# The eigenmode formations of ICRF waves in the central cell of GAMMA10

## GAMMA10におけるICRF波動の固有モード形成


YAMAGUCHI Yuusuke, ICHIMURA Makoto, HIGAKI Hiroyuki, KAKIMOTO Shingo, HORINOUCHI Kentarou, IDE Kouhei, INOUE Daisuke, NAKAGOME Kenichirou, NAGAI Hirohisa, FUKUYAMA Atsushi [1], and CHO Teruji

Plasma Research Center, University of Tsukuba
[1] Department of nuclear engineering, Kyoto University

e-mail: yamaguti@prc.tsukuba.ac.jp


## INTRODUCTION

The production of high density plasmas (>$10^{19}$m$^{-3}$) is required in the present tandem mirror experiments.

**PREVIOUS**

Plasma production with **fundamental ICRF** → **Density saturation**

**PRESENT**

**fundamental ICRF** + **High Harmonic Fast Wave** → **The density increases again.**

The plasma production depends on the wave excitation in the plasma. Eigenmodes are strongly excited when the boundary conditions in the axial and radial directions are satisfied. The formation of eigenmodes is investigated in both cases of HHFW and waves with near the fundamental ion-cyclotron frequency.

## ICRF SOURCES

Three ion cyclotron range of frequency(ICRF) sources (RF1,RF2, and RF3) are used in the experiments. Two types of ICRF antennas are located at near both ends of the central cell.

