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

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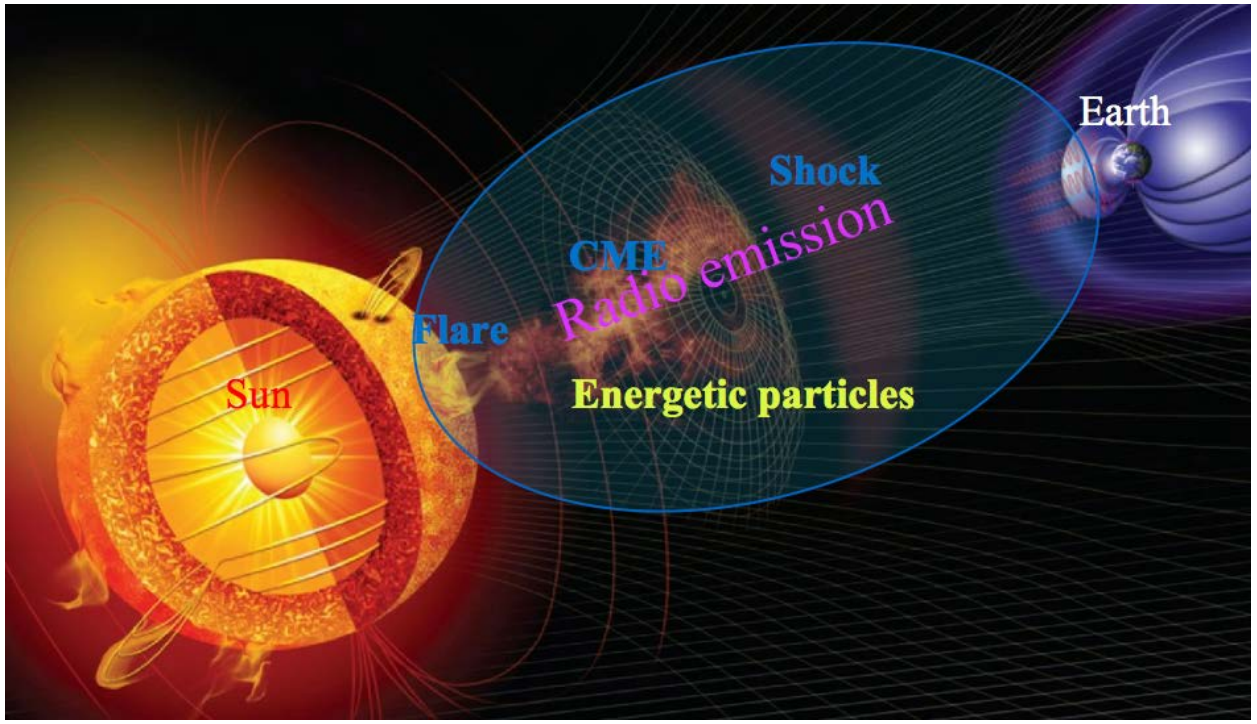
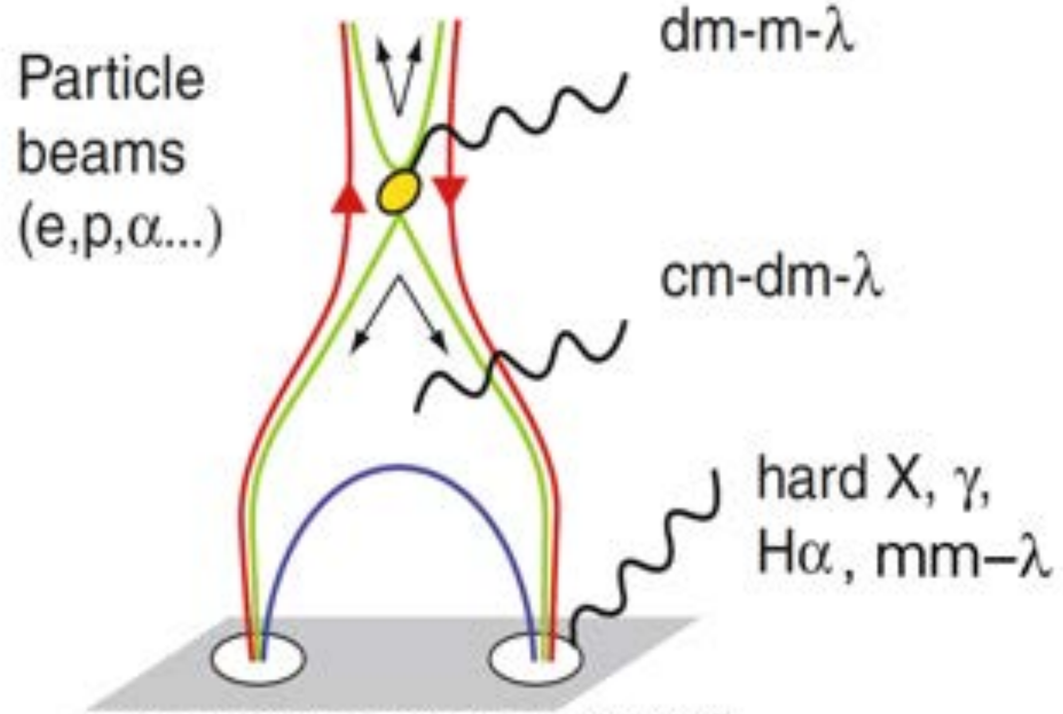
Introductions-Radio emissions

- 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.

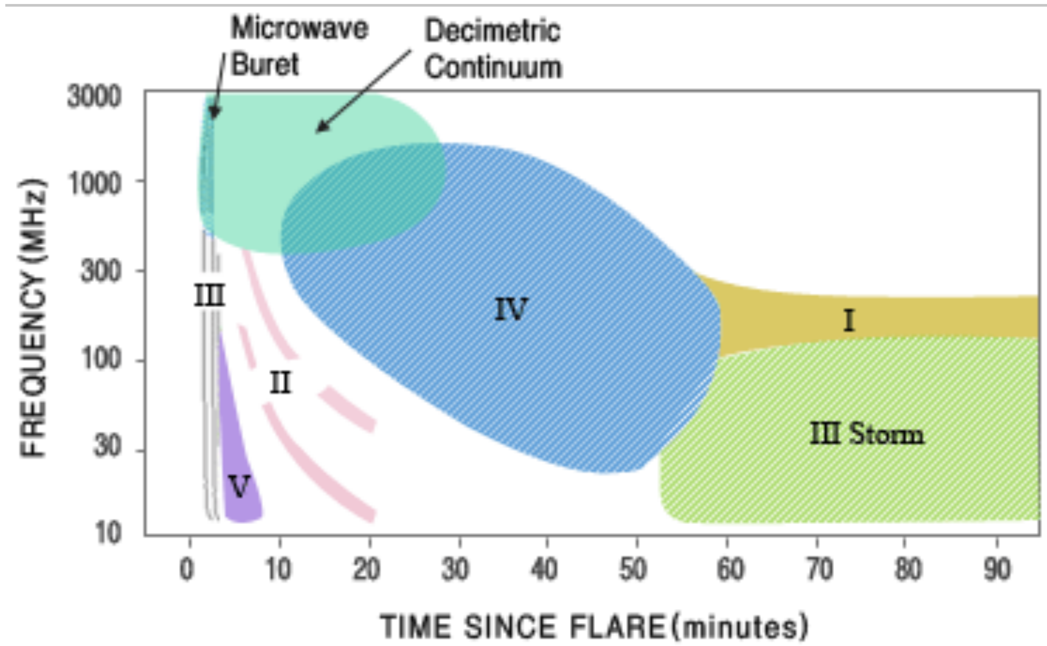
(Aschwanden & Benz. 1997 , Bastian et al. 1998, Gary & Keller 2004; Pick & Vilmer 2008)





(Klein & MacKinnon, 2007)

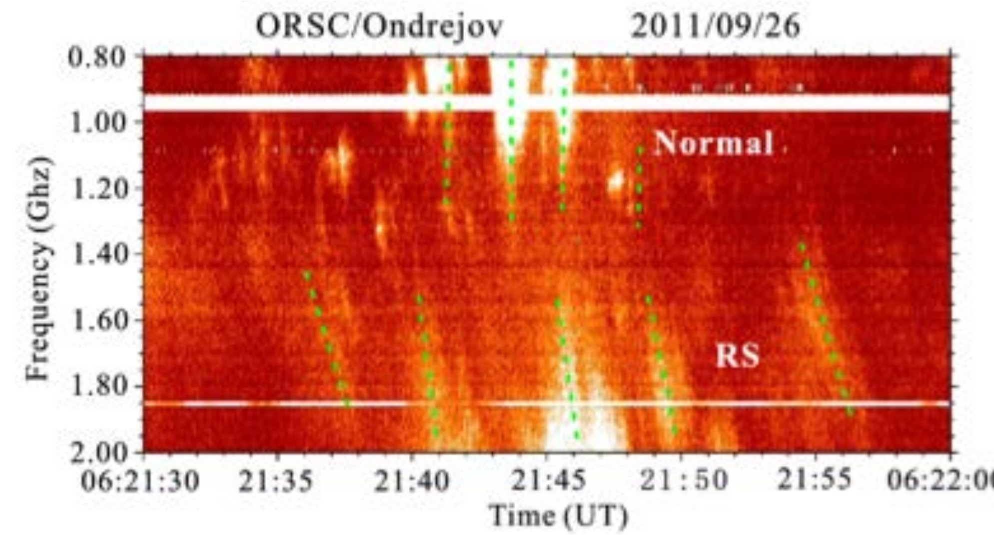
Solar Radio Bursts-Spectrum Structures



(From website of Korean Space Weather Center)

