Spatially resolved analysis of an oscillatory flaring event

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Abstract

Aims: To perform a spatially resolved analysis of a quasi-periodic pulsation event from 8th May 1998 using data from multiple instruments, such as the Nobeyama Radioheliograph and the Yohkoh satellite[1].

Methods: We perform time series analysis using the Lomb-Scargle periodogram method to find the period of the oscillations. The pixon image reconstruction algorithm is used to generate images from the hard X-ray data from Yohkoh. Cross-correlation analysis is also used to investigate the phase relationship of the microwave emission.

Results: The locations of hard X-ray and microwave sources are consistent with the standard flaring model. The presence of an X-ray source at the loop apex indicates a "Masuda-type" event[2]. The period of oscillation is 16 s with over 99% confidence in both microwaves and hard X-ray channels.and the strong correlation of the microwave flux along the flaring loop is indicative of the presence of an MHD sausage mode.

Microwave and X-ray oscillations

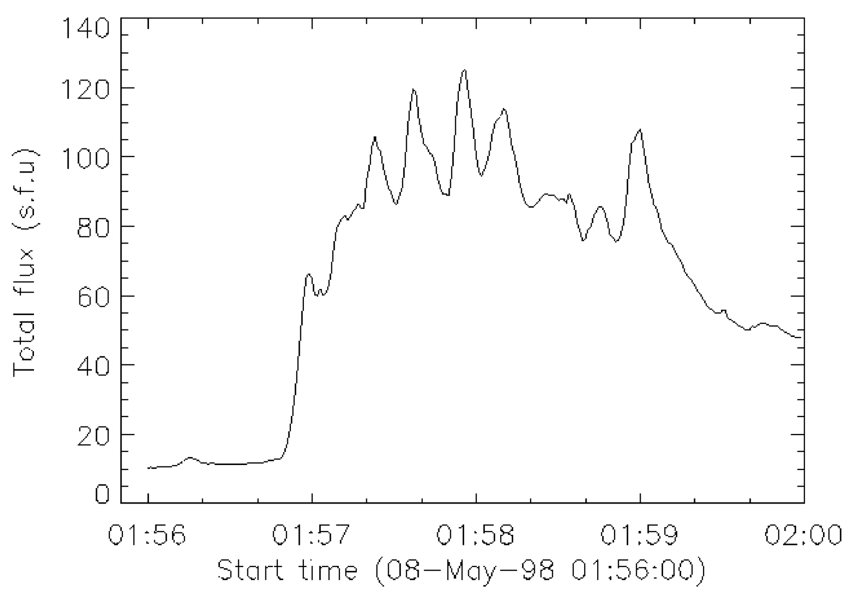

FIG. 1 – Total microwave flux from the solar flare of 8th May 1998. Oscillations in the flux are clearly visible.

The microwave flux from this event, as observed by the Nobeyama Radioheliograph in Japan, shows a very clear periodicity, with a modulation amplitude of ~ 15%.

These observations were confirmed at 17GHz by the separate Nobeyama Radiopolarimeters. Oscillations were also seen at 9GHz and 3.75 GHz.

The maximum flux was observed in the 9 GHz band, indicating that the gyrosynchotron turnover frequency was in this region.

The periodicity seen in the microwave emission is mirrored in the hard X-ray time profiles obtained from the Yohkoh satellite.

Analysis also confirms that the hard X-ray oscillations are coincident in time with the oscillations observed with the Nobeyama Radioheliograph and Radiopolarimeters, and have the same period.

