Precursors of solar flares in the microwave range

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The aim of our work is to study the oscillations of microwave emission of active regions at the preflare stage.

On the one hand, this may shed light on understanding the processes of the onset of solar flares. On the other hand, it can help develop prognostic criteria.

INTRODUCTION

Quasi-periodic fluctuations of solar radio emission

Quasi-periodic fluctuations (QPFs) of solar radio emission were discovered some 50 years ago (Durasova et al., *Nature*, **229**, 82, 1971; Kobrin et al., *Radiophys. Quantum Electron.*, **16**, 1036, 1973).

Almost immediately, evidences that the parameters of QPFs are related with flare activity were found (Aleshin et al., *Radiophys. Quantum Electron.*, **16**, 571, 1973). In particular, the effect of increase the power of the QPFs of microwave emission before the flare was discovered (Aver'yanikhina et al., *Issled. Solntsa Krasnykh Zvezd*, no. 16, 61, 1982; Kobrin et al., *Soln. Dannye*, no. 10, 79, 1973; Kobrin et al., *Astron. Tsirk.*, no. 1201, 1, 1981).

Originally detected on small antennas, this effect was confirmed in observations by the radiotelescopes RT-22 (Institute of Physics, Russian Academy of Sciences), RT-22 (Crimean Astrophysical Observatory), and TNA-1500 (Arbuzov, *Radiophys. Quantum Electron.*, **22**, 803, 1980; Avdyushin et al., *Dokl. Akad. Nauk SSSR*, **283**, 67, 1985; Berulis et al., *Radiophys. Quantum Electron.*, **16**, 1047, 1973; Berulis et al., *Sov. Astron.*, **27**, 563, 1983).

Moreover, a similar effect concerned the amplification of geomagnetic field pulsations before proton flares and its connection with pulsations of solar radio emission was found (Bystrov et al., *Sov. Astron.Lett.*, **4**, 76, 1978; Bystrov et al., *Geomagn. Aeron.*, **19**, 197,1979).

Recently, a similar effect was found in soft X-ray according to GOES data (Tan et al., *Astrophys. J.*, **833**, id 206, 2016).

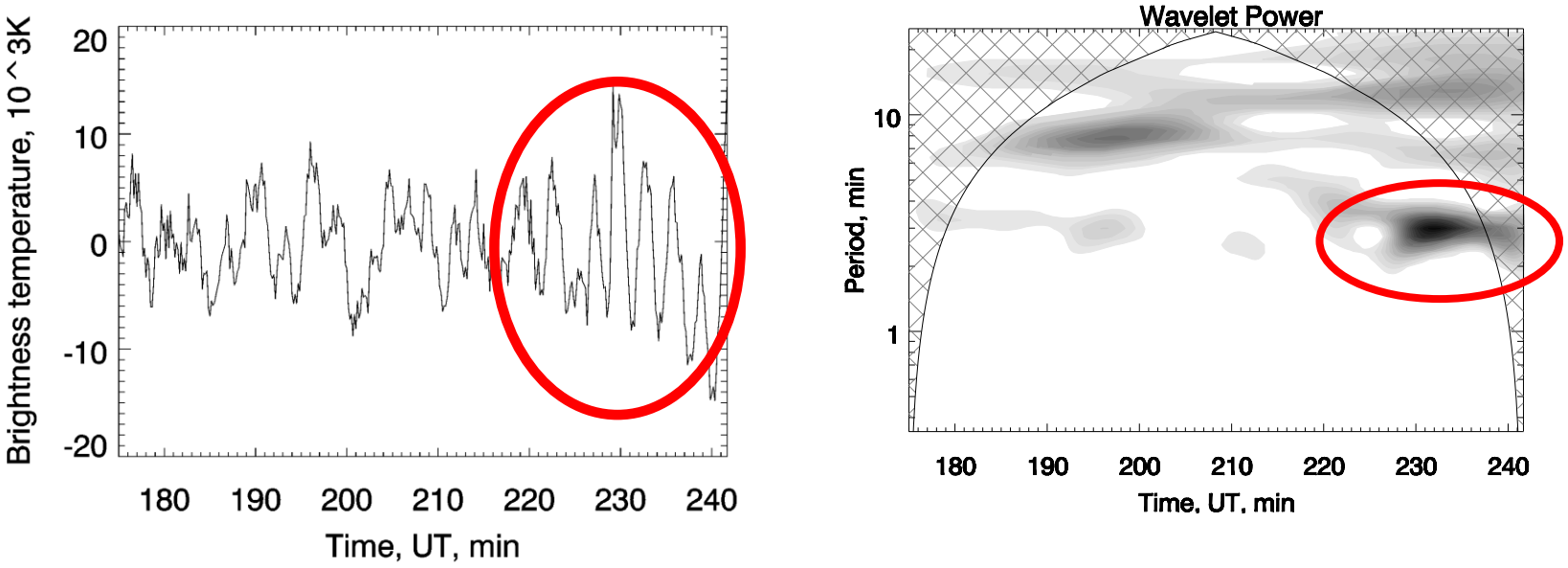
INTRODUCTION
NoRH observations

Observational data from the Nobeyama Radioheliograph (NoRH) were used to conduct detailed investigations of QPFs of microwave emission with different periods (Gelfreikh et al., *Solar Phys.*, **185**, 177, 1999; Shibasaki, *Astrophys. J.*, **550**, 1113, 2001; Gelfreikh et al., *Publ.Astron. Soc. Japan*, **58**, 29, 2006).