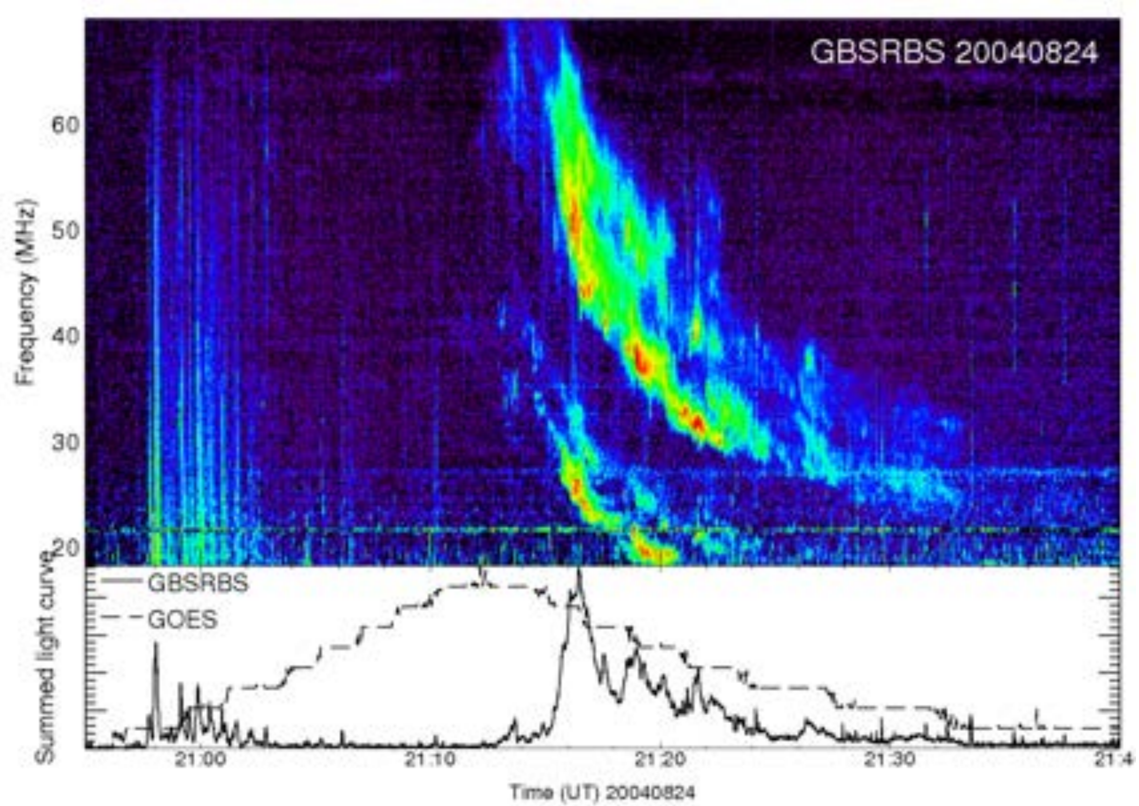
Spectrum : frequency VS time.
Classified by : frequency drift rate ,features

Type III bursts (Signature of electrons)



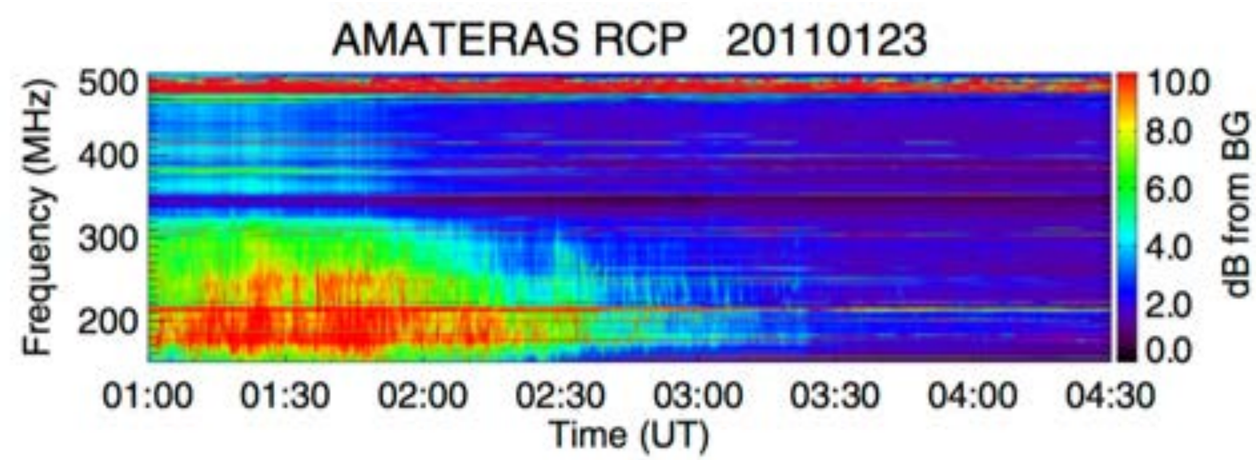
(Tan et al, 2015)

Type II bursts (shocks, CME)



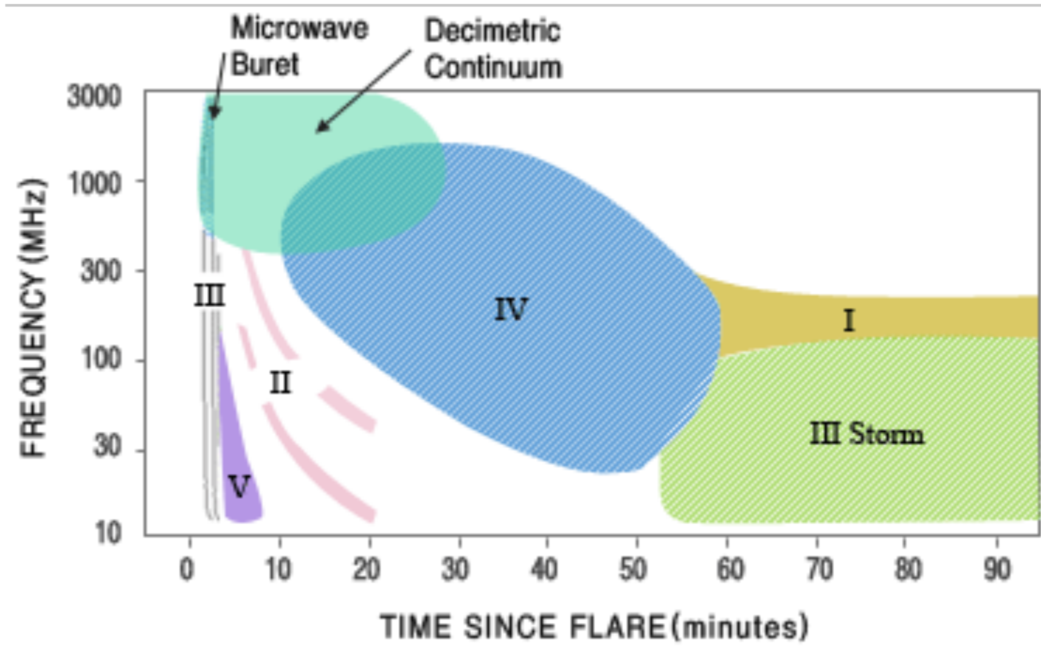
(White et al, 2007)

Type I bursts (Trapped Non-thermal electrons)



(Iwai et al, 2014)

