Peripheral plasma measurement in Heliotron J using fast cameras

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Abstract

In this paper the measurement of peripheral plasma behaviour using Langmuir probes, magnetic probes, and fast cameras were reported. Filamentary structure is known as one of typical peripheral plasma behaviour. Topics are mainly this filament behaviour as turbulence and/or fluctuation behaviour in peripheral region during ECH(70GHz, 450kW), NBI(30keV,700kW), and the supersonic molecular beam injector (SMBI). ECH is used to get the first discharge in Heliotron J plasma. In general peripheral plasma behaviour was easily observed during additional heating (or during high power heating). However, in Heliotron J device it was found that turbulence was suppressed under some conditions during NBI. Also, SMBI is used to increase the electron density and to reduce the total recycling; as a result improved confinement mode would be expected. In ECH+SMBI or ECH+NBI+SMBI experiment even the electron density raised over the threshold density of H-mode, the transition did not occur frequently. Filamentary structure behaviour seems to be “dithering to transit from L-mode to H-mode” before and after SMBI. In helical system the radiation collapse occurs almost always at high density H-mode plasmas, and it is not favourable phenomenon. Therefore, it is very important to understand peripheral plasma behaviour and fast cameras have recently shed much new light on the complex nature of these phenomena.

1. Introduction

Fast cameras have been installed in Heliotron J [1,2] since several years [3-5]. Recent progress of fast cameras enables us to get information on the peripheral plasma behavior with very high speed up to ~1000,000 frames per second (FPS). In particular, using a conventional gas puff, supersonic molecular beam injection (SMBI) [5], and solid target such as limiter [3] are very useful to visualize complex peripheral plasma behavior. Also, a combination of conventional peripheral plasma measurement (Langmuir probe, magnetic probe, etc) and fast cameras gives us the powerful method to study plasma turbulence [4].

In the first SMBI experiment it was found that after SMBI a kind of improved confinement mode “Phase I” [6-8] appeared instead of H-mode. Camera images show filamentary structure of peripheral plasma rotated with L-mode direction (if the motion was due to ErxB drift, Er would be positive.), and sometimes the rotation changed to H-mode direction (also if this was due to ErxB drift, Er would be negative). As if the filaments dither to rotate with L-mode direction, and this “dithering” was one of the feature of “Phase I” in Heliotron J. In the first SMBI experiment, low frequency MHD activity occurred after SMBI and the energy confinement degraded. It was supposed by too much gas quantity of SMBI. However, some shots maintained “Phase I” and they did not reach H-mode. The latter case the electron density rose more than the transition threshold.

In Heliotron devices the rise of the electron density after H-mode is uncontrollable, and usually plasma reach radiation collapse with short time after the transition.

On the other hand “Phase I” sometimes did not reach H-mode, and the energy confinement of “Phase I” is not better than that of H-mode. However, it did not reach radiation collapse. Therefore, “Phase I” is prominent improved mode to be able to control the density.

In recent experiment the gas quantity of SMBI was adjusted carefully and more improved confinement energy of Heliotron J plasma was realized. In this paper peripheral plasma behavior measurement using mainly the fast camera during this SMBI experiment was reported.

2. Experimental Setup

Heliotron J is a medium sized helical-axis heliotron device (averaged R/a=1.2m/0.17m, B=1.5T) with l=1, m=4 helical coil configuration. Figure 1 shows a top view of Heliotron J, main diagnostics used in this paper and the camera location.

In general the initial plasma is produced by ECH (70GHz, 0.45MW, non-focusing Gaussian beam) launched from a top port. Two NB systems (BL-1, 2; 30keV, 0.7WM) are installed with tangential port, and they faced each other. Selecting one of the two beam-lines or changing the direction of the confinement field, Co- or CTR-injection can be performed.

One SMBI and four conventional gas puff systems with piezoelectric valves are installed at the outer side and inner side ports, respectively.

