers – observations, ~30% – theory/modeling

If yes, it seems more reasonably to focus on *observational* rather than *theoretical* *aspects of QPPs*

What could be included in the new QPP review

I. Summary of recent (2016-2019) progress in QPPs (mentioned above + not mentioned)

II. Lists of observable features of the main QPP models

III. Near future perspective directions of QPP study

QPP properties

Time features

- Quasi-period
- Multi-periodicity
- Number of cycles/peaks
- Damping/non-damping
- Modulation depth
- Non-stationarity
- Phase-shift in different ranges
- Flare phase
- ….

Spectral features

- Wavelength ranges
- Thermal/non-thermal
- Spectrally resolved lines
- Doppler shift
- Line broadening
- …

Spatial features

- Position of emission sources
- Dynamics of source position
- Flare type (eruptive, confined, two-ribbon, circular-ribbon, etc.)
- Magnetic structure
- …

QPP model feature table: we need to create it

Property	Model-1	Model-2	…	Model-N
Time property				
Range of P				
Multiperiodicity				
…				
Spectral property				
Wavelength range				
Thermal/nonthermal				
…				
Spatial property				
Loop top				
Footpoint motion				
…				

Near future perspective directions of QPP study

- Further progress in QPP searching methods (QPP non-stationarity)
- More large-scale searches for QPPs (different wavelengths, different flare phases)
- More scaling laws for QPPs (less-scale parameters than AR-scale)
- 3D forward modelling for different mechanisms (different wavelengths, MHD+kinetisc)
- Detailed spatially & spectrally resolved observations of QPP sources in different wavelengths
- New similarities/differences of solar & stellar flare QPPs
- Possibilities of new instruments

What can be done during this week

- Vote for the need of another QPP review - put Y, N, Y/N in front of your name in my WH, and mark by ◯ if you want to be a co-author

- Let me know your ideas/comments (both positive & negative) and suggestion about potential contribution

- Give/send me some useful materials (papers, links, short extractions, figures, etc.)

Thank you for attention!