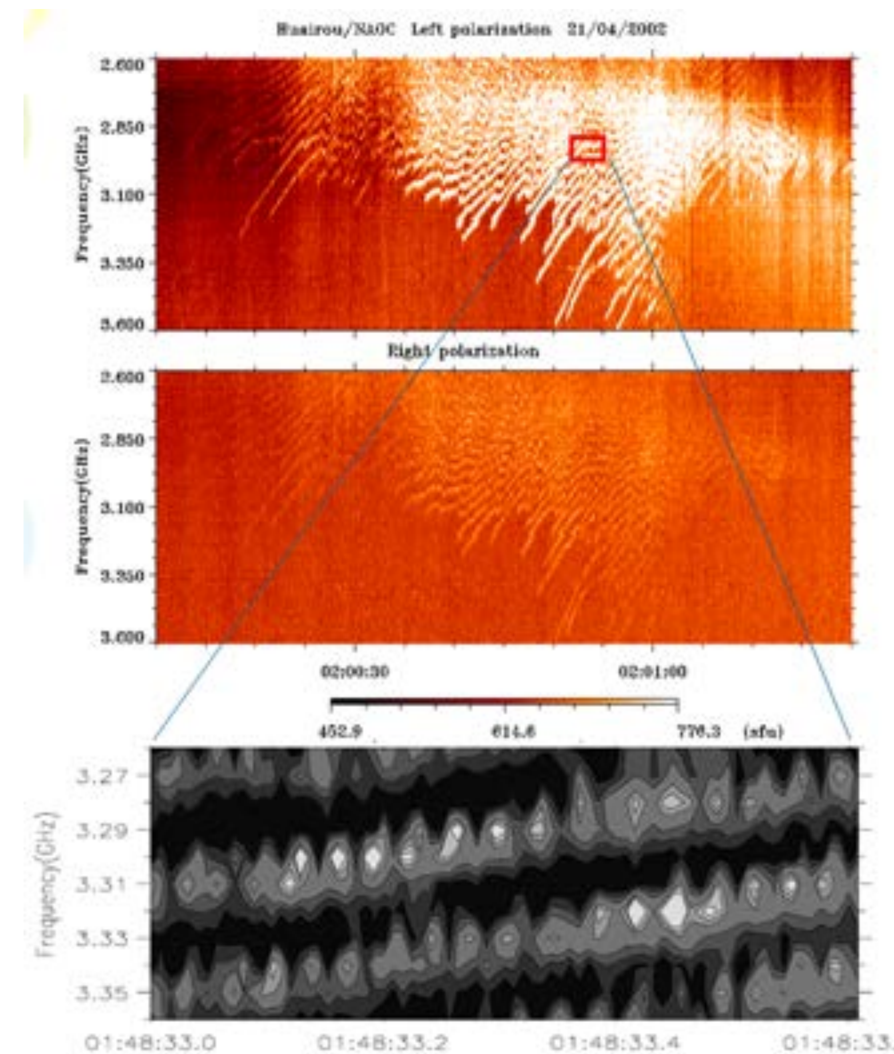
Solar Radio Bursts-Spectrum Structures



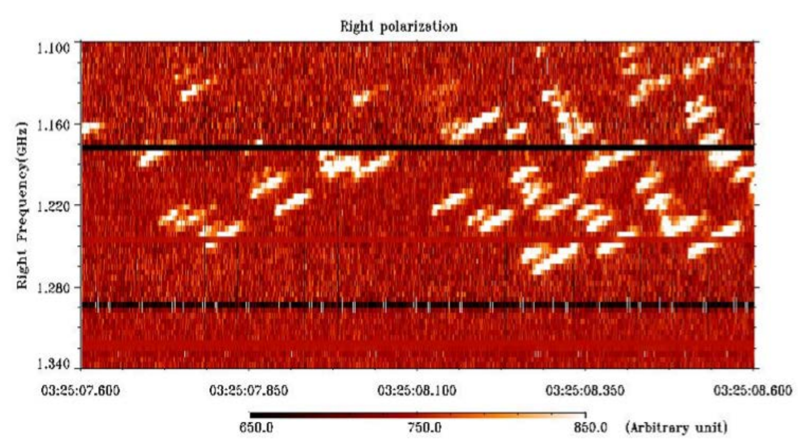
(From website of Korean Space Weather Center)

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

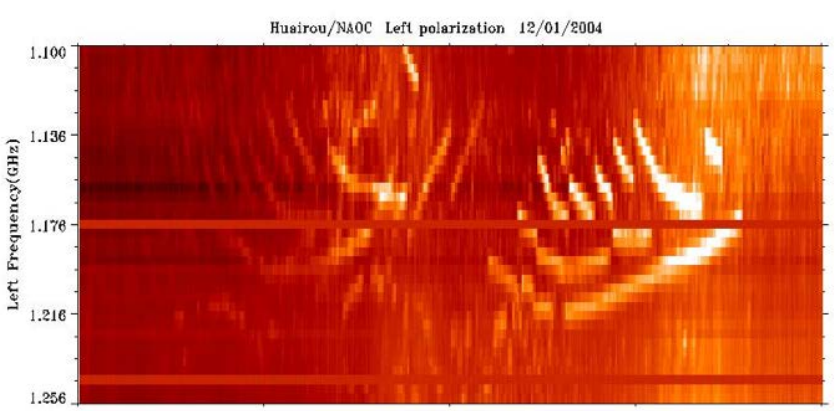
Zebra pattern



Fish groups



Finger-like

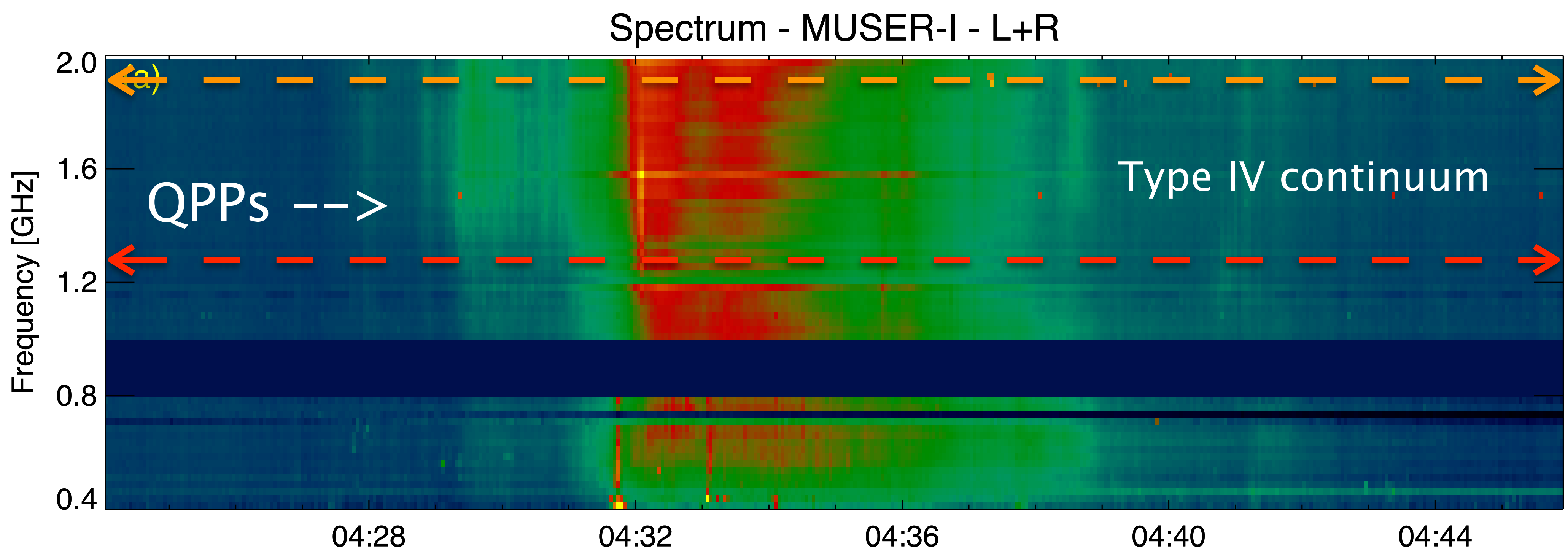


(Huang et al, 2007)

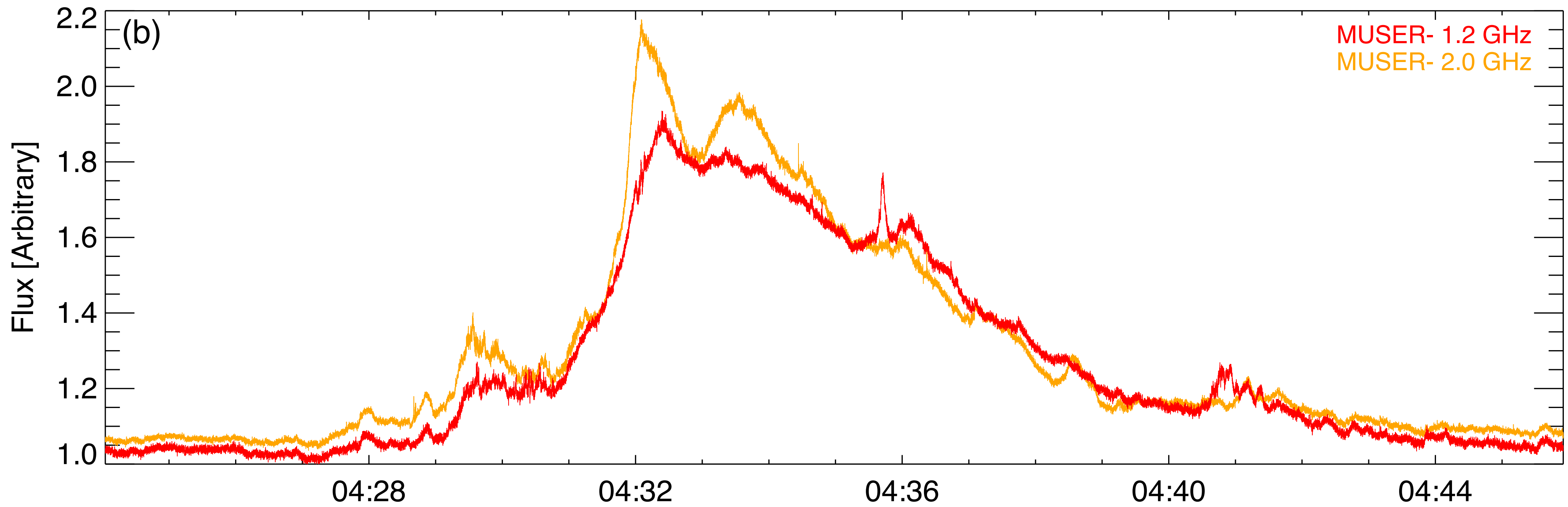
(Wu et al, 2007)

(Tan, et al., ApJ, 2007 ; Yan et al, SoPh, 2007; Tan et al., ApJ, 2012)