**Nagoya Type Ⅲ Antennas**

EAST **RF1(9.9HMz)**
WEST **RF1(10.3HMz)**

→ *Plasma production in Central & ICRH in Anchor*

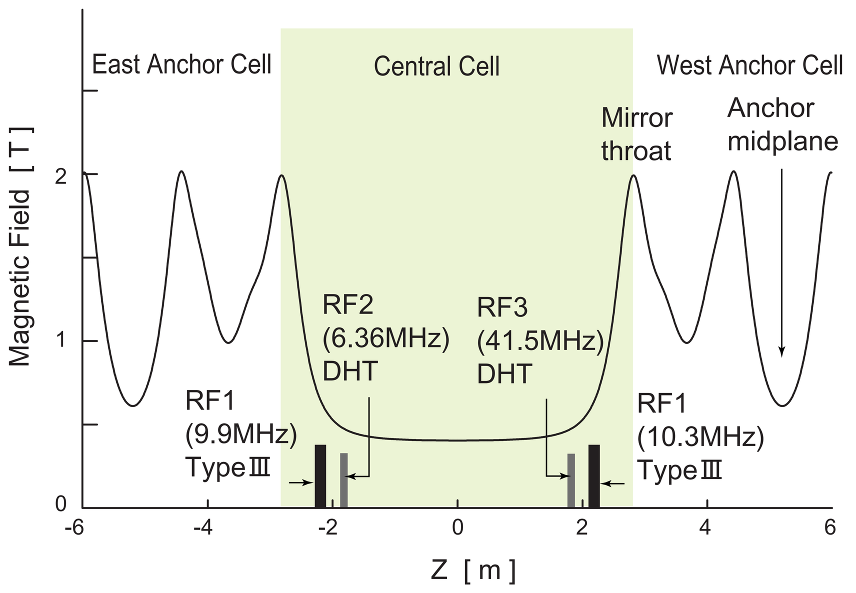
**Double Half-Turn Antennas**

EAST **RF2(6.36MHz)**

→ *ICRH in Central*

WEST **RF3(41.5MHz) HHFW**

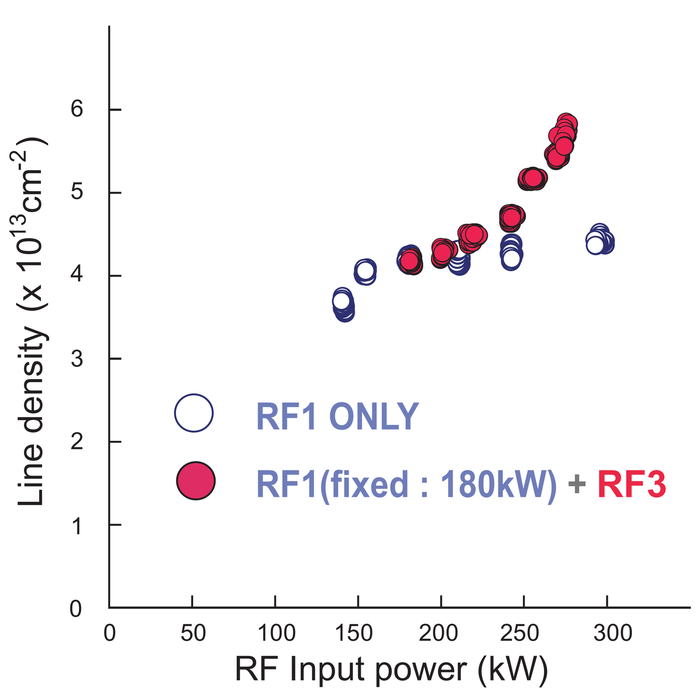
→ *High density plasma production in Central*




## The density clamping when RF1(Fundamental ICRF) is used, and the release of the density clamping by RF3(HHFW)

In the previous experiments, the density saturation had been observed with RF1.

The density saturation has been released due to the superposition of RF3 to the RF1 produced plasma.




## 2-D calculation for the wave propagation in inhomogeneous and axisymmetric plasmas

(With Prof. A.FUKUYAMA in Kyoto Univ)

**The formation of eigenmodes in ICRF waves is investigated in the GAMMA10 central cell by using the two-dimensional wave calculation code.**

- The Maxwell equation for the vector and scalar potential is solved by FEM.
- The dielectric tensor is cold plasma approximation including the collision.
- The wave fields are calculated on the bounded, inhomogeneous, and axisymmetric plasmas in the mirror magnetic fields.

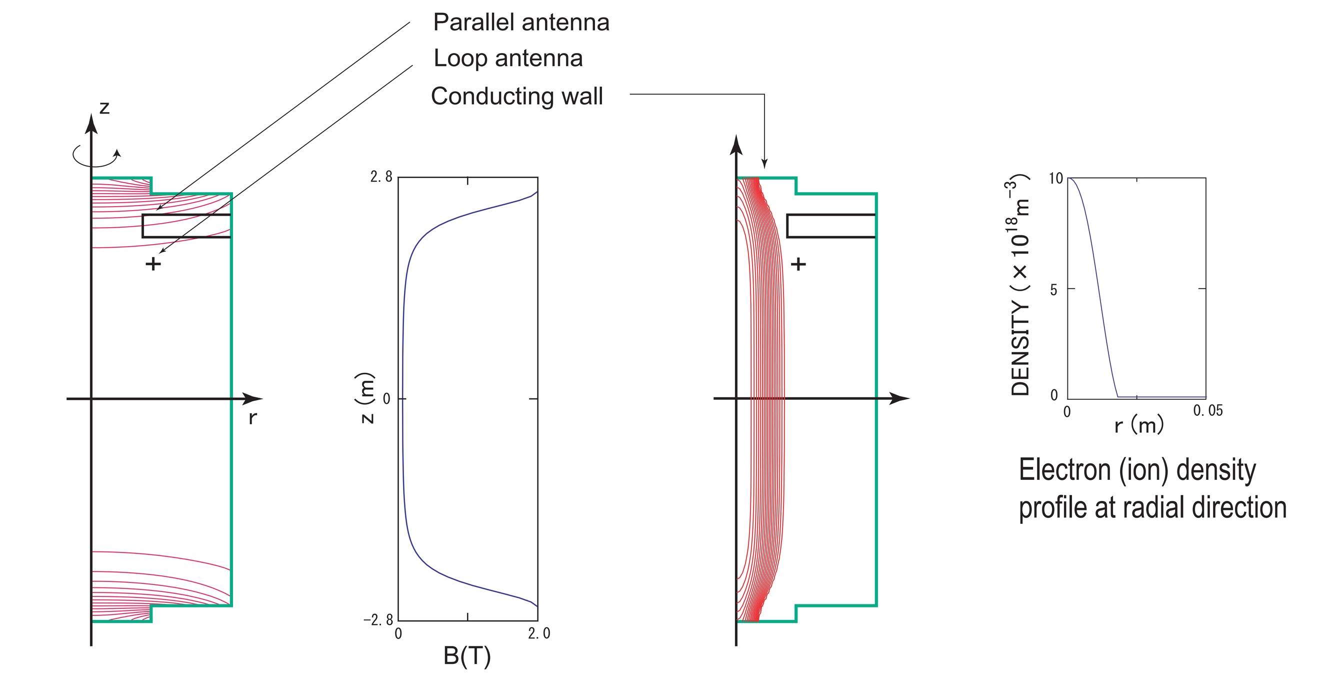
Maxwell equation for the potential (coulomb gauge : $\nabla \cdot A = 0$)

