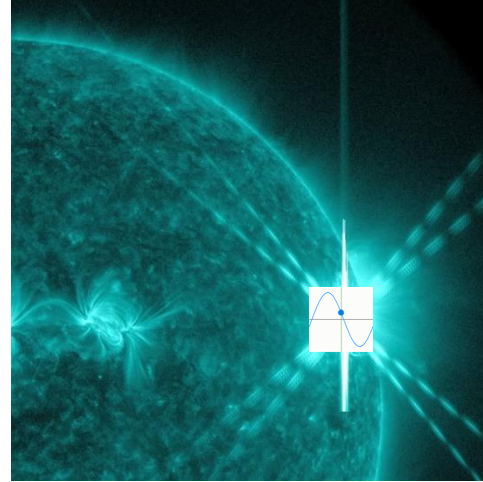


# Team Meeting Introduction



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Welcome to Beijing! Welcome to China!



# Discovery of QPPs in solar flares

THE ASTROPHYSICAL JOURNAL, Vol. 155, February 1969

50th anniversary is coming soon!

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

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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.

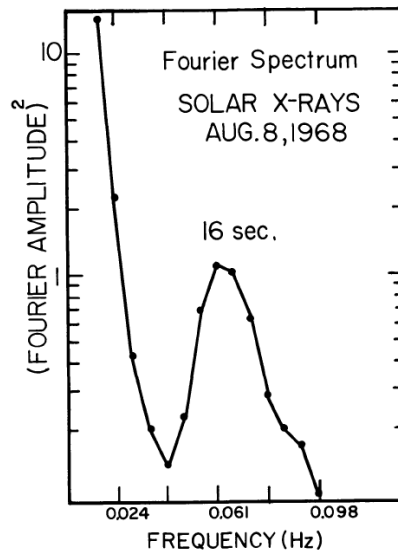


FIG. 2.—Result of Fourier analysis of X-ray data. Peak is centered about a 16-sec period

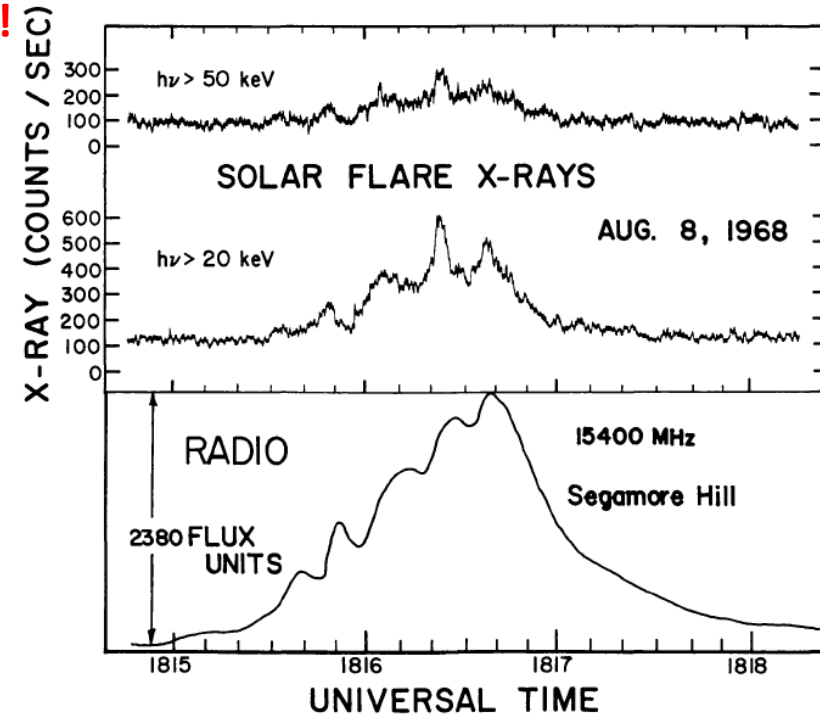


FIG. 1.—Time profiles of analogue X-ray count rate and original microwave-emission data are shown for the August 8, 1968, flare.

But did we solve the QPP problem? - Not yet!?



# Renaissance of QPP study



Accidental coincidence(?): there are two international teams working on the QPP problem now:

- ISSI Team “Quasi-periodic Pulsations in Stellar Flares: a Tool for Studying the Solar –Stellar Connection” led by Anna-Marie Broomhall