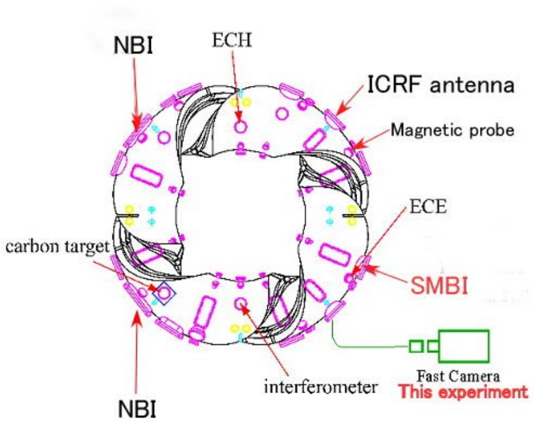

Fig.1 Top view of Heliotron J
The fast camera can view the ICRF antenna and SMBI with a coherent fiber bundle.

3. Results and discussion

The waveforms with or without SMBI are shown in Fig.2 and 3, respectively. After SMBI the diamagnetic signal rose gradually with a few ms delay, and ~13 ms later the diamagnetic signal began to decrease. From ECE and AXUV signals (not shown in the figure) it was inferred that the electron temperature decreased due to SMBI [9, 10] and the electron density increased. It seemed that these effects cancelled out each other, and the diamagnetic signal did not increased just after SMBI. Afterwards the diamagnetic signal increased gradually due to NBI heating. However, more precise profile information is needed to conclude this scenario.

The important thing is that after SMBI the electron density became larger than the threshold of the L-H transition, however, plasma did not reach H-mode. Therefore, plasma terminated without the radiation collapse. This feature is called ‘Phase I’ in Ref [5].

The fast camera images with 40,000 FPS show that filamentary structure was seen near the ICRF antenna, and it was brighter when filament hit the antenna. Fig.4 shows the fast camera image during SMBI. Near ICRF antenna the motion of filamentary structure rotate with anticlockwise firstly. However, after ~190ms sometimes rotation direction changed to clockwise. Therefore, it was recognized that plasma was ‘dithering phase’ after ~190ms. To visualize this motion clearly two-dimensional phase images of 8.75kHz frequency component were shown in Fig. 5.

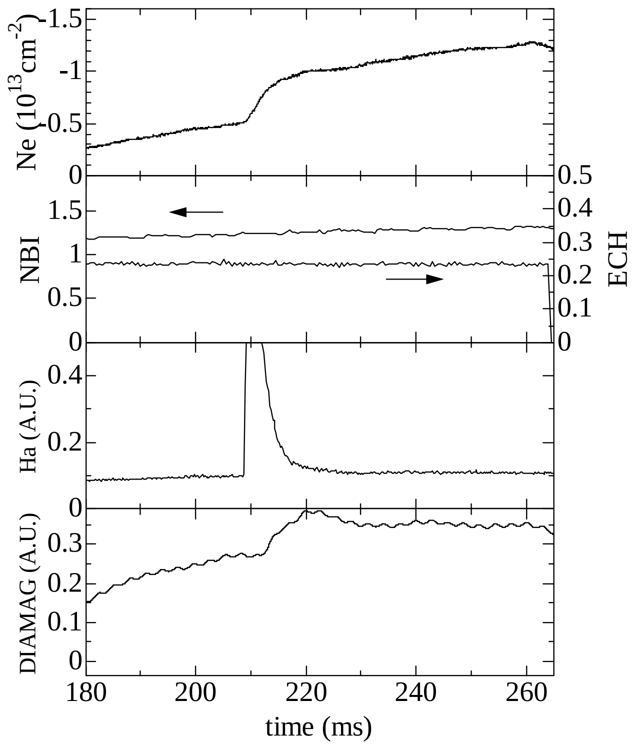

Fig.2 Typical waveform of Heliotron J plasma with SMBI (#32816)