$$-\nabla^2 A - \frac{\omega^2}{c^2}\overleftrightarrow{\varepsilon} \times \left[A + \frac{i}{\omega}\nabla\phi\right] = \mu_0 J_{ext}$$

$$-\nabla \times \overleftrightarrow{\varepsilon} \times (\nabla\phi - i\omega A) = \frac{1}{i\omega\varepsilon_0}\nabla \times J_{ext}$$

## The example of input parameters

The experimental conditions in the GAMMA10 central cell are used in this calculation.

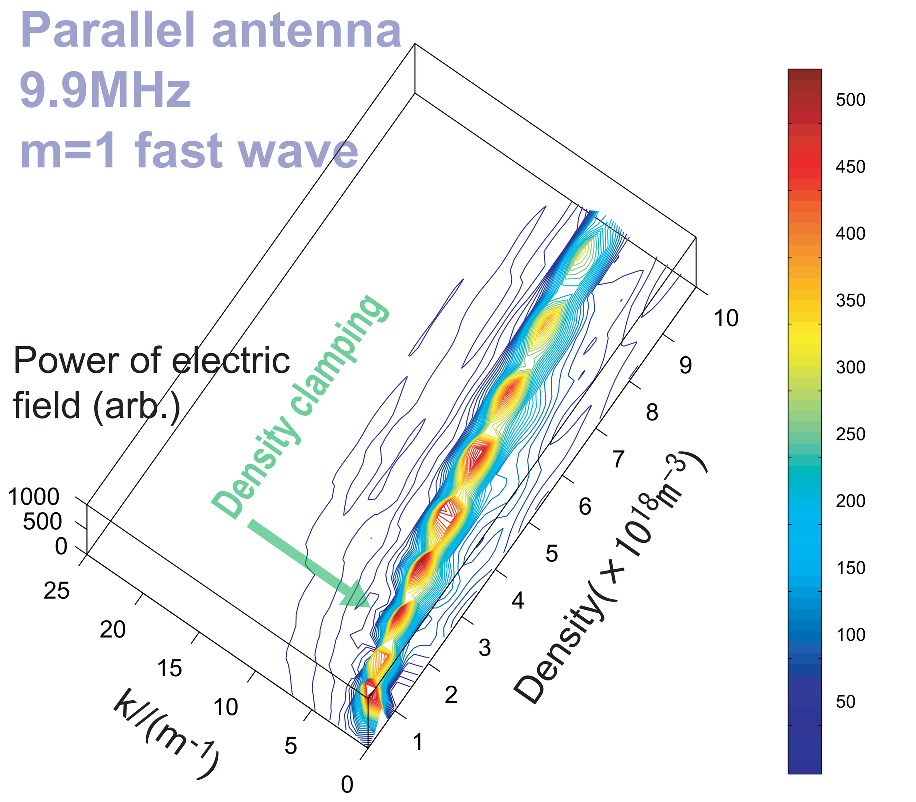



Contour lines of the magnetic field. Magnetic field intensity at axial direction. Contour lines of the electron (ion) density.