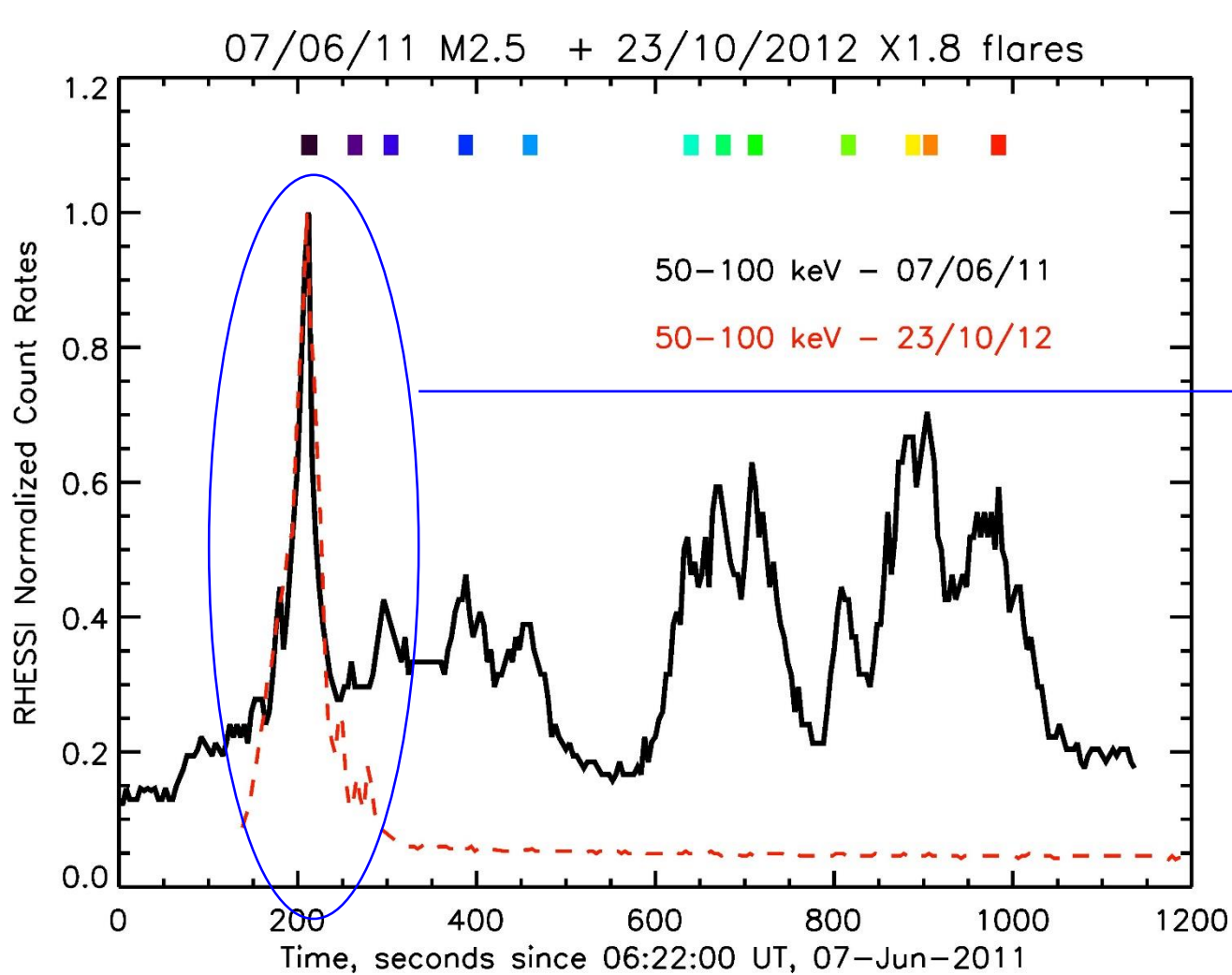


- ISSI-BJ Team “Pulsations in solar flares: matching observations and models” led by Ivan Zimovets & Zongjun Ning



# Pulsations (in all flares or not?)

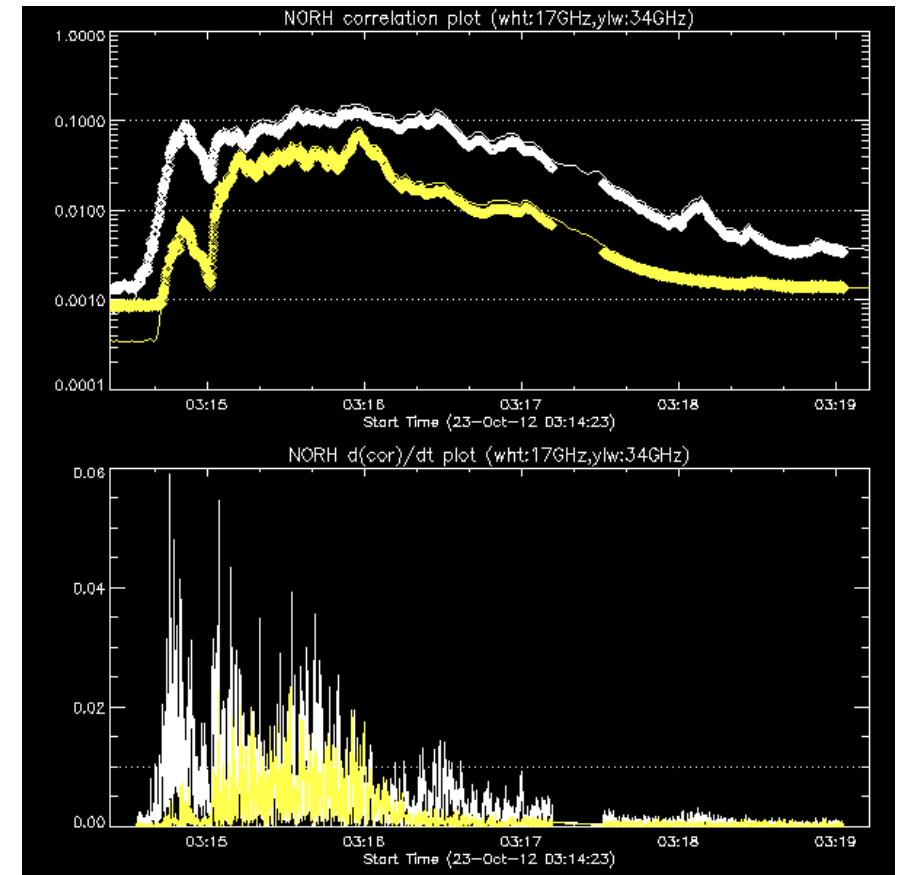
It is, probably, a matter of instrument sensitivity & time resolution