Dynamic Spectrum

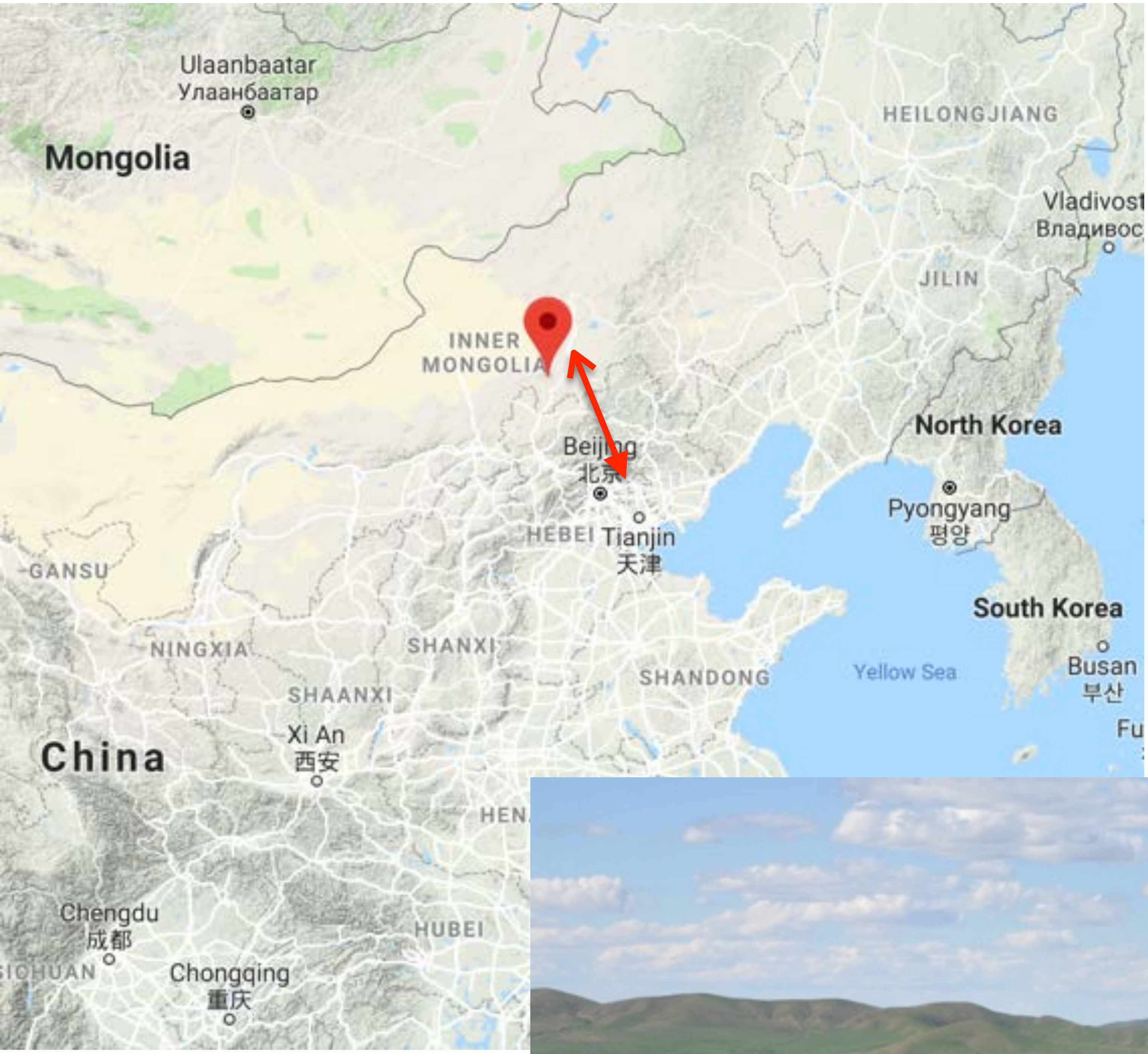


- QPPs overlaid on a type IV radio continuum burst



- Flux curves at 1.2, 2.0 GHz from MUSER

MingantU SpEctral Radioheliograph (MUSER)



MingantU SpEctral Radioheliograph (MUSER)

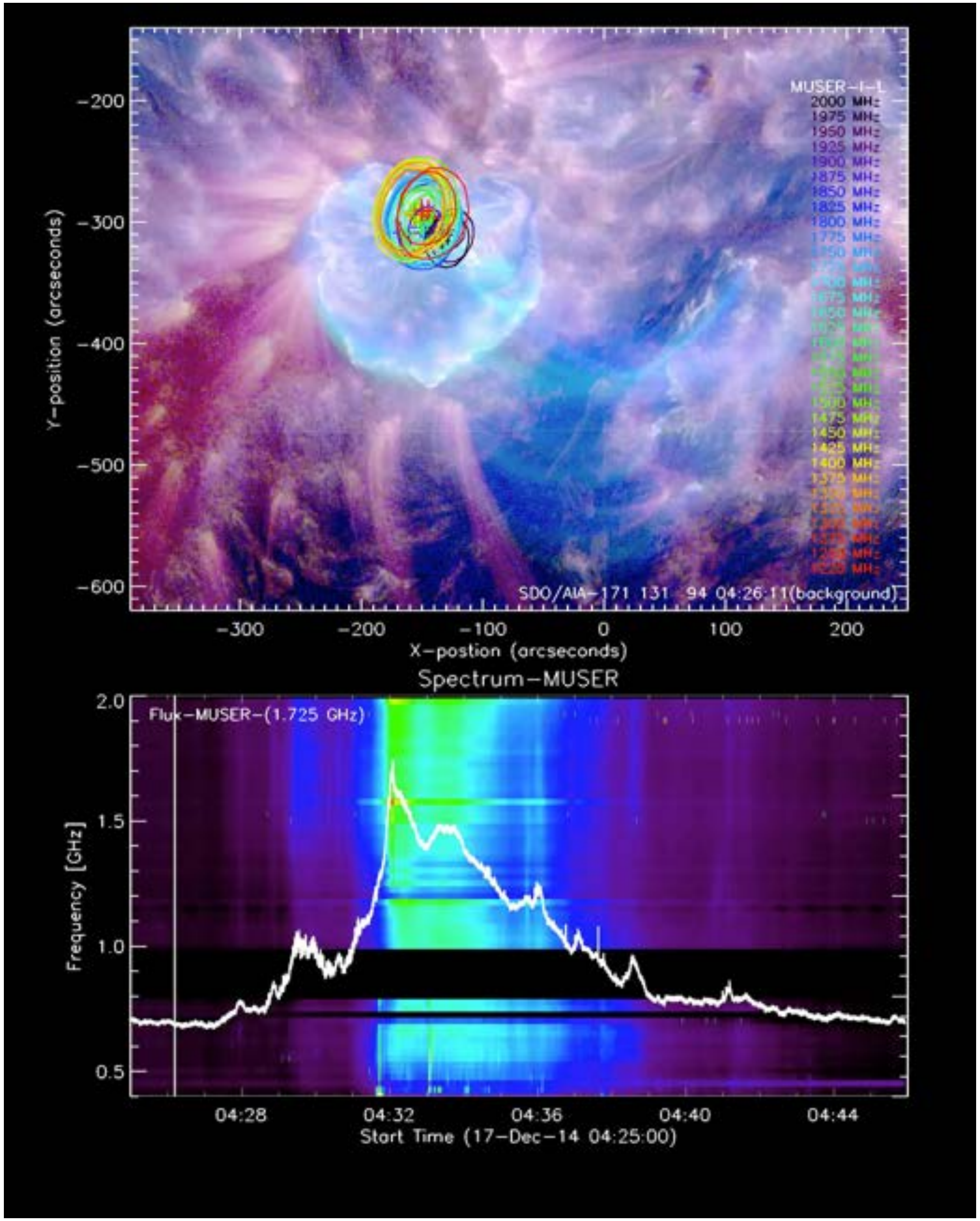
MUSER-I

- 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:



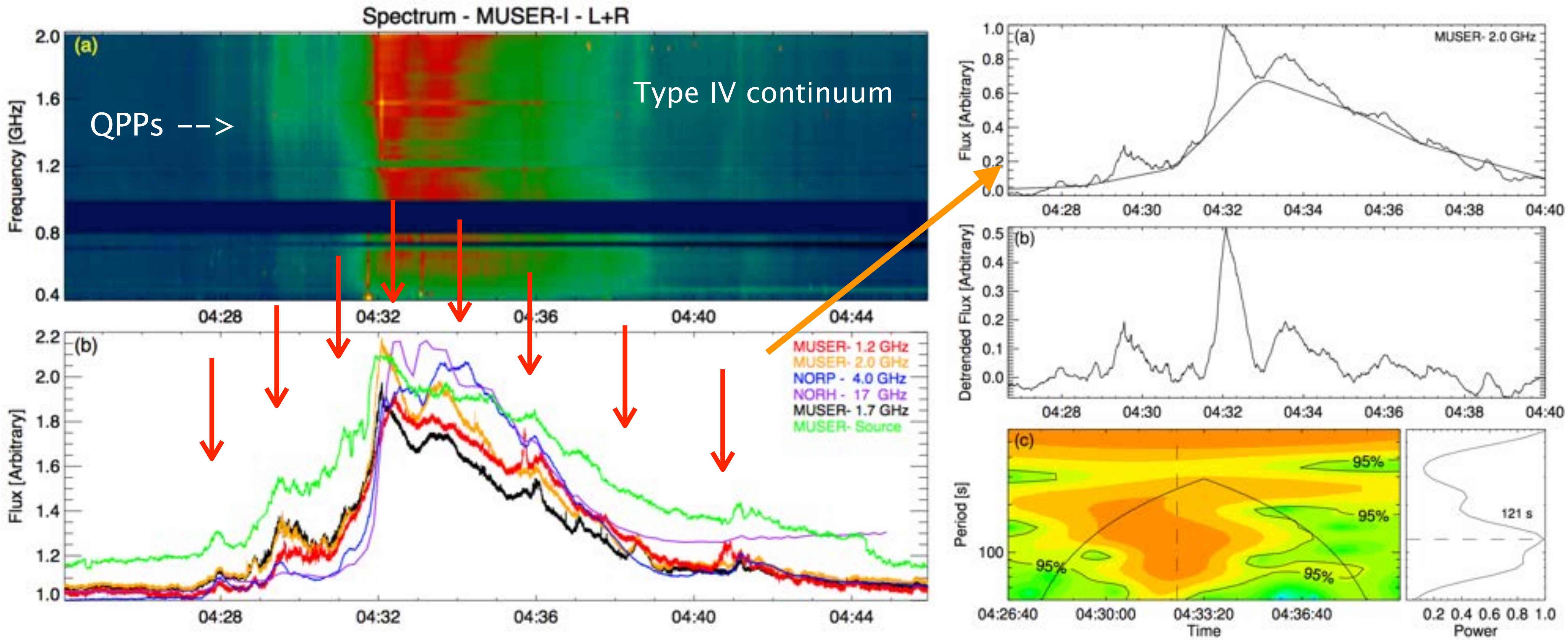
(a) Imaging of MUSER-I
Contours of radio source overlaid on a composite of SDO/AIA image.

- 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.

(Chen et al, 2019, ApJ)

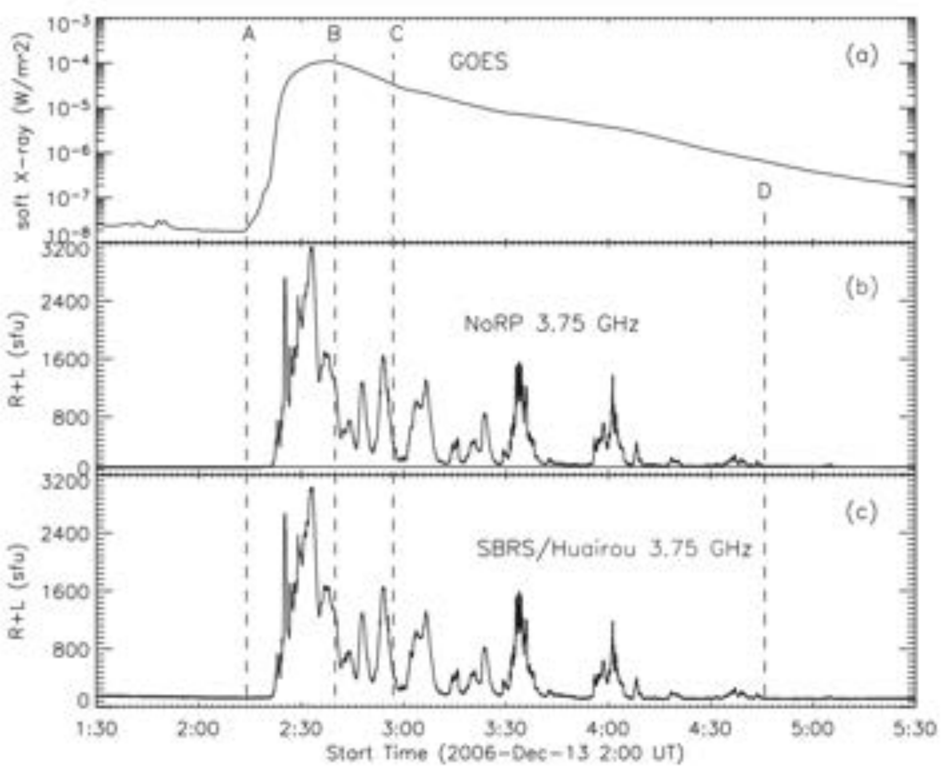
Dynamic spectrum analysis:



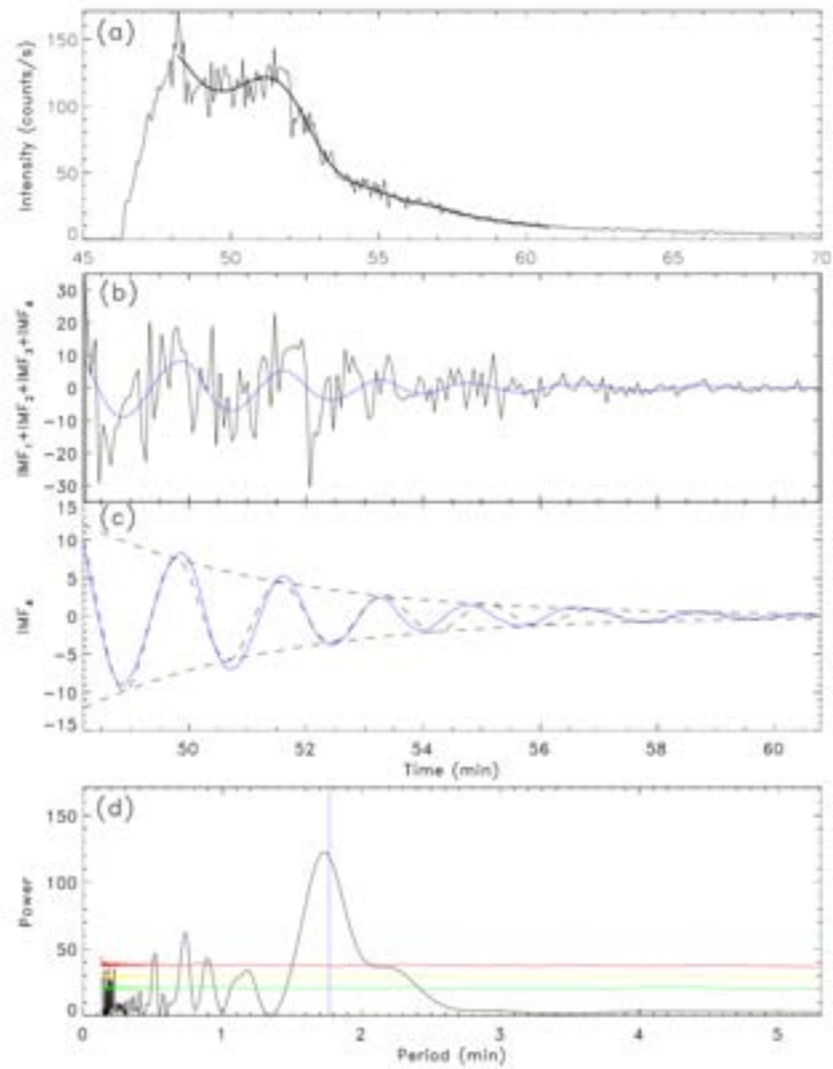
- Flux calculated from the imaging of the source at 1.7 GHz shares similar profile with the flux from the spectrum.
- QPPs ~2 min at 1.2 and 2.0 GHz

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:



(Tan et al, 2010)