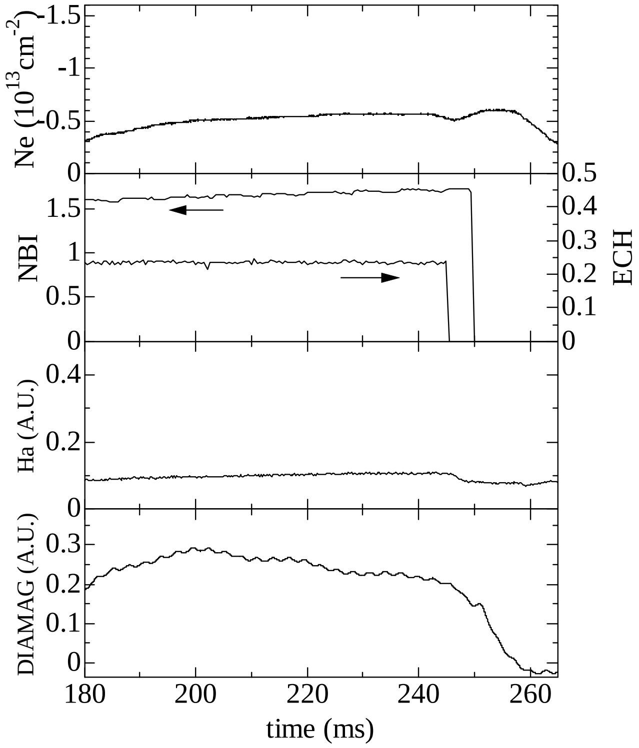

Fig.3 Typical waveform of Heliotron J plasma without SMBI (#32783)