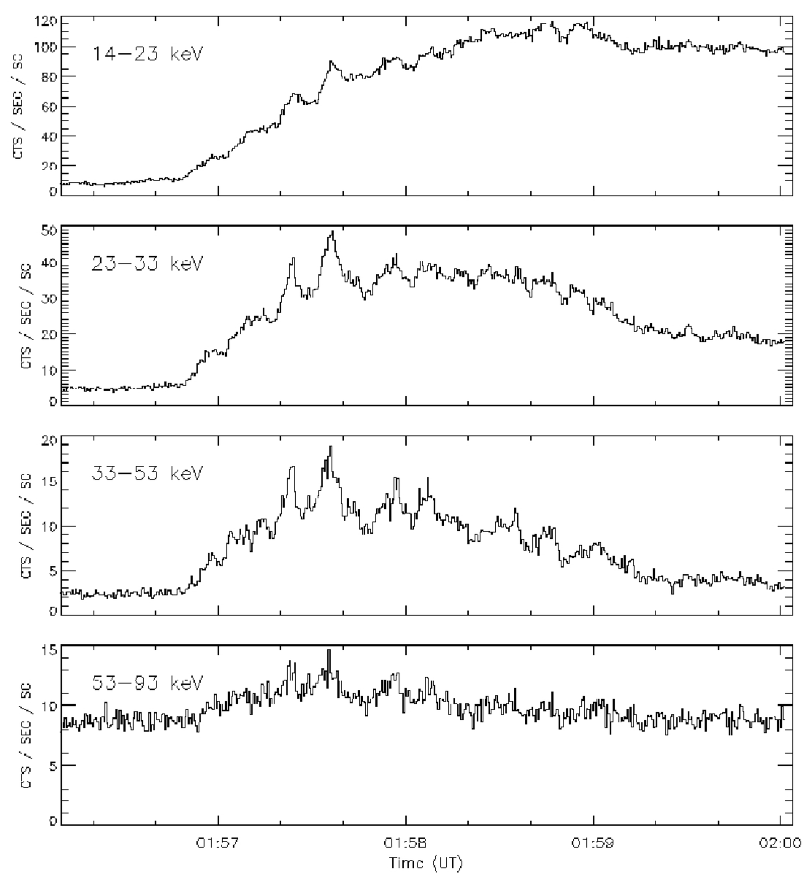

FIG. 2 – Hard X-ray flux from the flare of 8th May 1998 as observed by the Yohkoh satellite. Oscillations can be clearly seen in the L (13-23 keV), M1 (23 – 33 keV) and M2 (33 – 53 keV) channels.

Periodogram analysis of solar flux data

Scargle periodogram[3] analysis is performed on the microwave and hard X-ray signals by first subtracting a smoothed (20 s) background function from the original data.

The 17 GHz data shows a very pronounced periodicity of 16 s, well above the 99% confidence level, estimated according to Horne and Baliunas[4]. The use of windowing functions leads to the suppression of the spectral sidelobes, suggesting they are artificial. Therefore, the shorter period peaks are unlikely to be real.

The 20 s cadence time of the soft X-ray data prohibits the use of periodogram analysis in this channel.

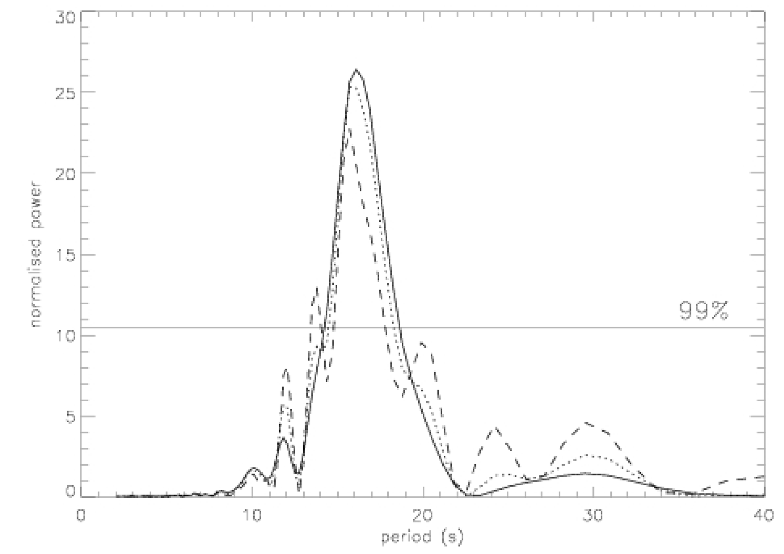

FIG. 3 – Scargle periodogram of 17GHz signal from the Nobeyama Radioheliograph. The black line shows how the Blackman-Harris window suppresses the spectral sidelobes.