A number of cases of increased QPFs capacity before flares with different periods were found: 3 min (Sych et al., *Astron. Astrophys.*, **505**, 791, 2009; Abramov-Maximov et al., *Sol. Phys.*, **273**, 403, 2011), 10 min (Abramov-Maximov and Bakunina, *Phys. At. Nuclei*, **81**, 379, 2018), and 100 min (Abramov-Maximov and Bakunina, *Geomagn. Aeron.*, **59**, 822, 2019).

Pre-flare wave train of 3-min oscillations from NoRH 2-dimensional observations

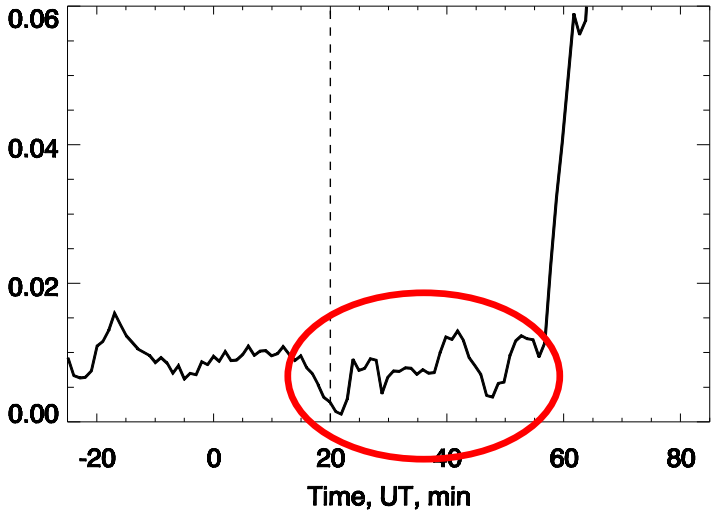
2002-Oct-07 NOAA10139

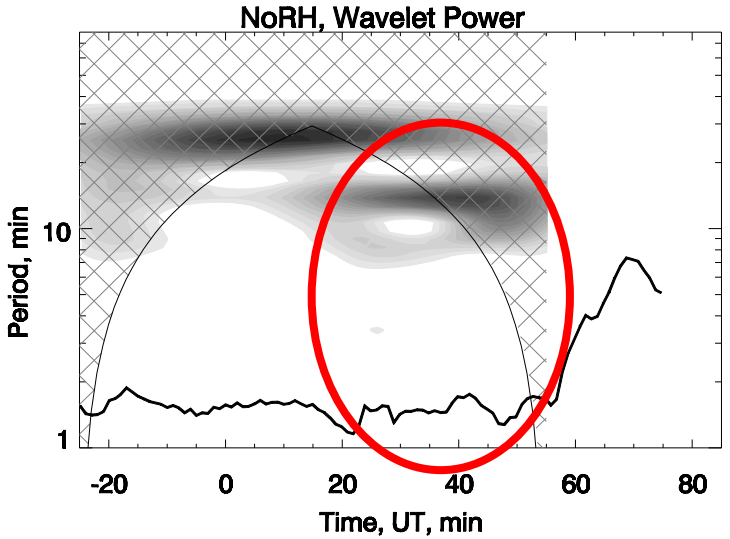


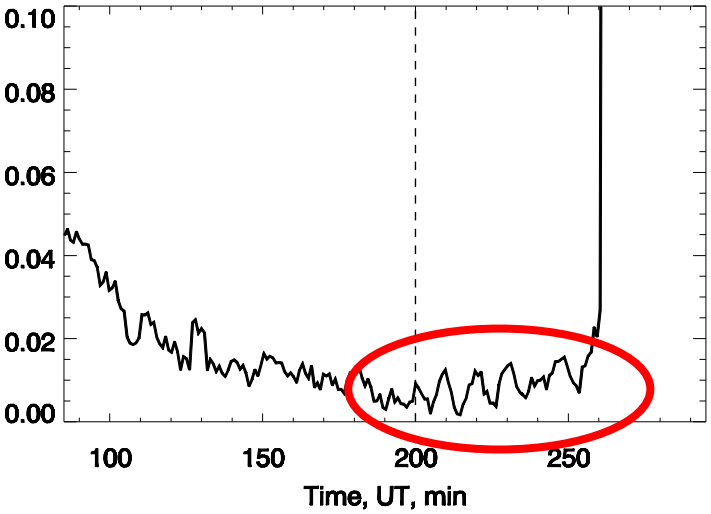
V. E. Abramov-Maximov, G. B. Gelfreikh, and K. Shibasaki, Solar Phys. **273**, 403, 2011.