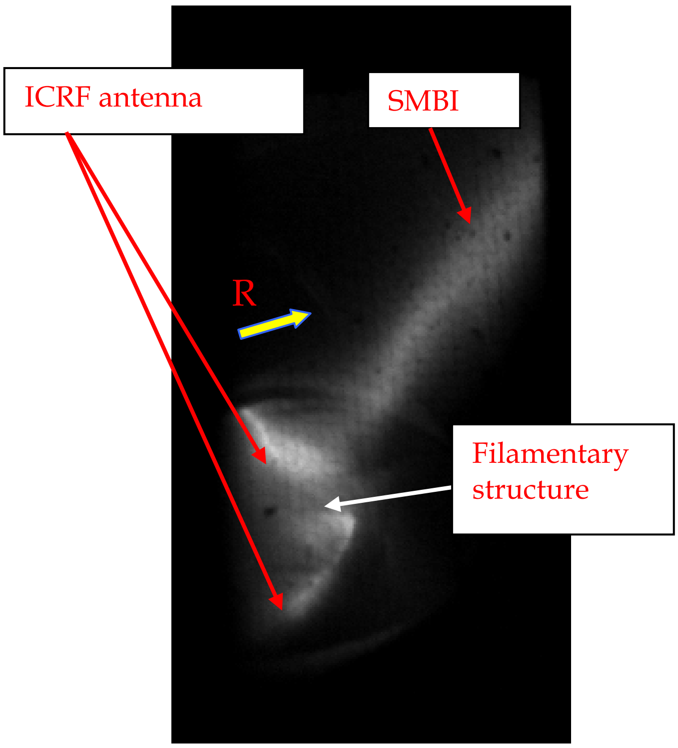

Fig.4 Fast camera image during SMBI

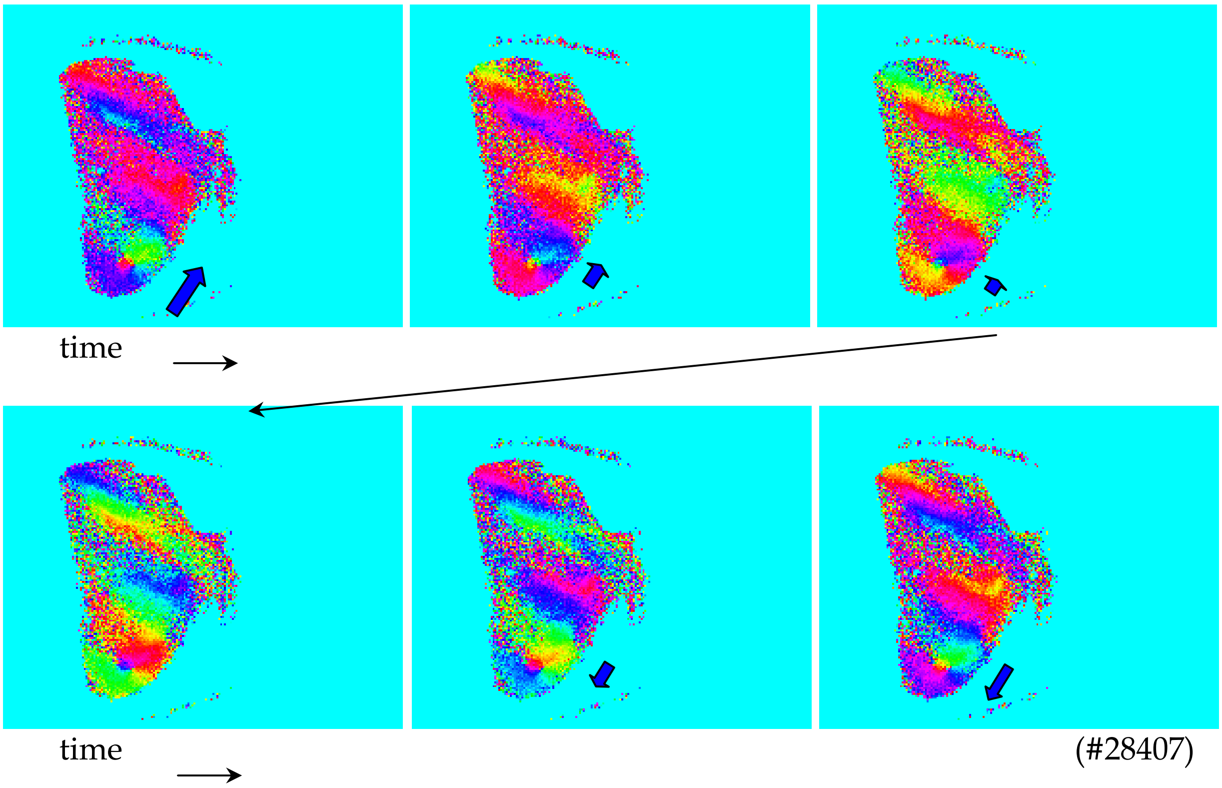

Fig.5 Two-dimensional phase images during "dithering phase"
A part of images near the ICRF antenna are shown.

The way to create these images is that first the frequency peak in the power spectra from FFT during suitable period for one pixel data in ROI (region of interest) is selected, and second the phases of the same frequency for all pixels are colored by color chart. Therefore, this phase images show the wavelength of the turbulence at the selected frequency and its motion. If there was no frequency peak in the spectra obtained by pixel data in ROI, typical frequency of the turbulence in Heliotron J plasma could be selected.

This time typical frequency of 8.75kHz in the frequency range of the peripheral turbulence (5-10kHz) in Heliotron J plasma was selected.

Just after SMBI the whole plasma began brighter and the whole picture was the same color in two-dimensional phase image, but afterwards the turbulent motion was recognized. The apparent filamentary structure motion was recognized "dithering phase", and that meant plasma was "Phase I". Without SMBI shot the "dithering phase" was confirmed after ~190ms, and it was believed that plasma was "Phase I"

The SMBI effect using the camera images is under investigation (see Appendix).

This SMBI experiment reproduced the former SMBI experiment very well, and it was not found the difference of the filamentary structure motion between the camera images before and after SMBI.