dt = 4 s

TBD

NoRH



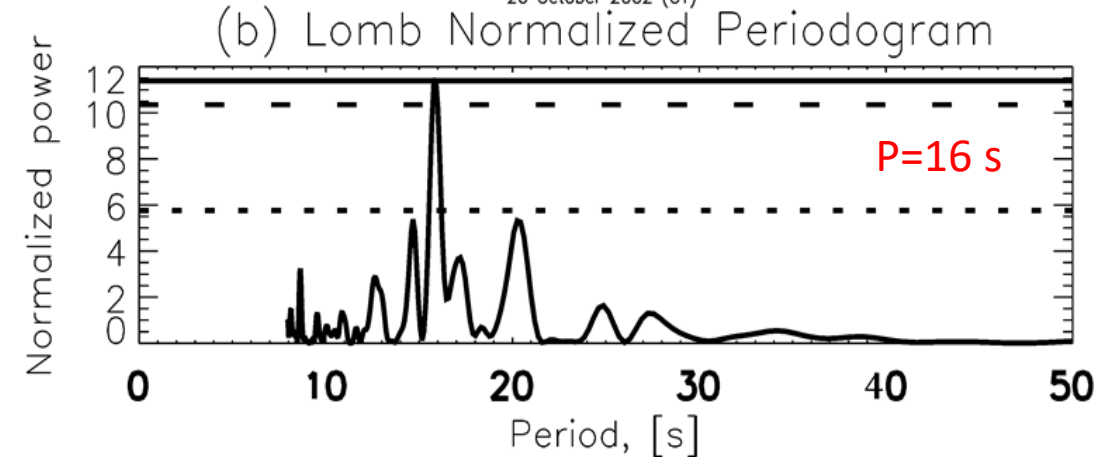
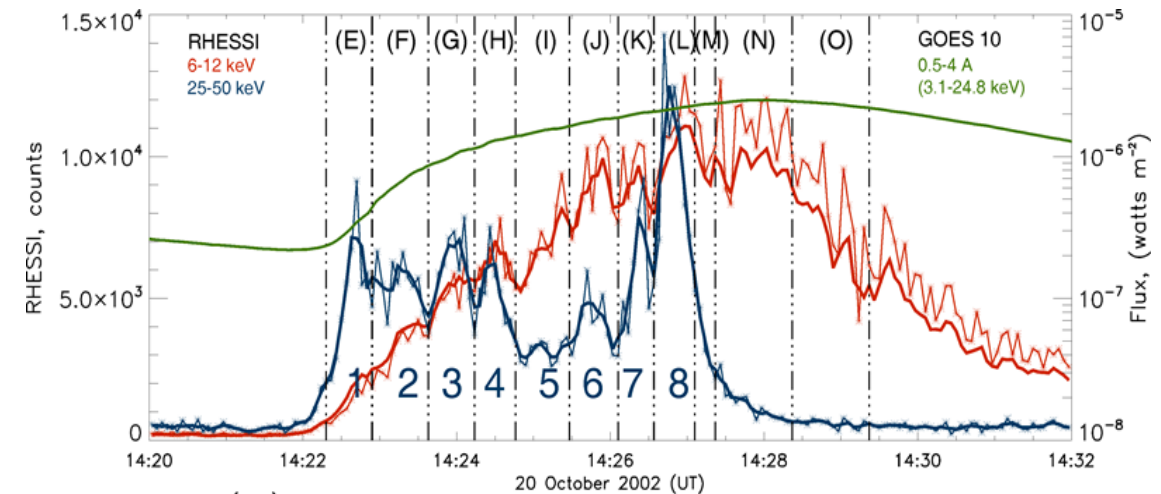
dt = 50/100 ms



# What are QPPs?

- There is no strict definition of solar flare QPPs yet! (TBD)
- But, there is a common intuitive definition:
- **QPPs are a sequence of peaks (bursts, pulses, spikes) of flare emission (often, in different wavebands) with *similar* durations & *similar* times between nearby peaks.**
- Often, QPPs are additionally evidenced by the presence of peaks in the Fourier or wavelet transforms of the emission time profiles. *But this can give false information sometimes.* (TBD)
- There is also an opinion that *almost* any sequence of flare emission bursts ( $N > 3$  or 4) can be called as QPPs.