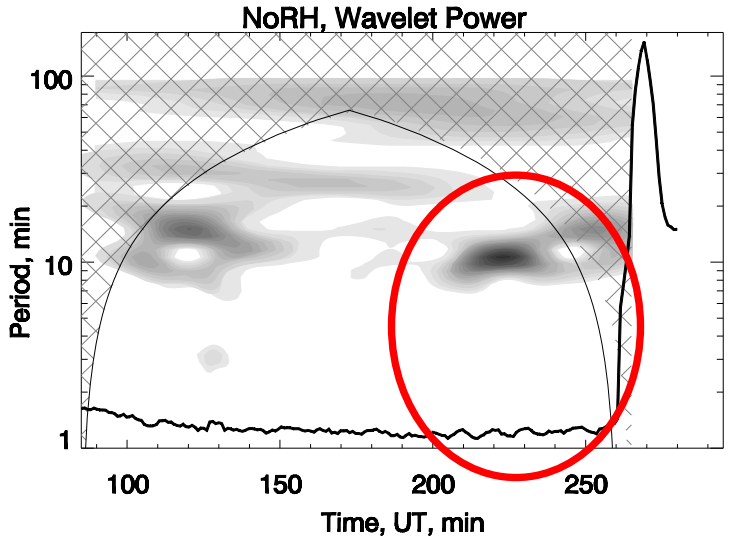
Pre-flare wavetrain of 10-min oscillations from NoRH 2-dimensional observations

17-Dec_2014, NOAA 12242





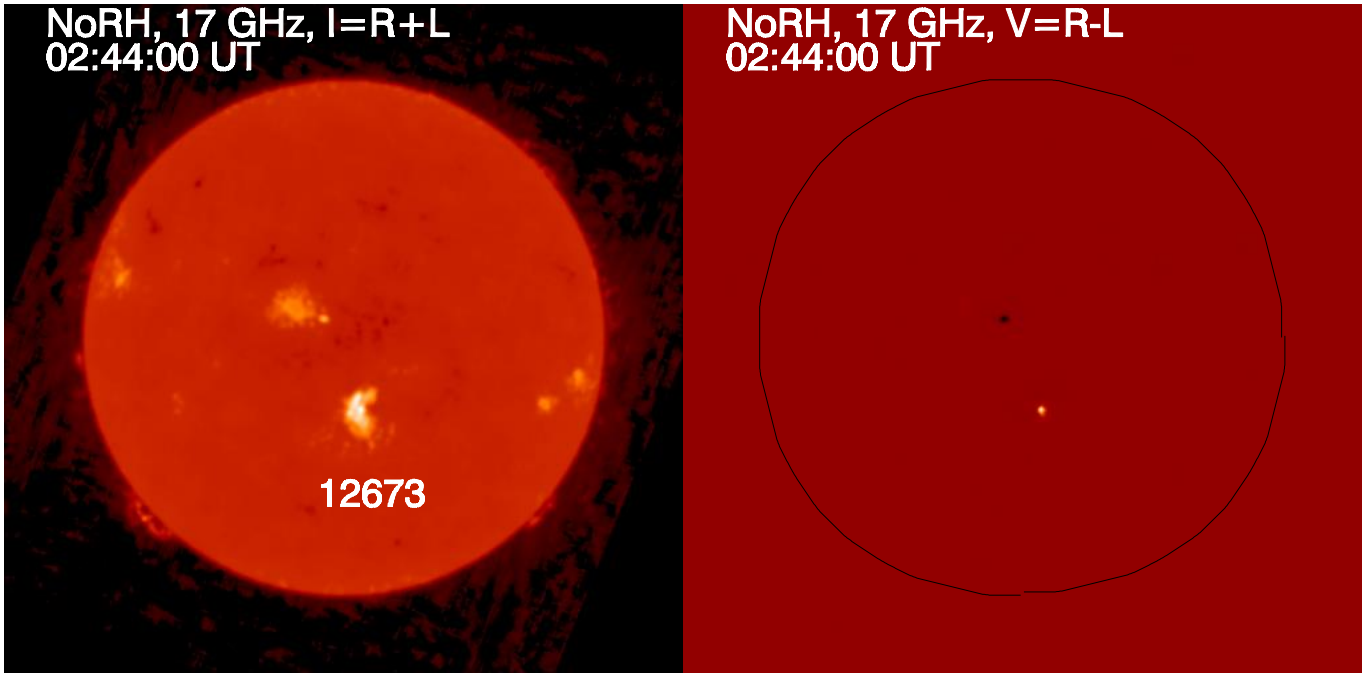




Abramov-Maximov and Bakunina, *Phys. At. Nuclei*, **81**, 379, 2018

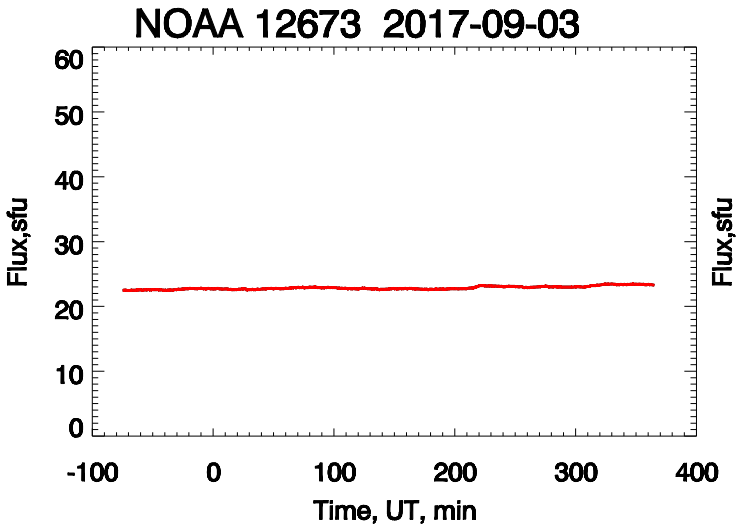
NOAA 12673 - What happened before the first M-class flare?