Spatial structure of flare emission

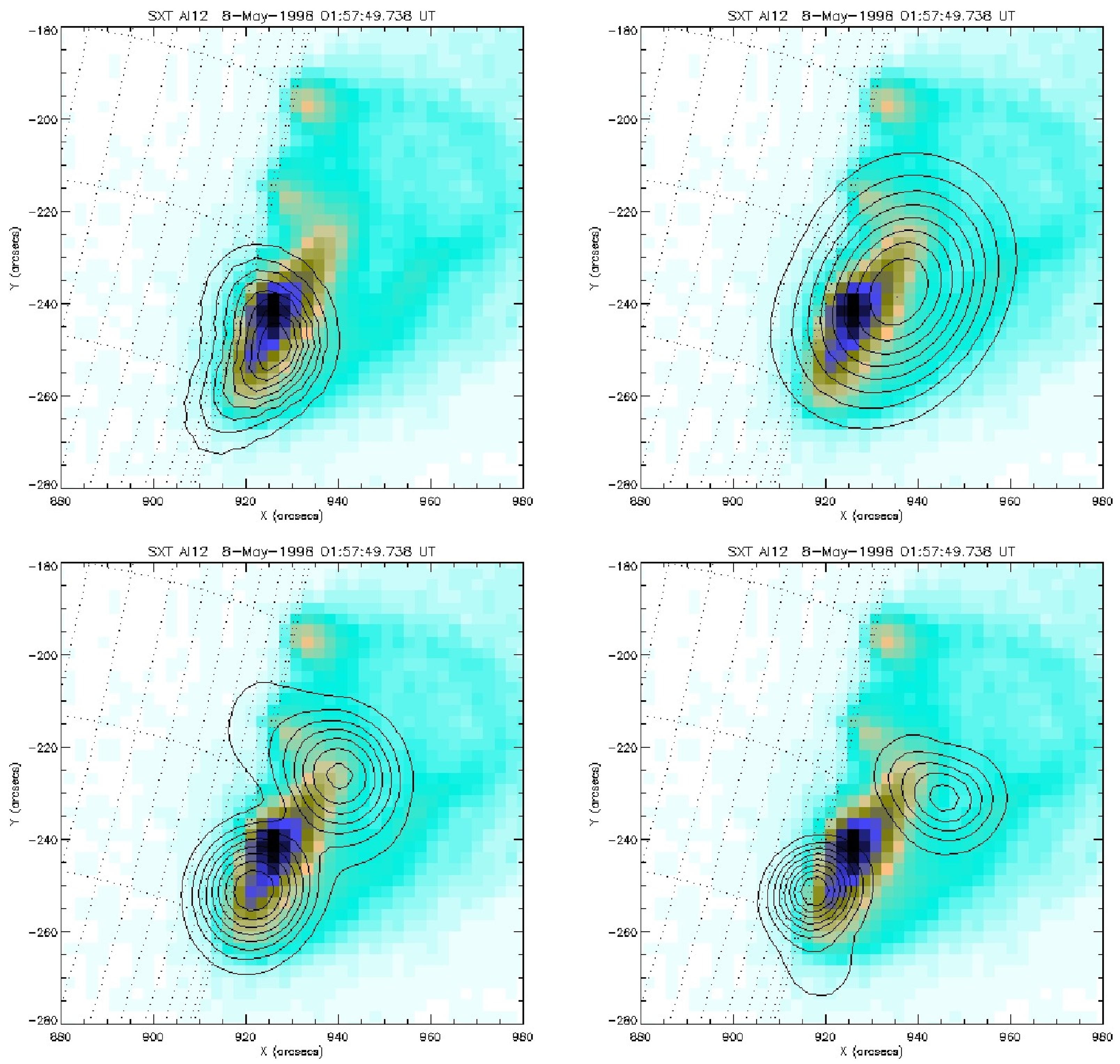

FIG. 4 – Soft X-ray images of the 8th May 1998 flare from the Yohkoh satellite, with various overlays. *Top left*: 17 GHz microwave emission; *top right*: hard x-ray emission in the L (13-23 keV) channel; *bottom left*: hard x-ray emission in the M1 (23 – 33 keV) channel; *bottom right*: hard x-ray emission in the M2 (33 – 53 keV) channel. The hard X-ray images were constructed using the pixon algorithm.

Spatial structure of the oscillations

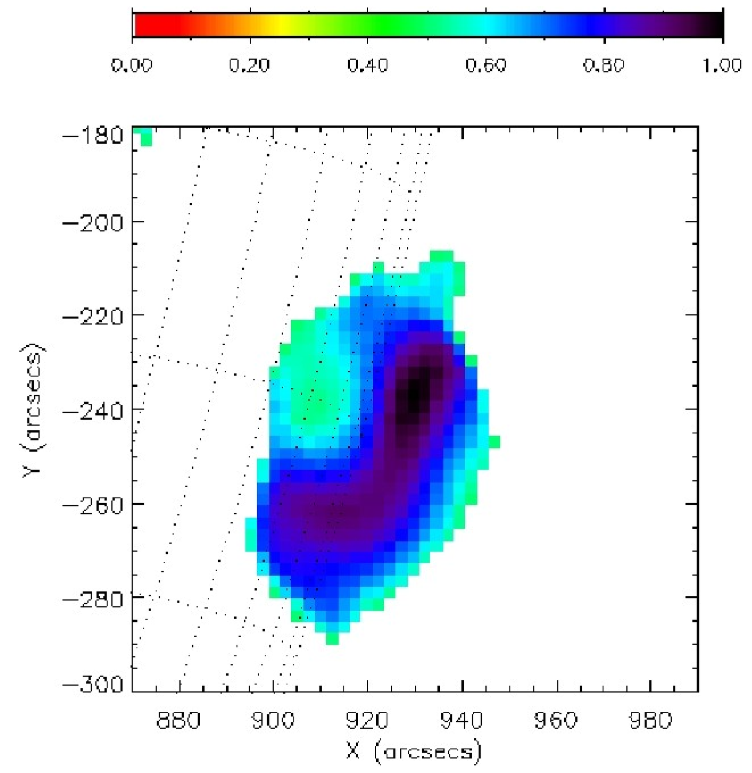

FIG. 5 – Cross-correlation power map of the microwave emission at 17 GHz. The body of the flare loop is shown to be well correlated.