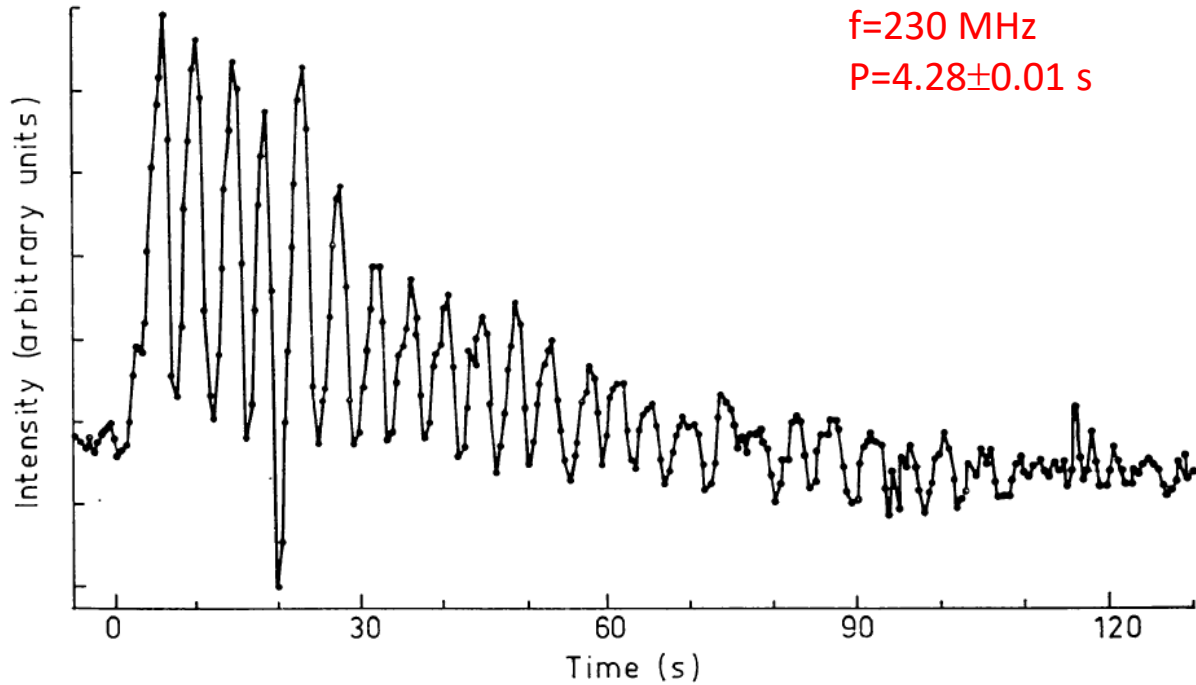
An example of a flare with QPPs of HXR emission



Zimovets & Struminsky (SP, 2010)

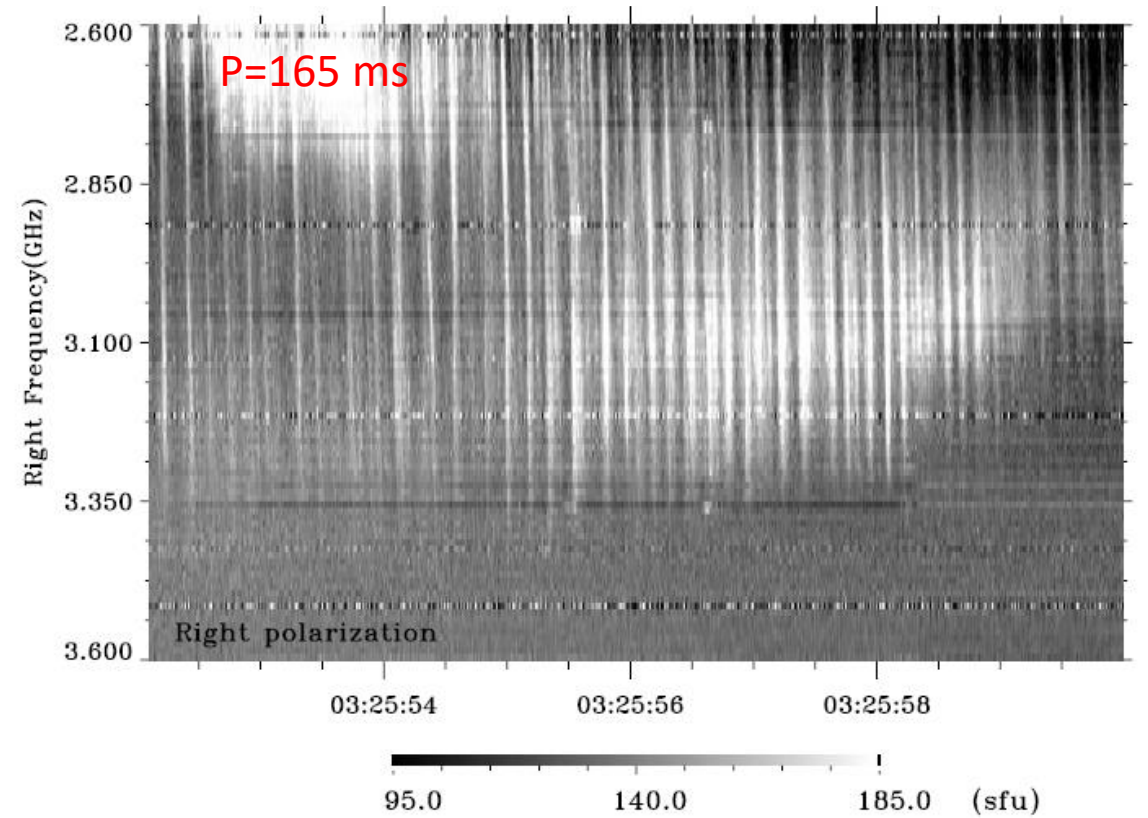
# A couple of examples of nice radio QPPs

The strong flare on 16-May-1972



McLean & Sheridan (SP, 1973)