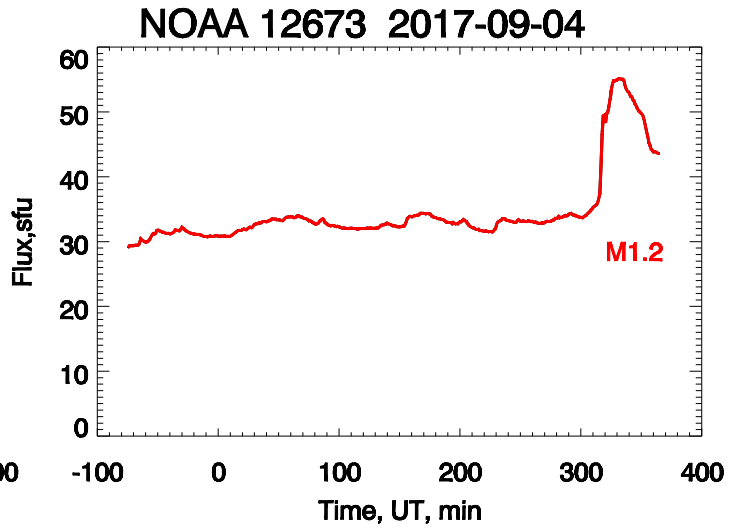
NoRH, 2017-09-04



Class	Day	Time
C1.1	03	20:50
C1.2	04	03:38
C1.8		04:11
M1.2		05:49

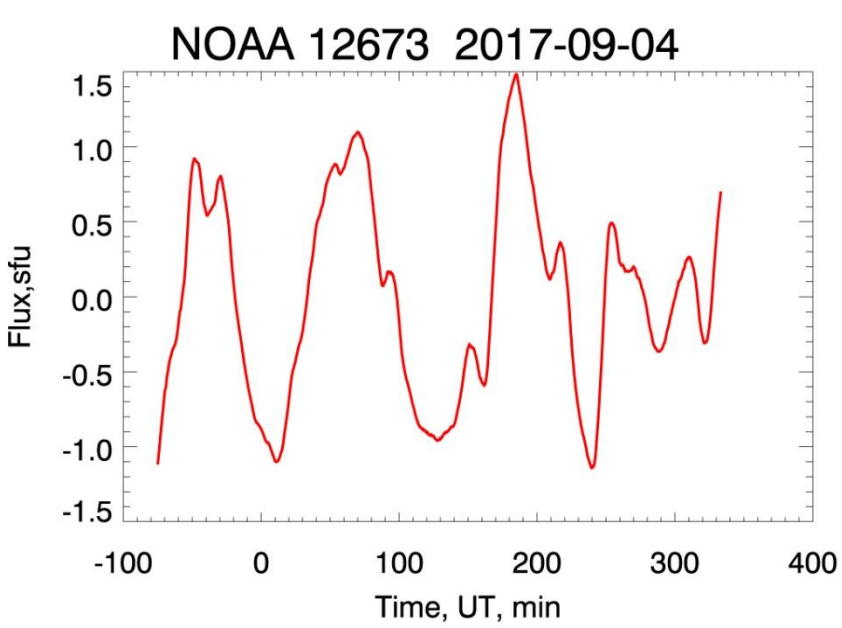
...

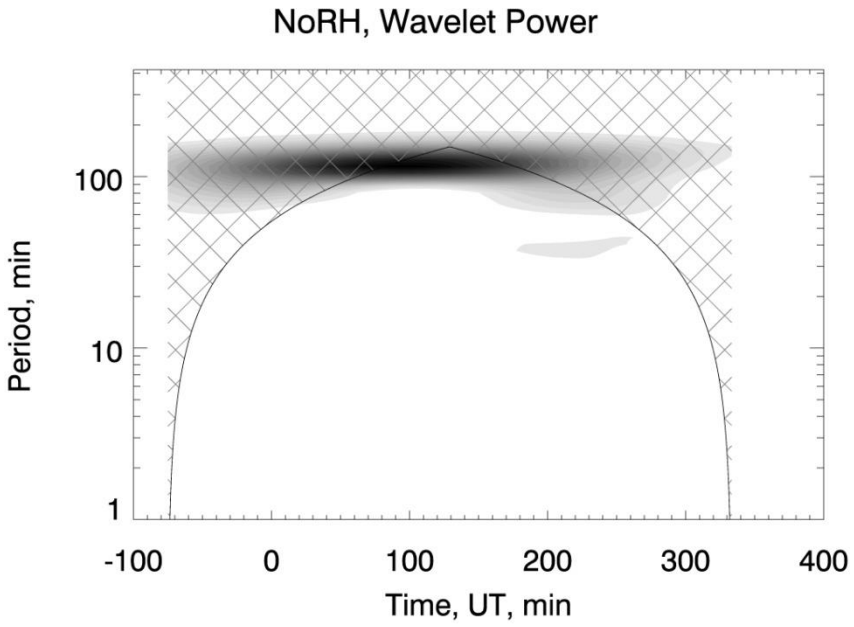




M1.2:
Begin 05:36
Max 05:49
End 06:05
(SWPC PRF 2193)