Figure 6 shows the magnetic probe signal for MHD activity. The time slices of the spectrum of this signal are shown in Fig. 7. The MHD activity in low frequency range of 10-20kHz grew from ~190ms and after 210ms (time of SMBI) this activity was decreased temporary. Afterwards (~220ms) this activity was growing again. It seemed that the effect of SMBI reduced this activity. Another frequency peaks in high frequency range were found and those were thought as GAE mode (global Alfven eigen-mode). However, those GAE mode existed with no relation to SMBI, therefore GAE mode in this experiment did not affect the characteristics of the energy confinement.

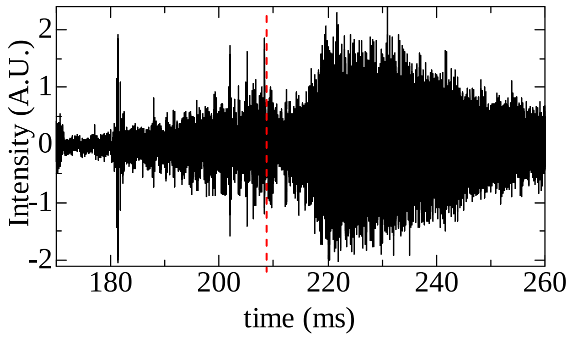

Fig.6 Magnetic probe signal (raw data) Red line shows SMBI time. MHD activity was decreased due to SMBI.

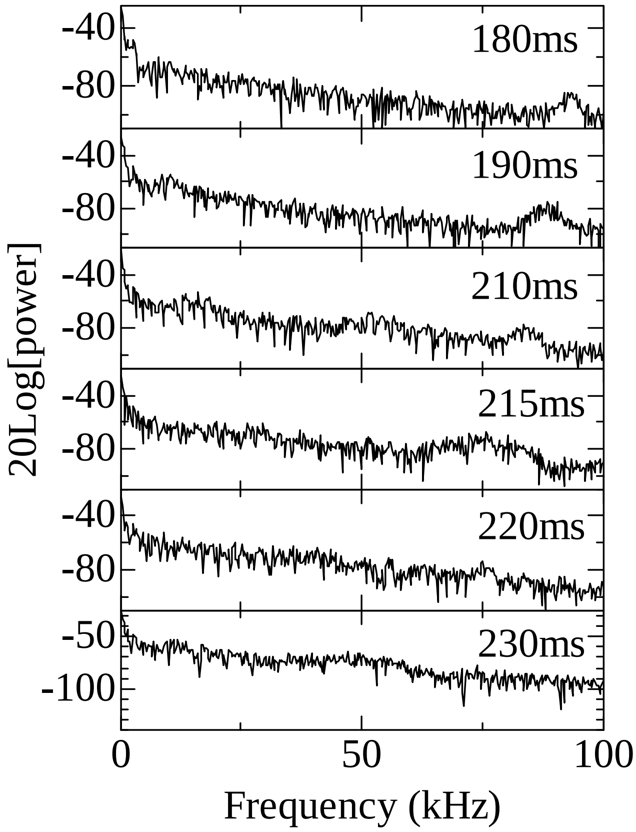

Fig.7 Spectra of magnetic probe signal
SMBI starts at 209ms and reduction of low frequency activity at 215ms was recognized.

Only difference between with or without SMBI was the former low frequency MHD activity. Thus, it possibly relate to the energy confinement of Heliotron J plasmas.

Unfortunately in this experimental series plasma was not so bright before and after SMBI, and the camera images could be taken up to 40000 FPS. Therefore, the turbulence of these frequency ranges could not be obtained.

Plasma is very bright during SMBI using the view port of this experiment, thus the view port at other toroidal section is needed for turbulence measurement included in SMBI period. Because Hα signals strongly depend on the toroidal section even during SMBI.

This is the experimental problem to be solved.

4. Conclusion

Using SMBI high stored energy shots, which could not be reached by conventional gas puff, were obtained. Also it was confirmed that these shots were a kind of improved mode “Phase I” by the fast camera images.