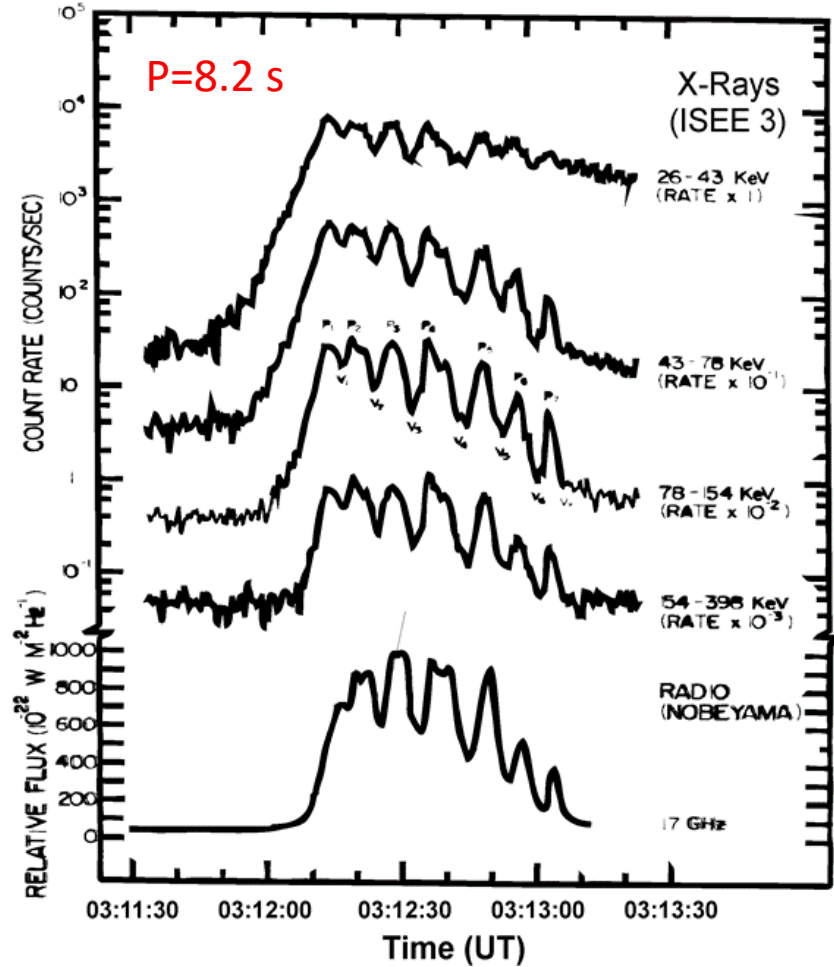
One episode of the X3.4 class flare on 13-Dec-2006



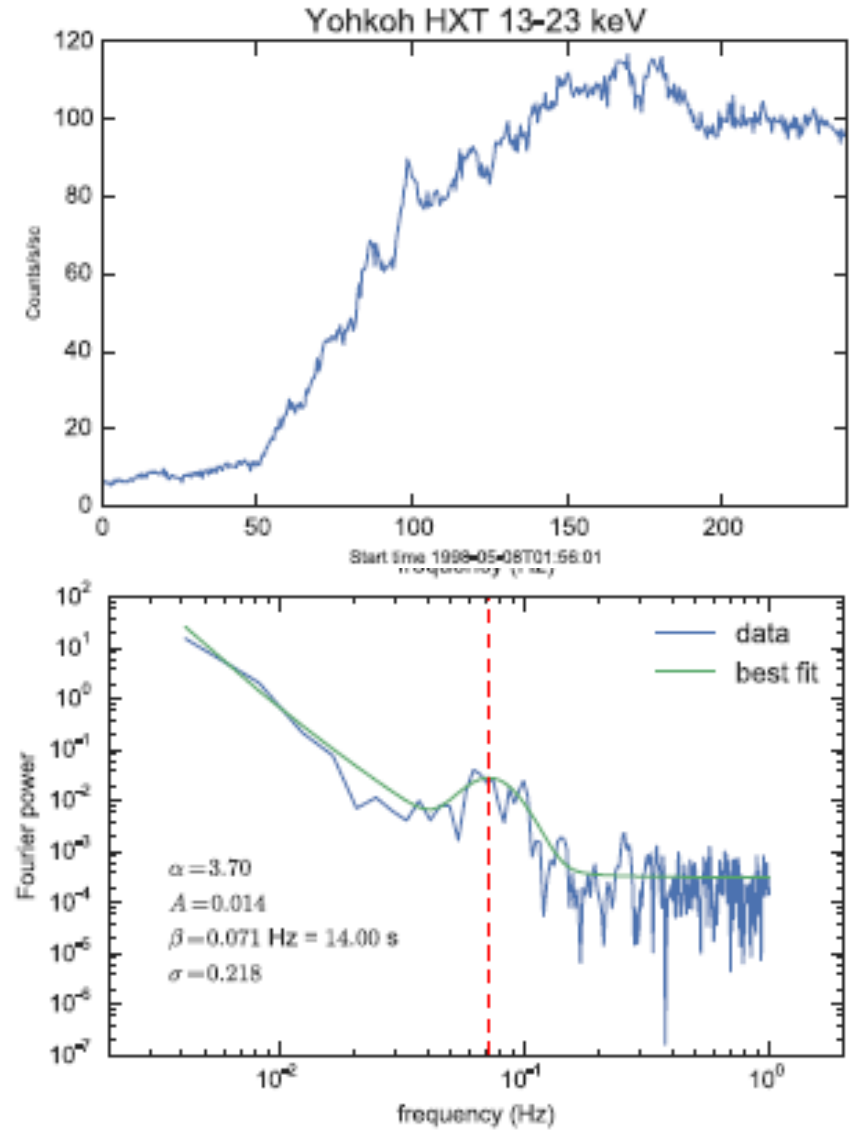
Tan et al. (ApJ, 2007)