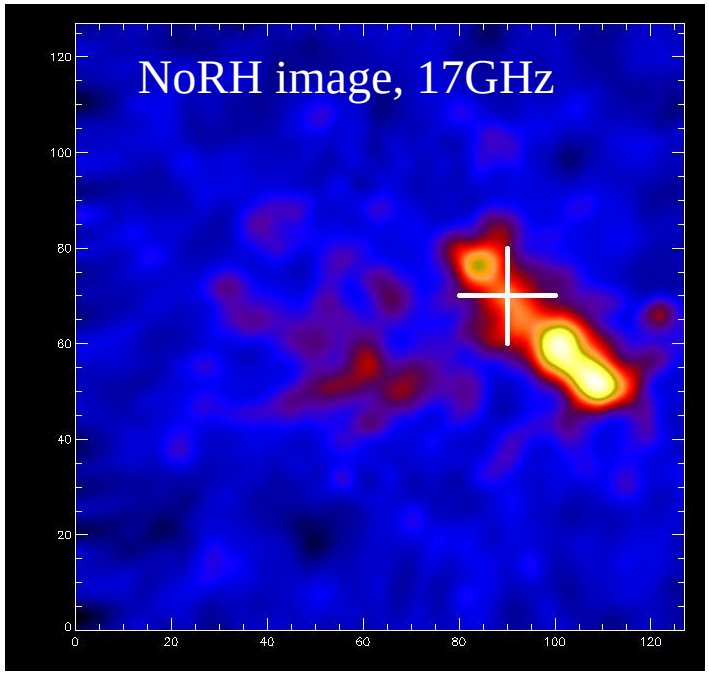
NOAA 12673 - What happened before the first M-class flare?

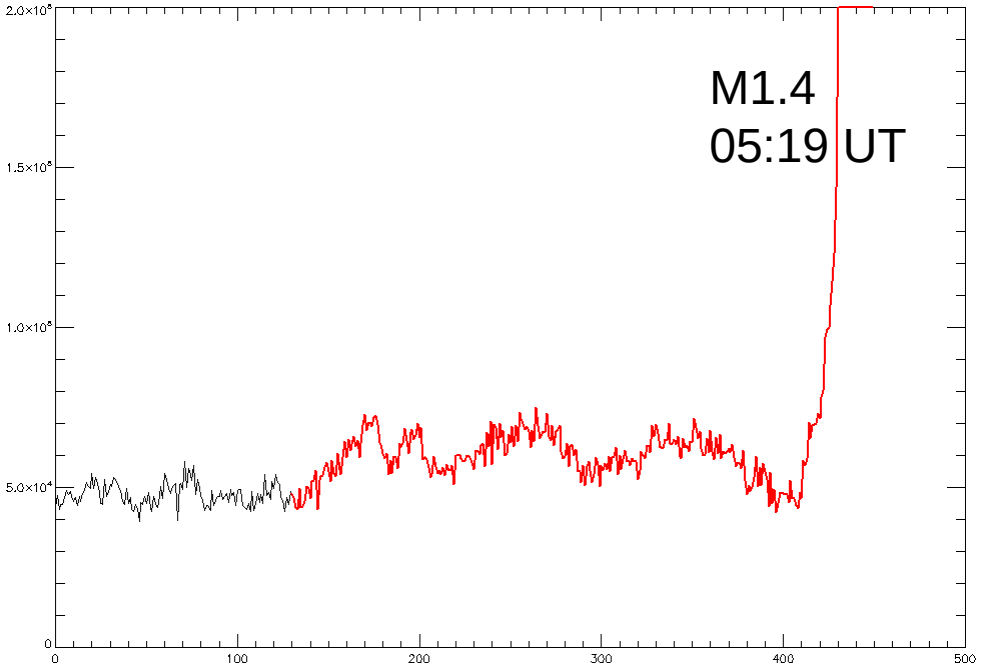




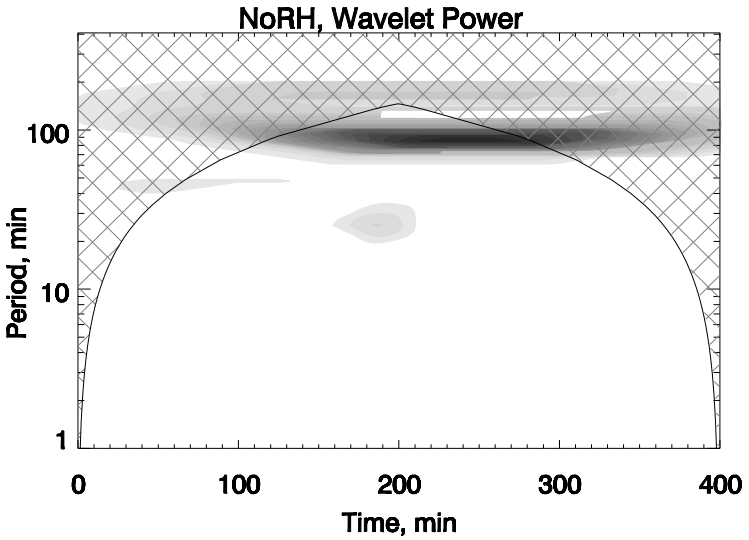
At least 7 hours before the first M-class flare,
after which a strong flare activity began in NOAA 12673, including X-class flares,
the long-term oscillations of microwave emission has appeared (increased significantly).