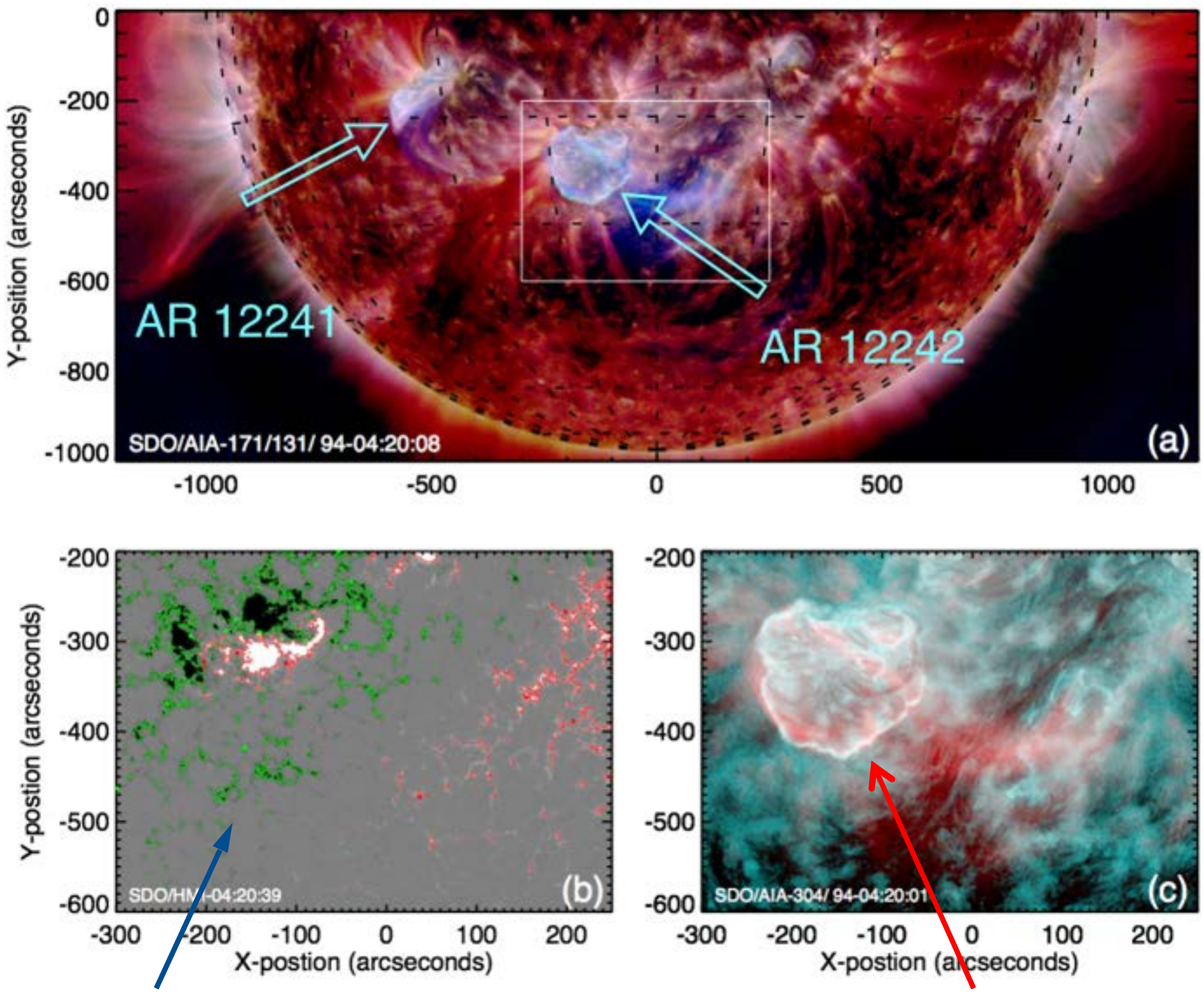


(I.H. CHO et al, 2016)

✤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

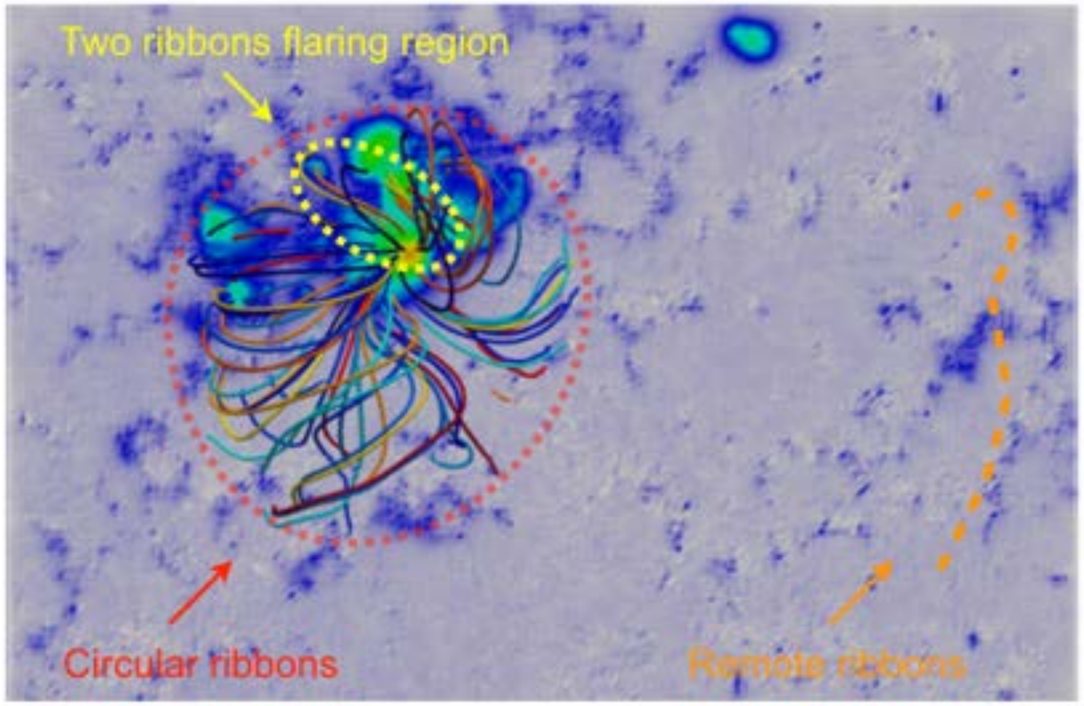
>MUSER & NORP :

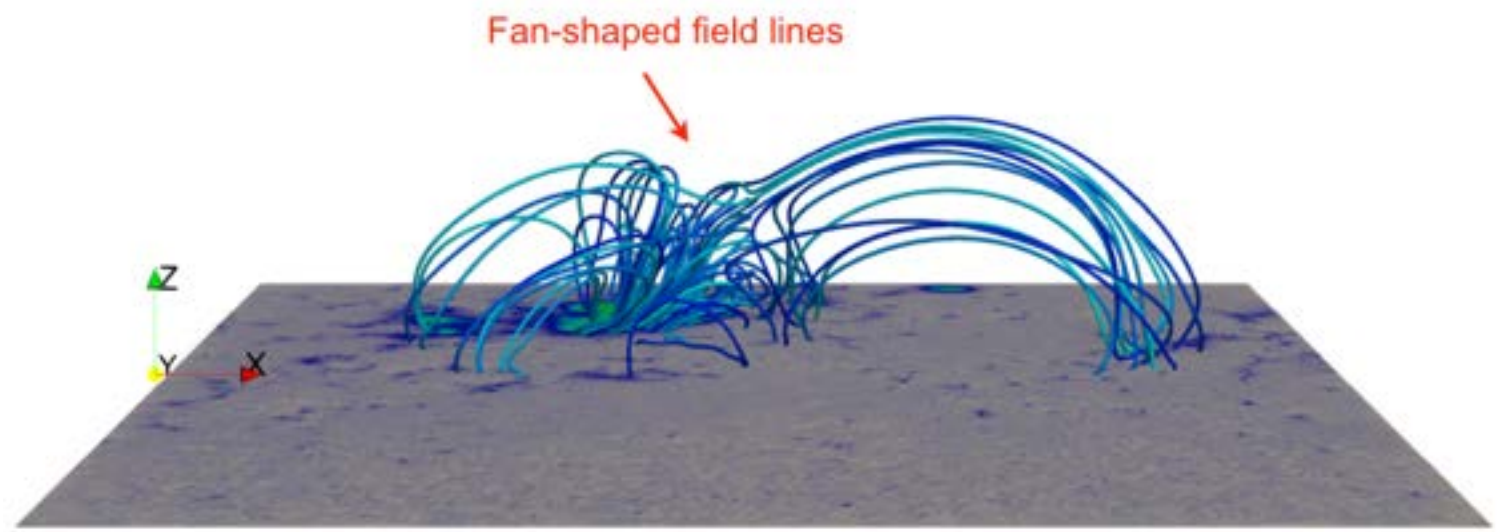
04:25-04:32-04:46 UT

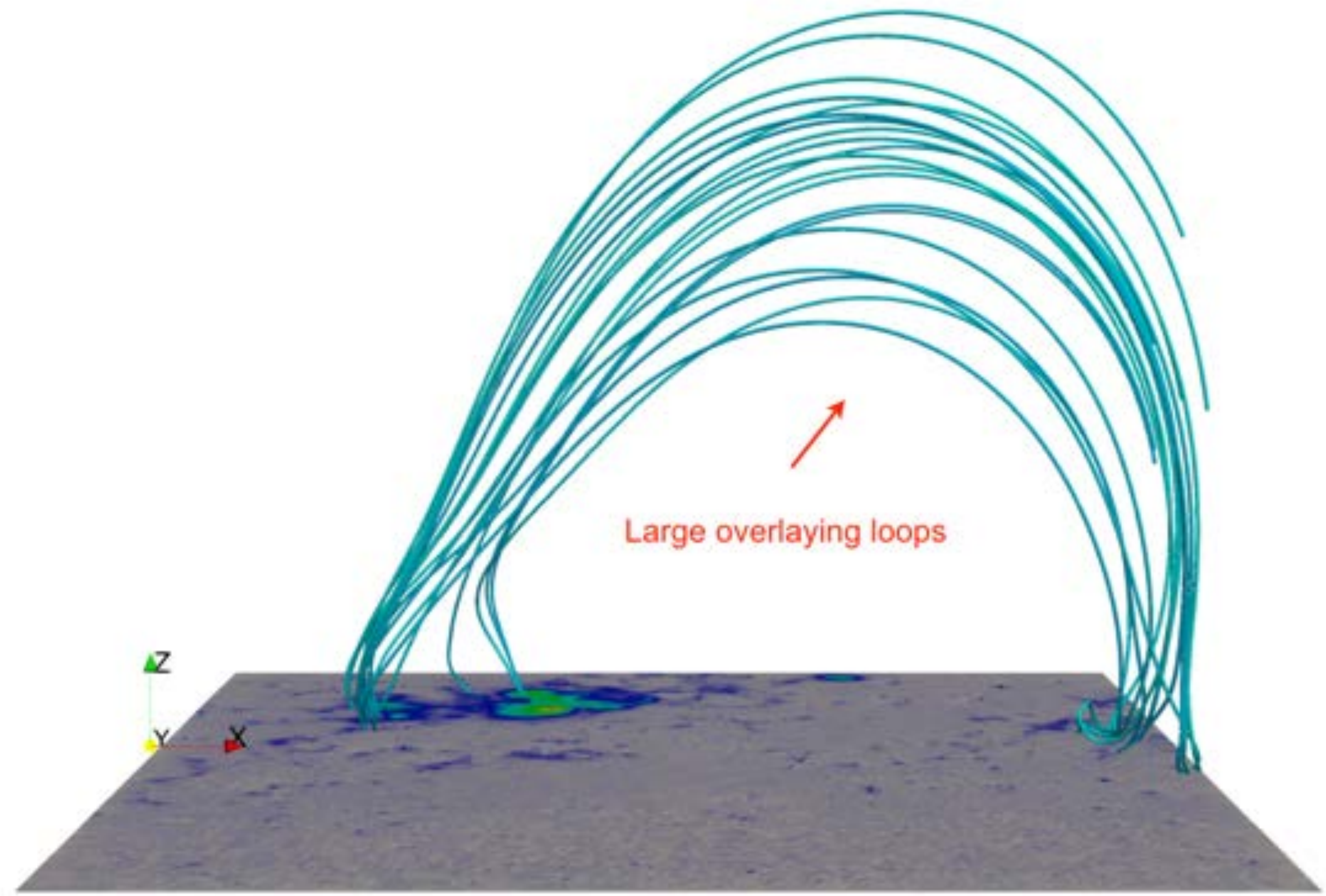
The positive surrounded by the negative magnetic field