Further investigation is necessary to understand the physical mechanism why “Phase I” plasma did not reach H-mode even though the electron density is over the threshold of the L-H transition. For this purpose the experiments are in progress in Heliotron J.

Acknowledgements

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Appendix Another camera image analysis

ECH+NBI+SMBI plasma is rather brighter than that of ECH+SMBI plasma. Fig.a1 shows the raw camera image with 180,000 FPS. Black to white image is not good for seeing image, therefore, blue and red color are used as black and white, respectively.

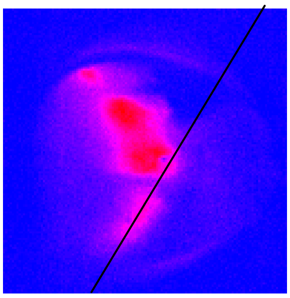

Fig.a1 Raw camera image
(blue and red color are used instead of black and white)

The camera has no filters and this image shows visible light emission. In the central region of the image two ICRF antennas were seen. Plasma is optically thin, therefore, any images are the line integral along the field of view. However, according to our experience, strong visible emission arose near the ICRF antennas due to plasma-surface interactions. In this image the streaming picture was created along the black line. Fig.a2 shows the streaming data to see the filament motion easily. This black line is almost perpendicular to the filament.
The filament motion from upper to lower in Fig.a1 (H-mode) is shown as positive slope line in Fig.a2, and that from lower to upper in Fig.a1 (L-mode) is shown as negative slope line in Fig.a2. In time elapsed streaming picture shows that before and after SMBI the rotation is “dithering” (not shown in figure).

A point of the black line is selected to get the power spectra of the light intensity. For example the power spectra of the specific pixel (shown in arrow in Fig.a1) is shown in Fig.a3.

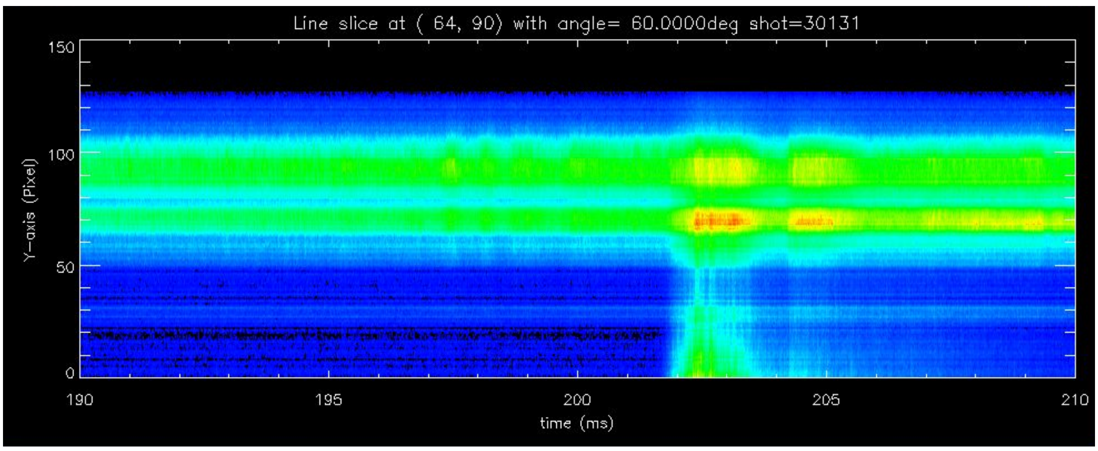

Fig.a2 Streaming picture almost perpendicular to the filament
Selected line is shown n fig as a black solid line. Horizontal axis is time and vertical axis is pixel on the image. Y=0 shows the upper point in fig.a1.

This image shows the perturbation of SMBI in the frequency domain. After SMBI the perturbation of SMBI last a few ms. This time is not so longer than that of SMBI effect to the light intensity in the image. Also Ha signal near the SMBI shows the tremendous increment of the light intensity recovery at ~10ms after SMBI.