## Results of caluculations

The wave dispersion relation was calculated in the GAMMA10 central cell.

**Parallel antenna 9.9MHz m=1 fast wave**

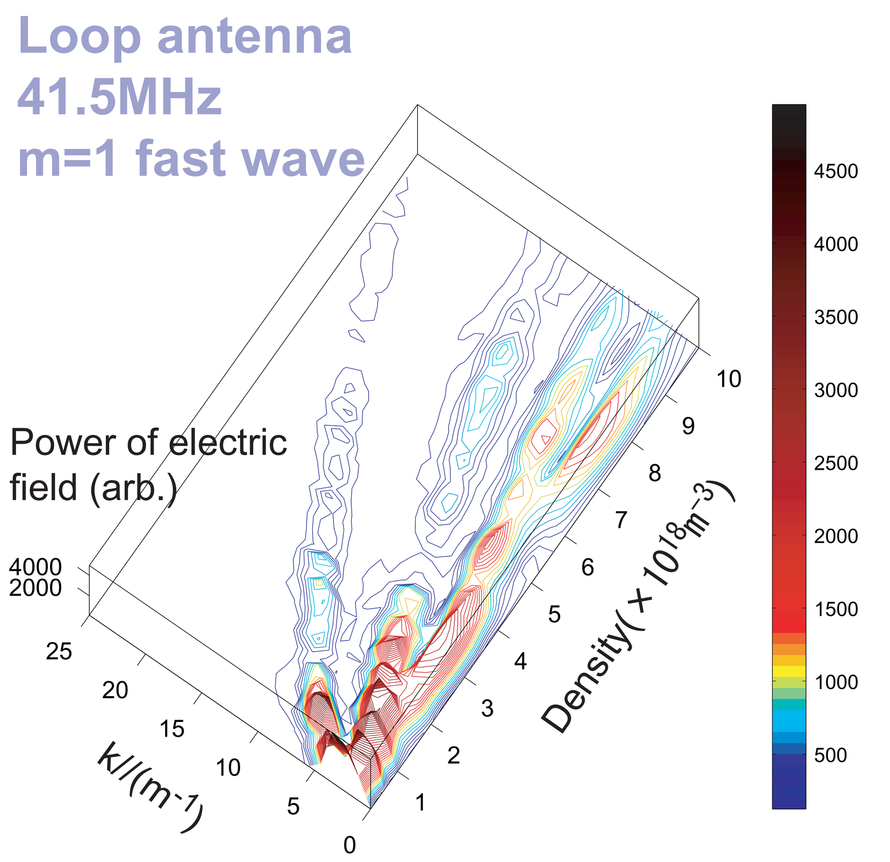



**RF1**

Only one eigenmode can be excited in this frequency resion. The power of the waves depends on the axial boundary conditions. The density will be clamped at the points where the wave is strongly excited.

