Quasi-periodic Pulsations before and during a Solar Flare in AR 12242

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Solar flares, coronal mass ejections and numerous smaller-scale events such as solar jets are often associated with accelerated particles that can cause emissions at radio wavelengths.

Radio emission from solar flares offers a number of unique diagnostic tools to address long-standing questions about energy release, plasma heating, particle acceleration, and particle transport in magnetized plasmas.

Solar Radio Bursts-Spectrum Structures

Spectrum: frequency VS time.
Classified by: frequency drift rate, features

Type III bursts (Signature of electrons)
Type II bursts (shocks, CME)
Type I bursts (Trapped Non-thermal electrons)

(From website of Korean Space Weather Center)

(White et al, 2007)
(Tan et al, 2015)
(Iwai et al, 2014)
Solar Radio Bursts-Spectrum Structures

Spectrum: frequency VS time. Classified by: frequency drift rate, features

(Zebra pattern)

(Finger-like)

(Fish groups)

(From website of Korean Space Weather Center)

(Huang et al, 2007)

(Wu et al, 2007)

Dynamic Spectrum

- **QPPs overlaid on a type IV radio continuum burst**

- **Flux curves at 1.2, 2.0 GHz from MUSER**
MingantU SpEctral Radioheliograph (MUSER)
MingantU SpEctral Radioheliograph (MUSER)

**MUSER-I**
- Frequency: 0.4-2.0 GHz
- Antenna: Φ 4.5m×40
- Channel: 64
- Freq. resolution: 25 MHz
- Cadence: 25 ms
- Spatial resolution: 10.3”-51.6”
- Image dynamic range: ≥25dB
- Polarization: R, L
- FOV: 2-7°

**MUSER-II**
- Frequency: 2.0-15.0 GHz
- Antenna: Φ 2.0m×60
- Channel: 512
- Freq. resolution: 25 MHz
- Cadence: 25 ms
- Spatial resolution: 1.0”-10.3”
- Image dynamic range: ≥25dB
- Polarization: R, L
- FOV: 0.6-2°
Imaging at multi frequencies:

(a) Imaging of MUSER-I
Contours of radio source overlaid on a composite of SDO/AIA image.

- Time: 20 min (start–peak–end, cadence = 12 s)
- Integration: 12s (time resolution = 25 ms)
- Frequency: 1.2–2 GHz (frequency resolution = 25 MHz)

(b) Spectrum of MUSER-I
The flux of at 1.7 GHz overlaid on the spectrum of 0.4-2.0 GHz.

Dynamic spectrum analysis:

- Flux calculated from the imaging of the source at 1.7 GHz shares similar profile with the flux from the spectrum.
- QPPs ~2 min at 1.2 and 2.0 GHz
Introductions - QPPs

- Quasi-periodic pulsations (QPPs) are commonly observed, which show periodic pulses in almost all phases of the flare. (some reviews by Nakariakov & Melnikov (2009), Nakariakov et al. (2016), and Van Doorsselaere et al. (2016))

- Detected in all wavelengths (from radio to gamma-rays) with different timescales from sub-seconds to tens of minutes. (Kliem et al. 2000; Sych et al. 2009; Liu et al. 2012; Simões et al. 2015; Hayes et al. 2016; Huang et al. 2016)

- Proposed mechanisms:

Proposed mechanisms:

- MHD oscillations, slow magnetoacoustic, kink, sausage, torsional Alfven mode to modulate the plasma parameters or the distribution of energetic electrons in flaring loop. (Nakariakov 2007; Nakariakov & Melnikov 2009)

- Cyclic self-organizing systems, share the principle of self-organization and are governed by an oscillatory phase of wave-wave or wave-particle interactions. (Aschwanden 1987; Nakariakov & Melnikov 2009; Aschwanden et al. 2018)

- Modulation of magnetic reconnection may lead to an intermittent energy release and particle acceleration. (Kliem et al. 2000; Karlický et al. 2005; Ofman & Sui 2006; Murray et al. 2009; McLaughlin et al. 2012; Zhang et al. 2016)
Overviews of this flare event:

Flare M8.7
AR 12242

>2014-12-17
>GOES:
04:25-04:51-05:20 UT
>MUSER & NORP:
04:25-04:32-04:46 UT

The positive surrounded by the negative magnetic field

A peculiar circular active region
Magnetic extrapolation results:

- Two ribbons flaring region
- Circular ribbons
- Remote ribbons
- Fan-shaped field lines
- Large overlaying spines

the inner spines
fan-shaped field lines
large overlaying spines
Processes of this flare:

- Large overlaying loops
- Small-size loops under the fan loops
- The null-point reconnection happens before the flare onset
- Flare starts.
- Microwave and HXR emissions.
> QPPs near the sunspot at 1600 Å during the whole process
Three components of oscillations

Findings:
1) the 4-min oscillations at 1600 Å near the sunspot sustaining for the whole process;
2) EUV QPPs of 3-min in the preflare phase;
3) Radio QPPs of 2-min in the flare impulsive phase.
Possible mechanisms

- **Sunspot oscillations**
  - 3-5 min the sunspot oscillations in umbral chromosphere, transition region and corona at multi wavelengths (*Thomas 1985; De Moortel et al. 2002; Khomenko & Collados 2015*)
  - UV emission at 1600 Å from the chromosphere

*(Sych et al. 2012)*
Our Proposals

- The intermittent magnetic reconnection
  - Downwards and upwards plasmoids near the reconnection site may heat plasmas (EUV brightening) and accelerate electrons (radio bursts).
  - Take place at a changing pace, faster during the impulsive stage with a shorter period.
**Our Proposals**

- **LRC mechanism** *(Zaitsev et al. 1998, 2000)*
  - The current-carrying plasma loop forms an LRC-circuit resonator, and the circuit oscillations will cause periodic modulations. *(Khodachenko et al. 2009, Tan 2016)*
  - $P=10^{12}/I$ [s], increase from $5e^9$ to $8e^9$ Ampere, similar to *Tan et al*(2007).
  - The electric current should be a key link between the preflare evidence and the flaring processes.
Conclusions:

• Radio imaging of the quiet sun and radio burst with good results at multi frequencies.
• Three components of oscillations: the 4-min UV QPP should be modulated by the sunspot oscillations, and the 3-min EUV QPP may be closely linked to the 2-min radio QPP by connecting source region in coronal loops and by intermittent magnetic reconnection or the similar LRC-circuit resonating mechanism.
• The spectrum and imaging of solar radio bursts improve our understanding of the flare event, looking forward to new radio telescope, MUSER(low-freq array), SKA.....