Crucial for the successful identification of the MHD mode responsible for QPP is to investigate the distribution of the emission over different parts of the flare loop[5]. Here we use a cross-correlation analysis to investigate the phase relationship throughout the loop.

The data point corresponding to maximum emission intensity is chosen as a reference point. The signal of this point is then cross-correlated with every other point to produce the maps shown in Fig. 5 and Fig. 6.

Fig. 5 shows a strong correlation coefficient (greater than 0.7) throughout the main emitting region for microwaves at 17 GHz.

Of equal interest to the correlation coefficient is the time lag corresponding to the highest correlation. Fig. 6 is a phase shift map of the microwave emission. It illustrates that the bulk of the microwave emission is not only strongly correlated, but is strongly in phase as well.

This consistent phase relationship over the body of the emission is indicative of the presence of an MHD sausage mode, rather than the ballooning mode, as originally suggested for this event by Stepanov et al[6].

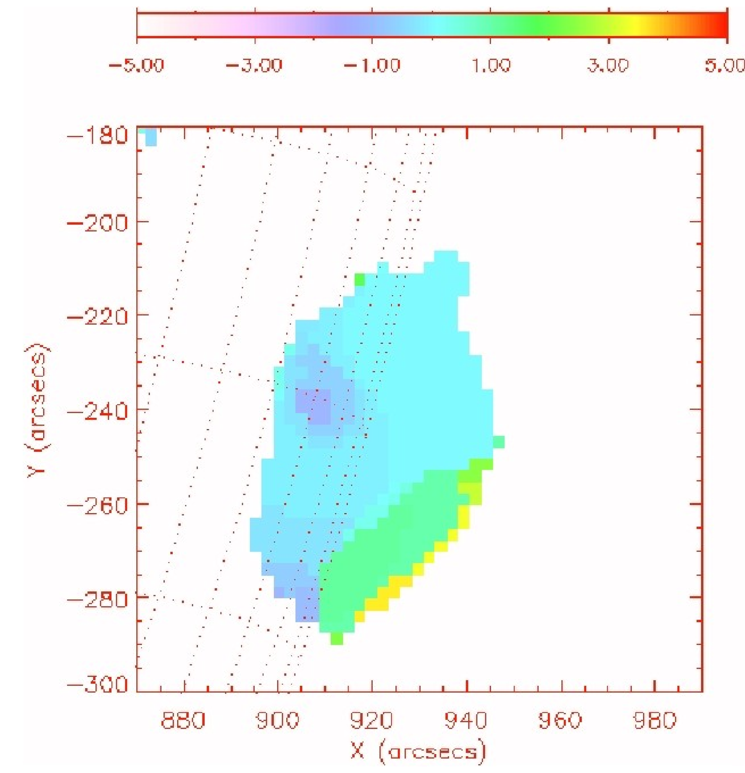

FIG. 6 – Cross-correlation time lag map of the microwave emission at 17 GHz. The loop body is shown to be in phase.

Conclusions

•Spatial analysis of the event shows the presence of a southern footpoint and a loop top source in hard X-rays at higher energies. This is consistent with a "Masuda-type" event.

•Quasi-Periodic Pulsations (QPP) of microwave and hard X-ray emission generated by the analysed flare are found to be caused by an oscillation of period 16 s, above the 99% confidence level.

•Strong correlation is observed between microwave and X-ray time profiles.

•The use of windowing functions indicate that peaks in the Fourier spectrum other than the primary 16s peak are spurious.

•All parts of the flaring loop are found to oscillate in phase.

•Given estimates of the loop length (70 ± 30 Mm), the oscillation is consistent with the MHD sausage mode.

References

1. A. R. Inglis et al., 2007, in preparation
2. S. Masuda et al., 1994, Nature, 371, 495
3. J. D. Scargle, 1982, ApJ, 263, 835
4. J. H. Horne & S. L. Baliunas, 1986, ApJ, 302, 757

1. V. F. Melnikov et al., 2005, A&A, 439, 727
2. A. V. Stepanov et al., 2004, Astro. Lett., 30, 480

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