A peculiar circular active region

Magnetic extrapolation results:





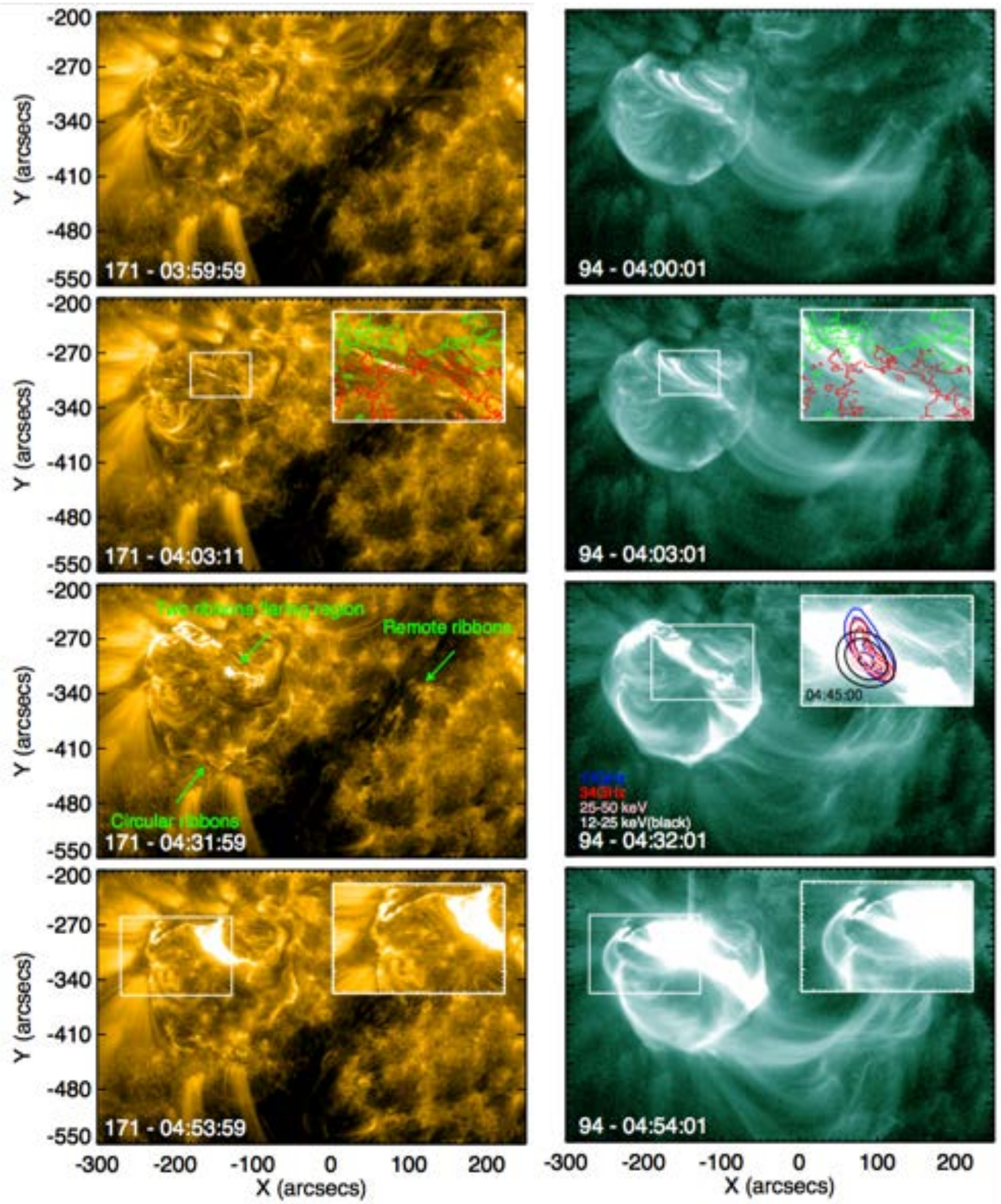


the inner spines

fan-shaped field lines

large overlaying spines

Processes of this flare:



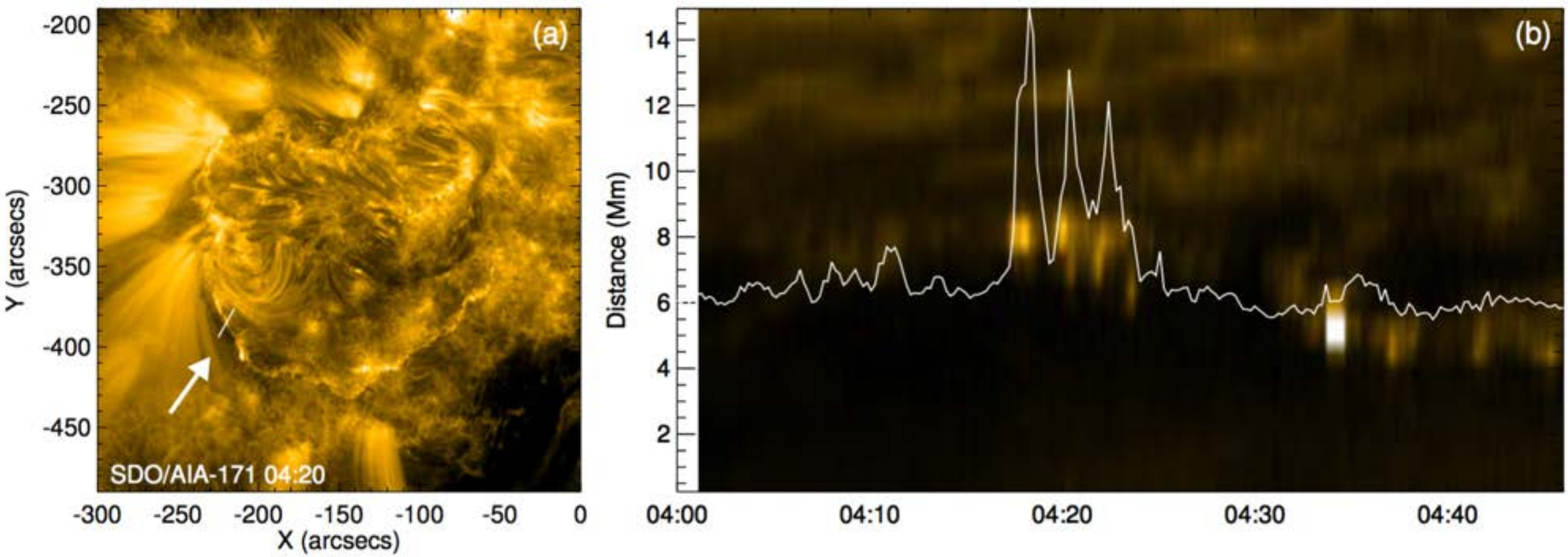
Large overlaying loops

Small-size loops under the fan loops

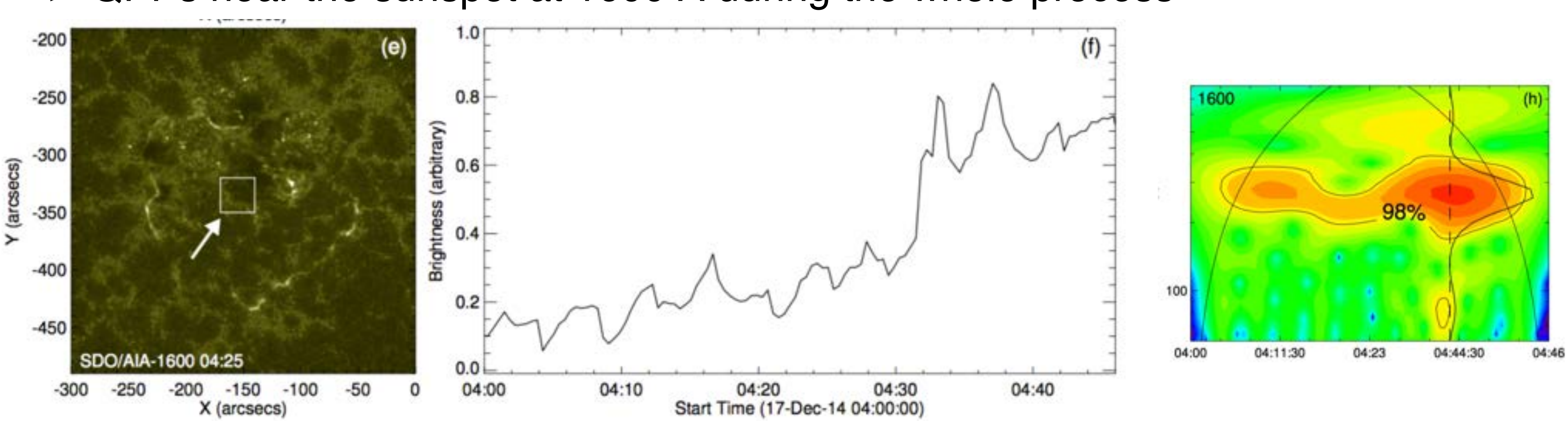
The null-point reconnection happens before the flare onset

Flare starts.