NOAA 11261 2011-08-02

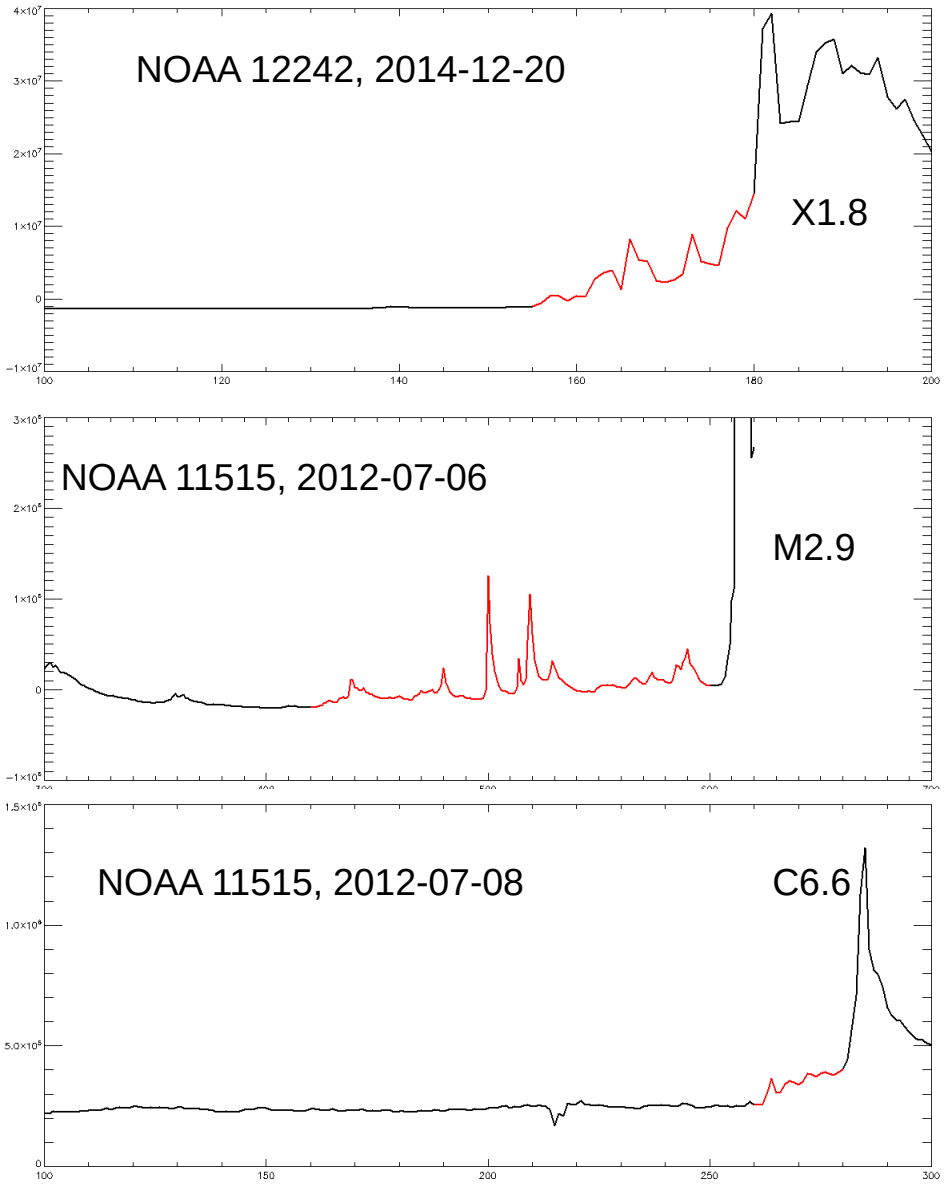




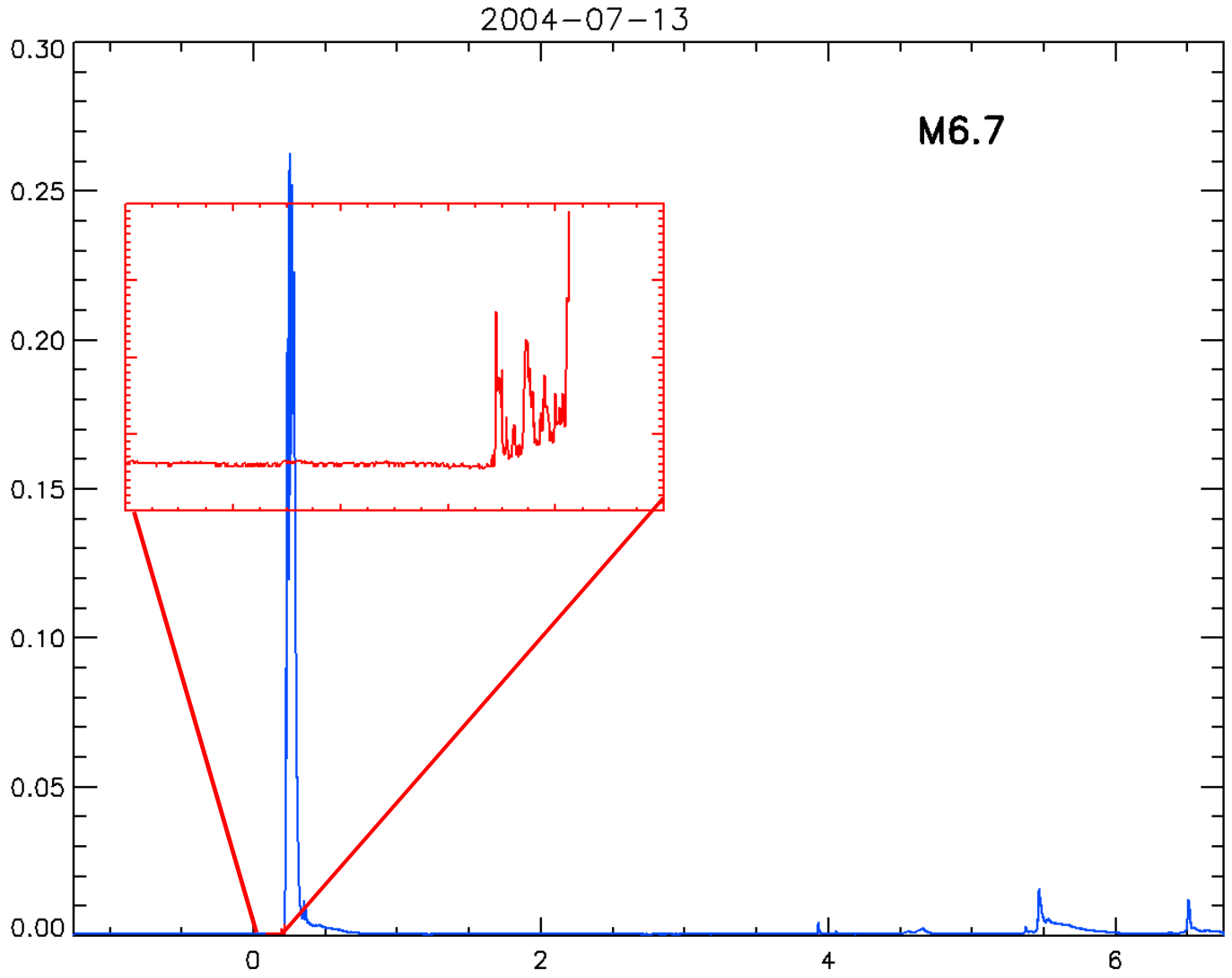
The cross marks the area
for which the time profile is shown
in the panel on the right.
Oscillations occur in the interspot area.



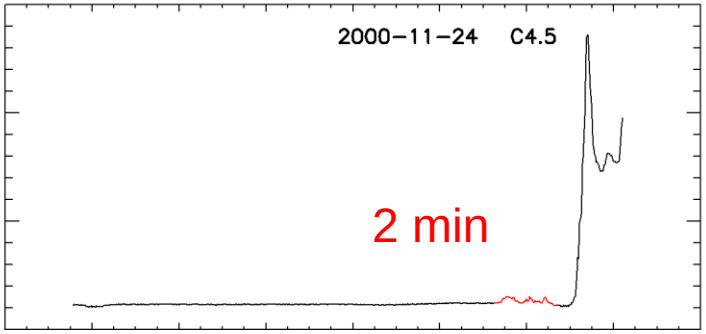