# A couple of examples with HXR QPPs

Famous “Seven sisters” flare on 7-June-1980



Kane et al. (ApJ, 1983)



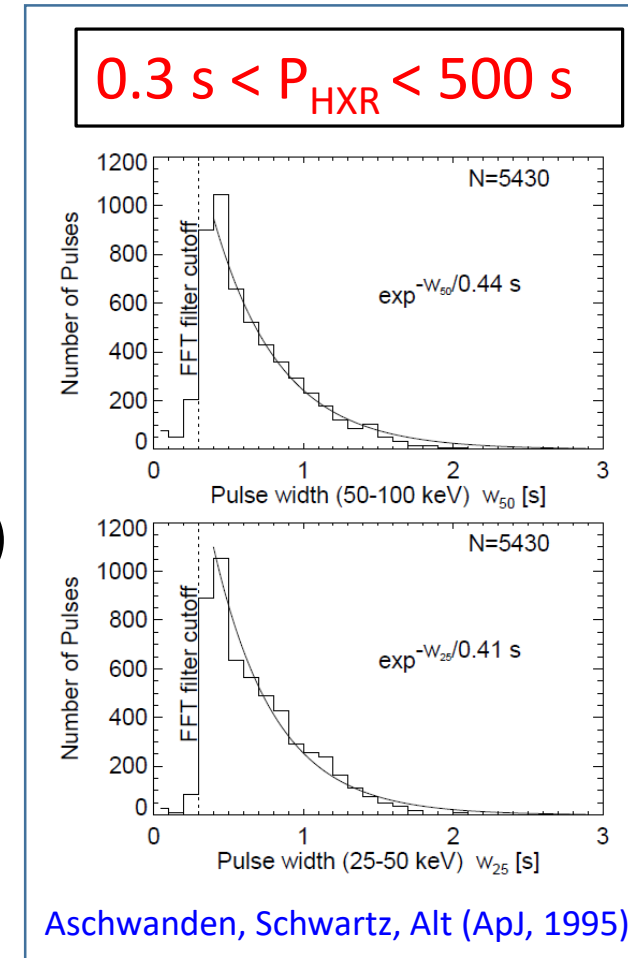
Inglis et al (ApJ, 2016)



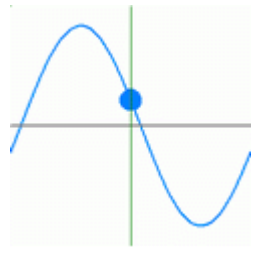
# Main properties of solar flare QPPs

- Occurrence: in many but not in all flares (technique, sensitivity matter?)
- Flare types: all (impulsive, long-duration, eruptive, compact, two-ribbon)
- Flare phases: all (pre-flare, impulsive, decay)
- Wavebands: from radio emission ( $\sim$ MHz) up to gamma-rays (MeV)
- Periods: from several milliseconds to tens of minutes
- Number per flare: from a few (3-4) to dozens (usually,  $\sim$ 4-10 in HXR & MW)
- Modulation depths: from a few % to almost 100%
- Some special characteristics: a) non-harmonicity  
b) non-regularity  
c) multi-periodicity  
d) multi-timescale

Especially for QPPs  
in HXR & MW



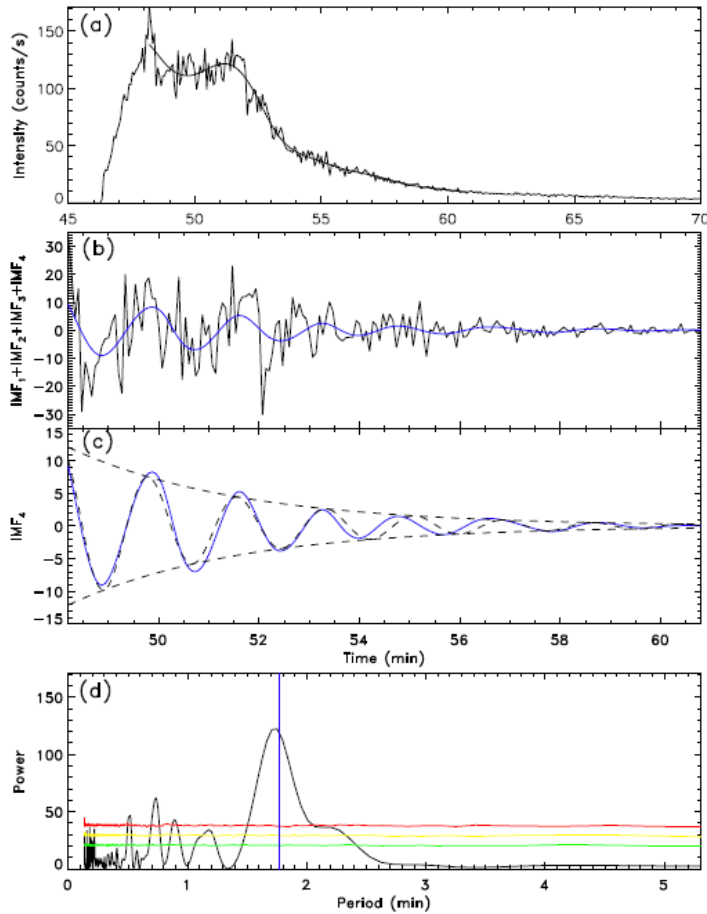
# Why to study QPPs?