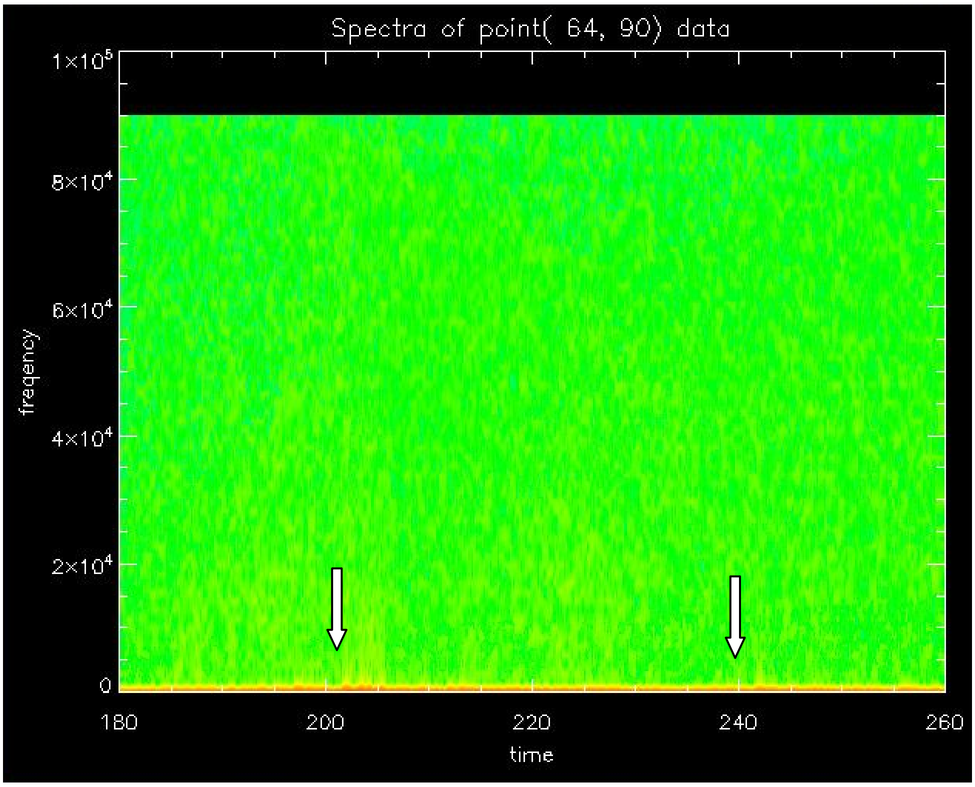

Fig.a3 Power spectra of pixel data
Horizontal axis is time, and vertical axis is frequency. The upper frequency is Nyquist frequency. The power is shown as R-G-B; red is the maximum and blue is the minimum. Two white arrows show the trigger time of SMBI.

To investigate the perturbation of SMBI in the real wave number domain, the image represented with the real space is expressed by the image. However in the experiment it is very difficult to get the real space image by one fast camera. Therefore we tried to get the perturbation of SMBI in the apparent wave number domain. Along the black line shown in Fig.a1 the FFT on space were performed. Fig.a4 show the result of FFT on dummy space. In figure the wave number k has the unit of 1/pixel. In the fugure the perturbation of SMBI last more than 20ms and the second SMBI is performed at 20ms after the first SMBI. This period is very longer than that of frequency domain.

Therefore, the perturbation of SMBI in the wave number domain would be stronger than that of frequency domain. To investigate the perturbation to the another direction, the line is selected to parallel to the filament (normal to the previous line on the specific point shown in Fig.a1). Fig.a5 shows the result of FFT on dummy space.