Some examples of pre-flare fluctuations of microwave emission by 2-dimensional observations on NoRH

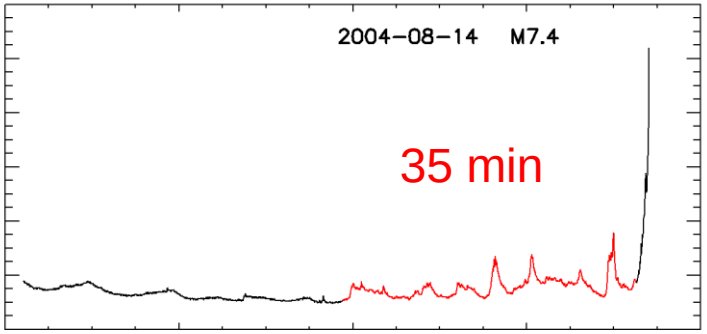


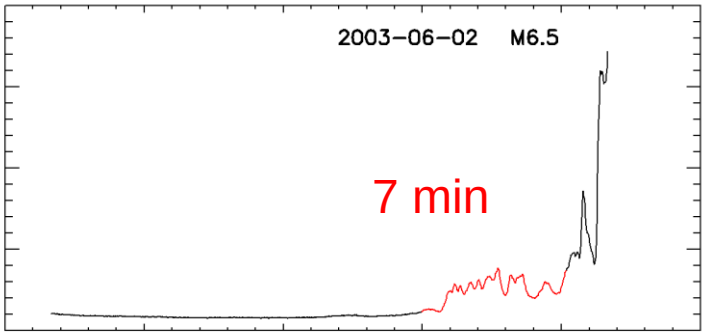
Example of pre-flare fluctuations by NoRH, Correlation Plot