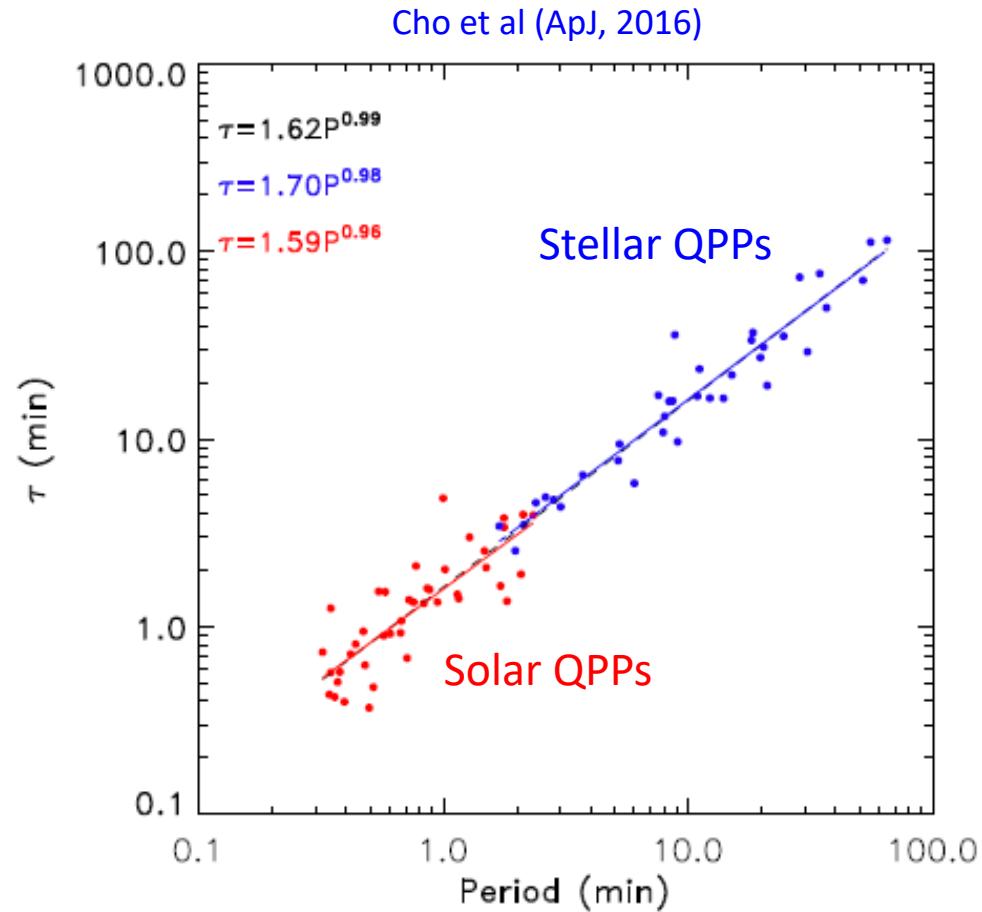
- It is nice and interesting – repetitive physical phenomena always attract people
- Can help to understand mechanisms of solar flares – adequate flare models must take QPPs into account, since QPPs accompany many flares
- Can help to diagnose physical characteristics of flare regions (at the Sun and solar-type stars) – QPPs can contain information about many important parameters of flare regions (plasma density/temperature, magnetic field, electric currents, characteristic size of magnetic structures, ...)