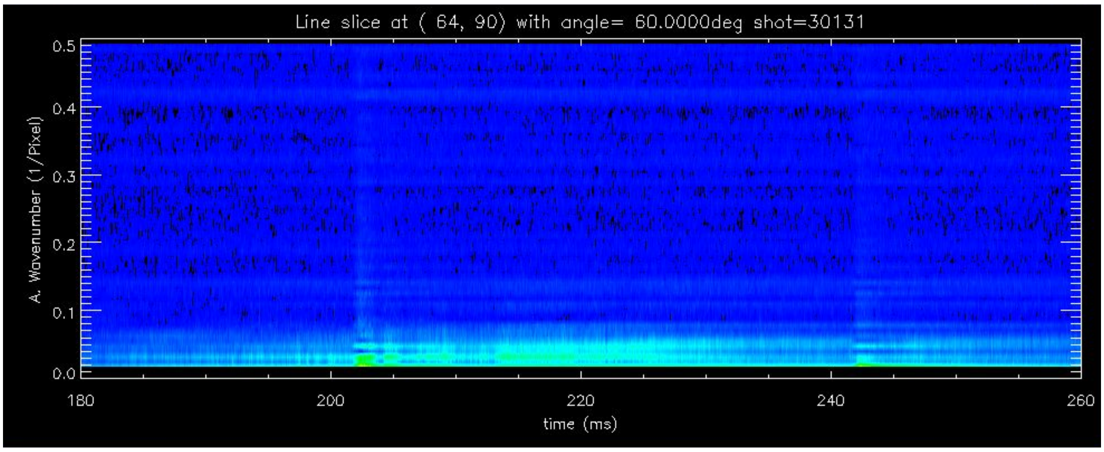

Fig.a4 Time dependent of the apparent wave number along the black line shown in Fig.
Horizontal axis is time and vertical axis is apparent wave number (1/pixel)
Low k region is omitted due to the ICRF antenna structure and fiber structure.

In this figure the apparent wave number does not affect so much. Therefore, SMBI may affect the space perpendicular to the filament (that is believed perpendicular to the magnetic field line), but may not affect the space parallel to the filament (that is believed parallel to the magnetic field line). However, SMBI provided local dense neutral gas and it is thought that the visible light emission is almost arisen by almost neutral gas excited by the electrons. Therefore, it is believed that the space profile or space variation of visible light emission suggest the

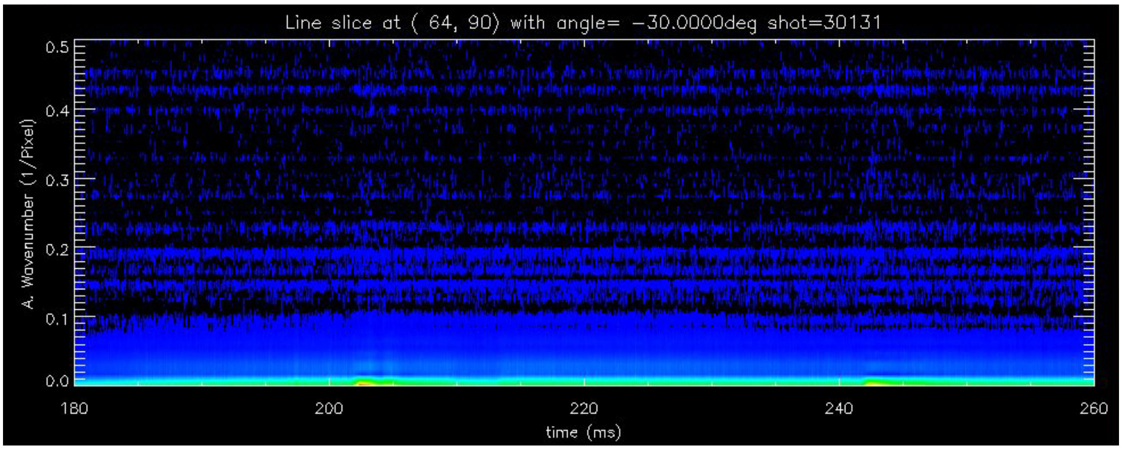

Fig.a5 Time dependent of the apparent wave number almost along the filament

difference of the electron density and/or temperature.
This is very interesting result, however, the mechanism of SMBI is under investigation.