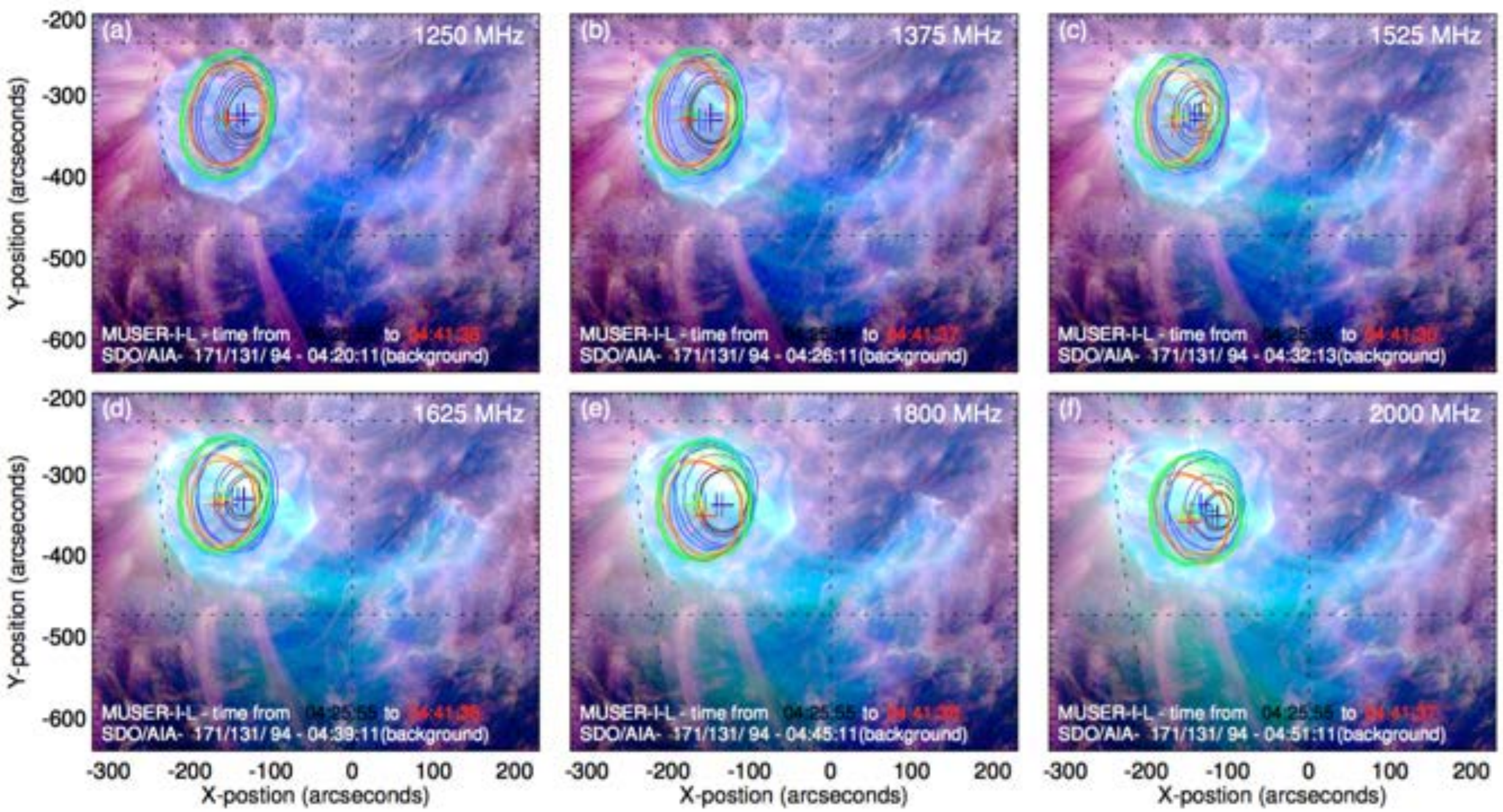
microwave and HXR emissions.



> QPPs near the sunspot at 1600 Å during the whole process



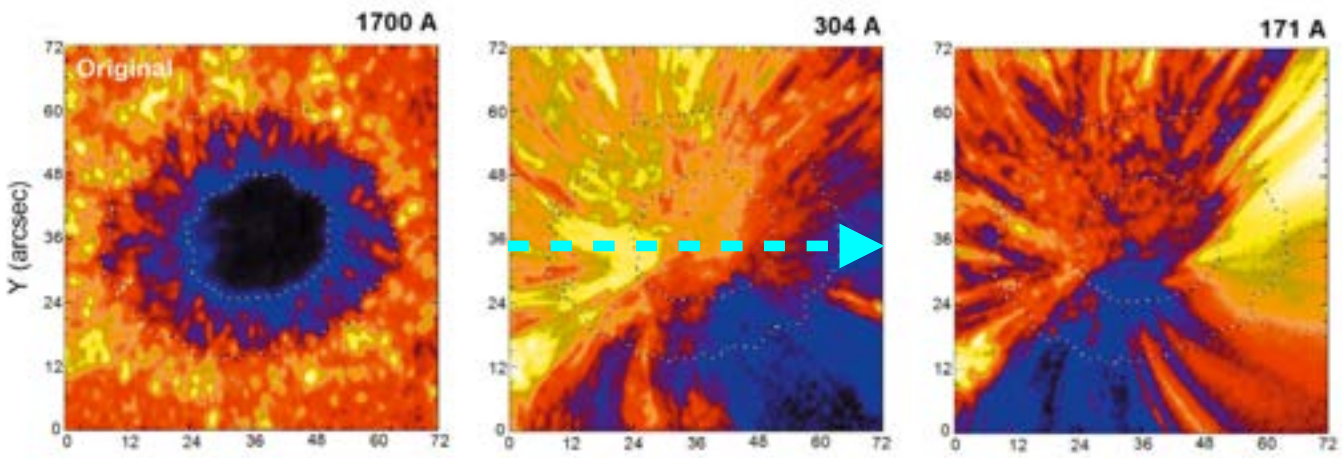
Three components of oscillations

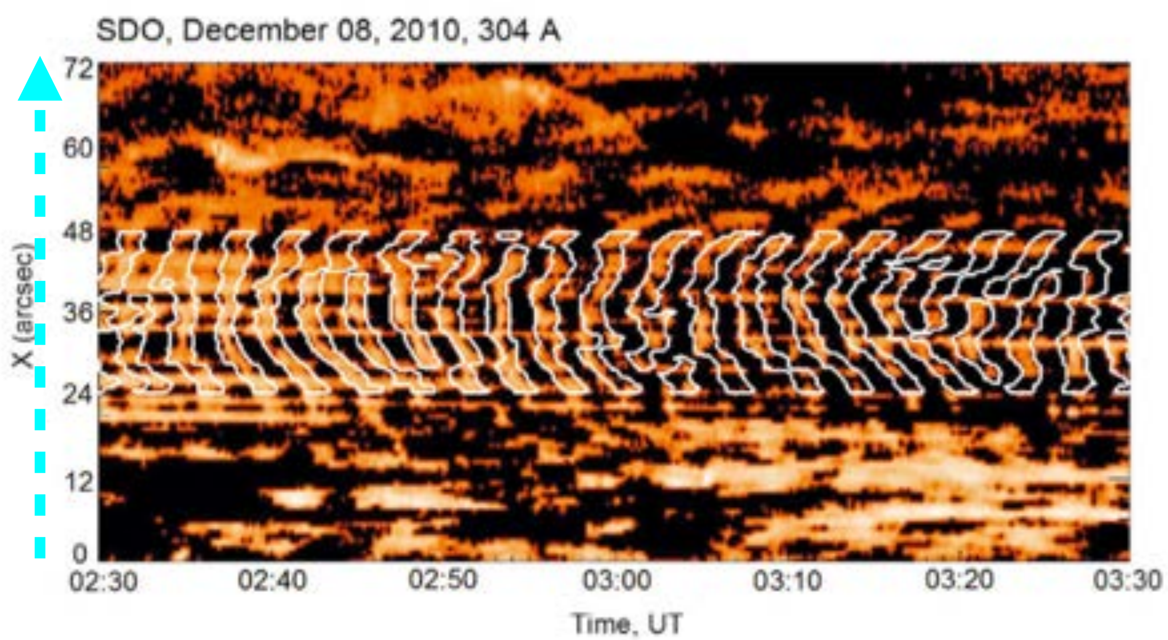


Findings:

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





(Sych et al. 2012)

✤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

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 5e9 to 8e9 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.....