# Similarity between damped QPPs in solar & stellar flares

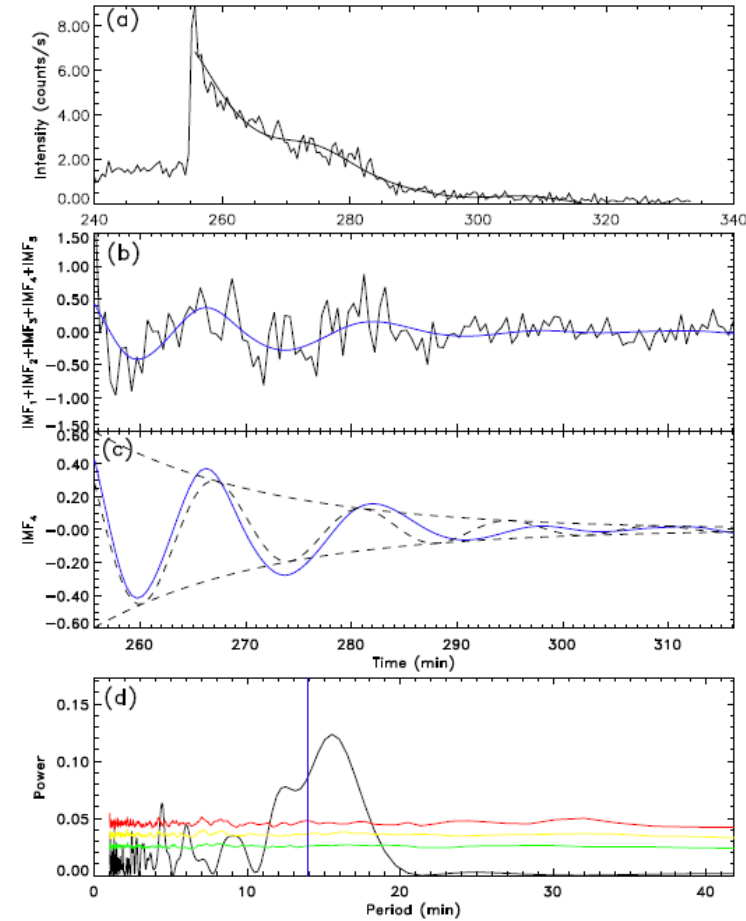
**RHESSI**



**Damping time - Period**

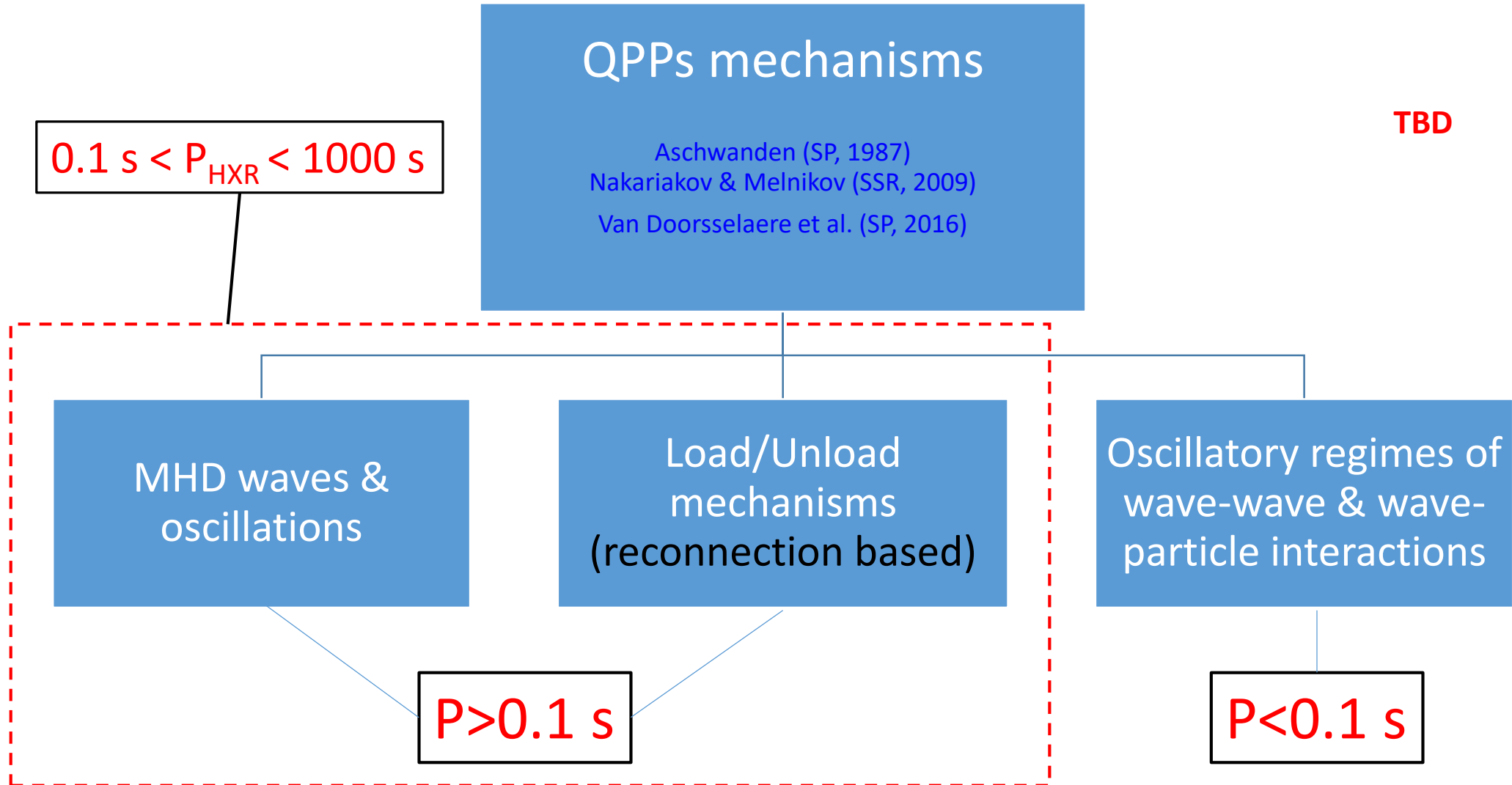


**XMM-Newton**



If we understand QPP mechanisms, and they are the same at the Sun and at other stars, we can have universal stellar flare plasma diagnostics

# General classification of QPPs mechanisms



# Our Team Science Goals

- develop more rigorous criteria of quasi-periodicity for solar flare light curves;
- utilize new methods of analysis of nonlinear and non-stationary datasets;
- develop an advanced classification of different types of pulsations in solar flares;
- perform detailed multi-wavelength spatially-resolved analysis of the sources of pulsations in the large sample of solar flares using modern observational datasets (RHESSI, Fermi, SDO, IRIS, Lomonosov, Vernov, Spectr-R, NoRH/NoRP, SSRT, etc.);
- assess adequacy and improve the existent flare models;
- ~~• evaluate the possible role of pulsations in solar-terrestrial connections;~~
- develop a strategy of exploration of pulsations in solar and stellar flares with space- and ground-based instruments in the coming years



# Our Team Organizational Matters

## **To discuss & initiate:**

- Joint research collaborations
- Joint grant applications
- Joint research publications
- Joint review (topical issue, monography) publications

small/big groups?