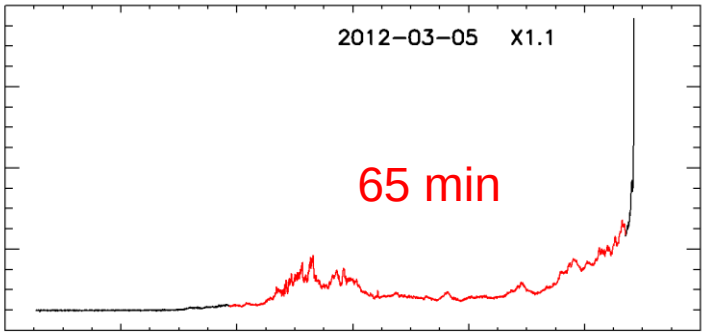


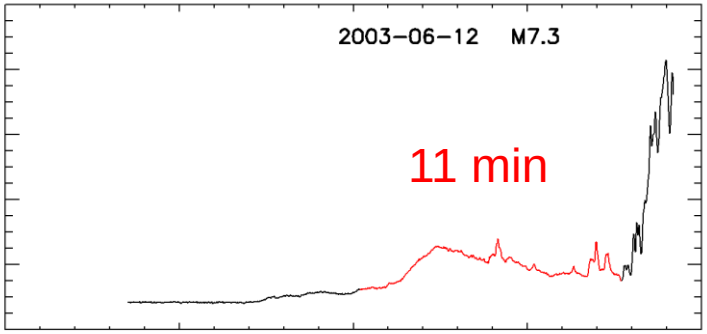
Some examples of pre-flare fluctuations of microwave emission by NoRH Correlation Plots

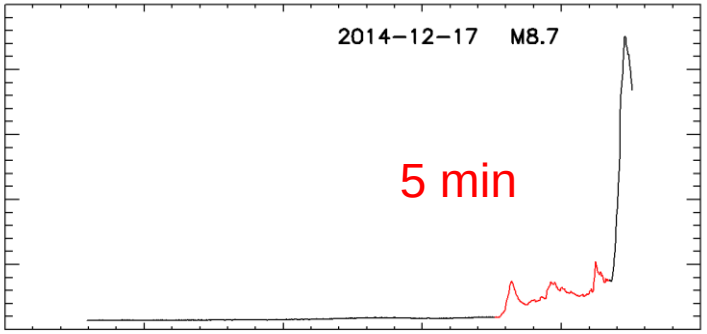










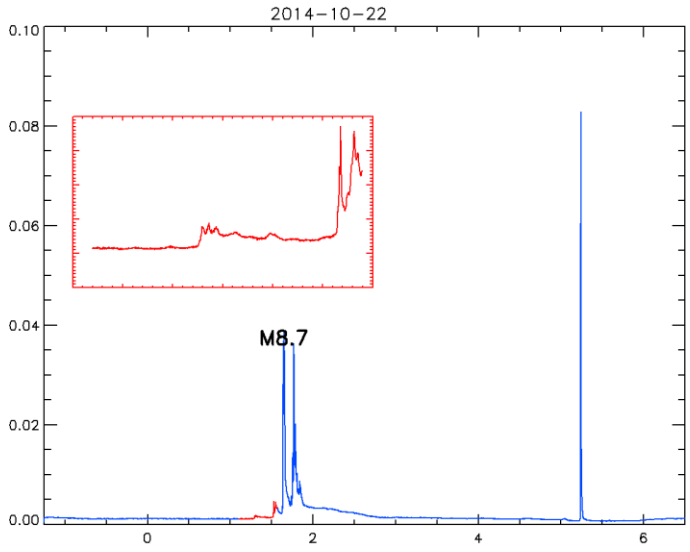


The duration of the wave trains is indicated

We have analyzed a total of 129 (45 X-class and 84 M-class) flares.

events with preflare QPFs:
total- 95 (74%), X - 32 (71%), M - 63 (75%)

events without preflare QPFs:
total- 34 (26%), X - 13 (29%), M - 21 (25%)



Conclusions :

1) According to NoRH correlation plots, preflare QPFs of microwave emission detected in 70–75% of the considered flares.
2) In various cases, different lengths of preflare wave trains (from 2–3 to 60–70 min) were revealed.
3) Various fluctuation periods (from several seconds to several minutes) are observed.
4) The length of preflare oscillation trains in the oscillation periods is 5-6 periods on average.
5) The fractions of flares with and without QPFs is to be approximately the same in class-X and class-M flares.

This effect maybe caused by an increase in the amplitude of MHD waves propagating in the active region before the onset of a solar flare (see the review by McLaughlin (*Space Sci. Rev.*, **214**, id 45, 2018) and references therein).