## Results of caluculations

**Loop antenna 41.5MHz m=1 fast wave**

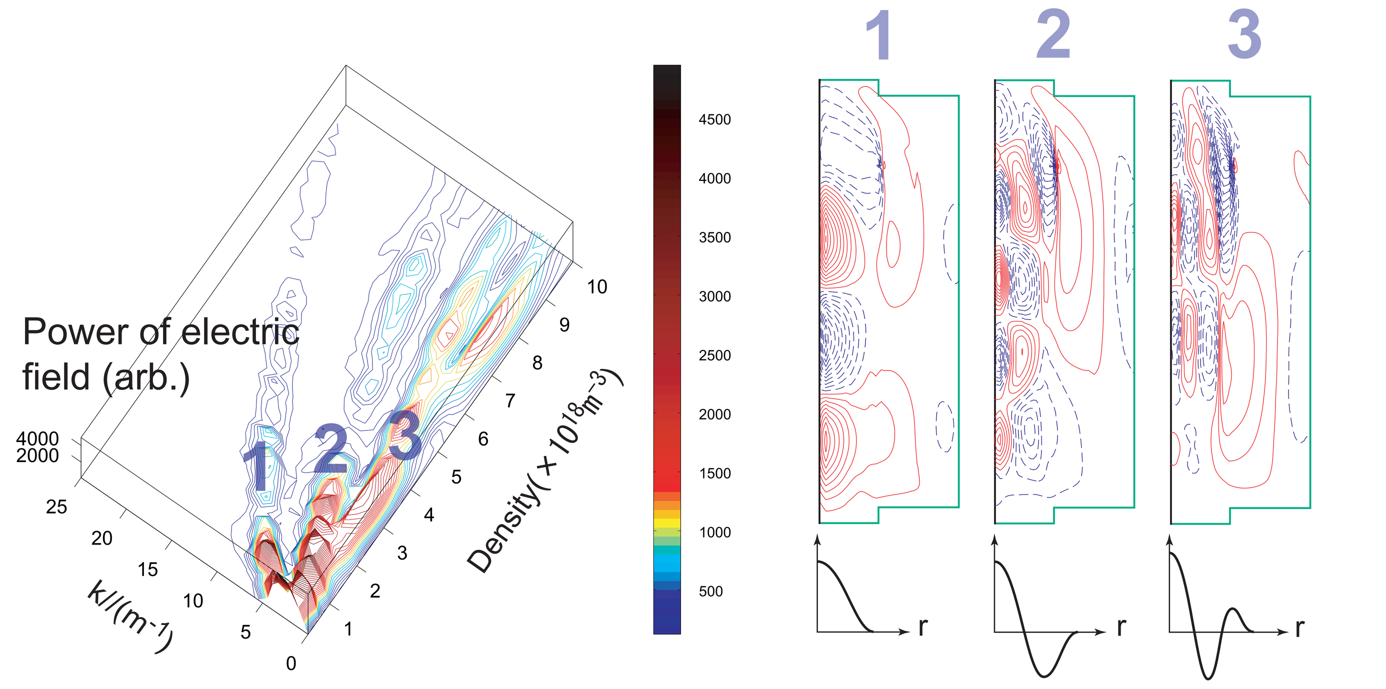



**RF3(HHFW)**

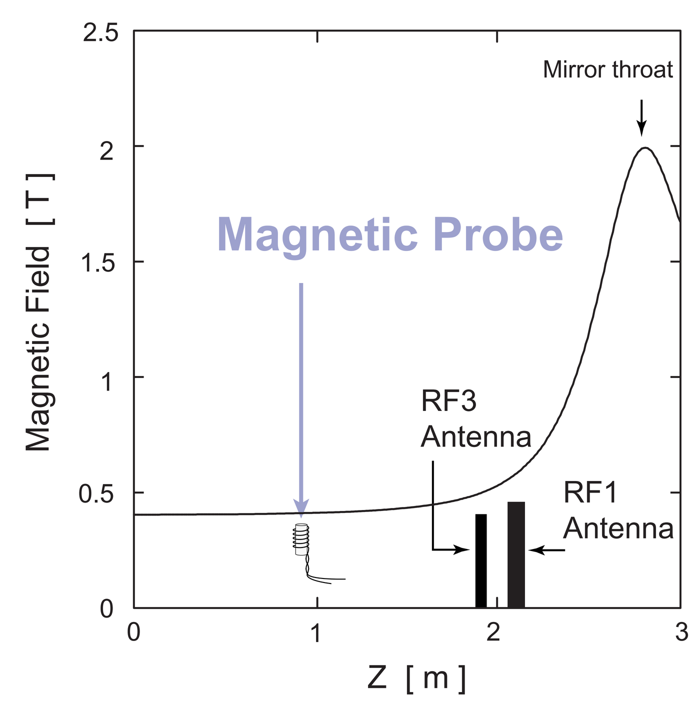
In the case of HHFW, several eigenmodes can be excited simultaneously in the large density range. As the density increases, a new eigenmode with higer radial mode number appears and its amplitude becomes larger.

## Change of the radial structure of wave electric fields accompanied with the new modes appearance

Each eigenmode has different radial structure of electro-magnetic fields.

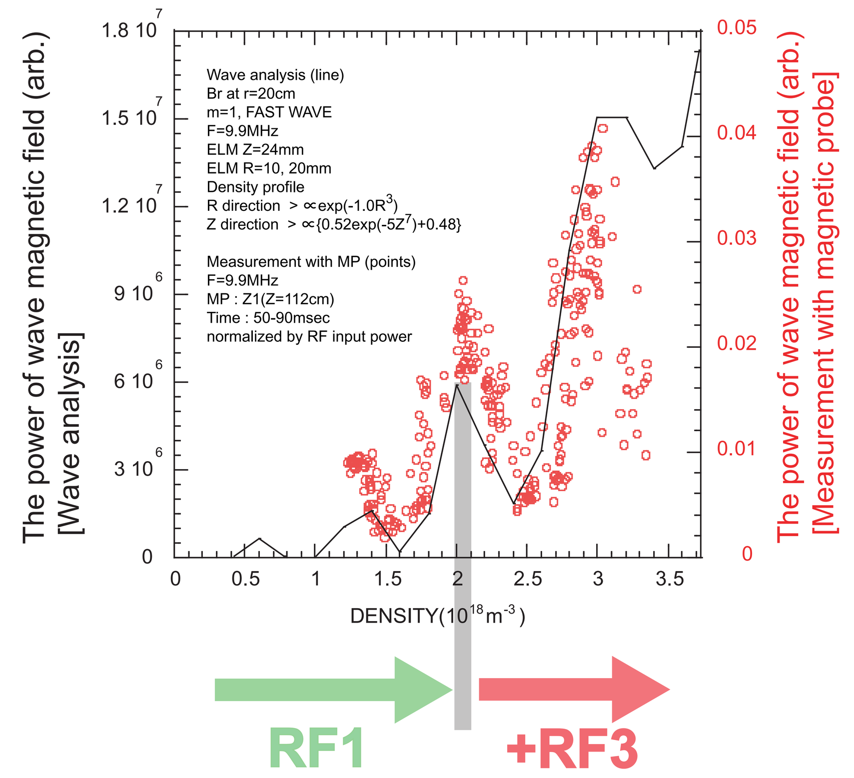



## Measurements with magnetic probes.




The power of the waves excited by RF1(9.9MHz) was measured using the magnetic probes located in the central cell.

## The result of the measurement.




The power of excited waves was measured with the magneric probe for the frequency 9.9MHz(RF1). The power of excited waves was also estimated from the calculation at the several radial locations. In the figure, measured values (red points) are plotted with the calculation (solid lines).

## SUMMARY

The formation of eigenmodes in ICRF waves is investigated in the GAMMA10 central cell by using the two-dimensional wave calculation code.

**RF1 (fundamental ICRF)**

**Only one radial eigenmode can be formed in the present density range. The density has been clamped at the point where the wave is strongly excited.**

**RF3 (HHFW)**

**HHFW can excite several radial eigenmodes simultaneously in the wide density range. As the density increases, the eigenmode with the higher radial mode number is excited strongly. It is suggested that the radial mode transition is essential for the density increase.**

Future works

Improvement for the boundary conditions of the central cell end.
Optimization for the high density plasma production by HHFW.