1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programatic relevance. Refer to any relevant program milestones.

This experiment is to investigate the poloidal plasma flow driven by the RF through mode conversion, and possible effects on plasma confinement. If the experiment is successful, it will provide a practical tool for plasma turbulence suppression.

2. Background

Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately.

With the application of RF waves, plasma flow may be generated as a result of direct momentum transfer, ponderomotive force exerted by the EM field, or the plasma counter-responses in terms of Reynolds stress (for a general review, see [1]). Because of the poloidal force balance equation only consists of relative small terms, the RF wave can drive observable poloidal flow. In some cases, the flow shear may be large enough to affect plasma confinement.

Short-wavelength waves are thought to be more effective to drive the plasma flow because they usually have larger electric field than the fast wave. Thus, the RF flow drive experiments were mostly done on direct launch Ion Bernstein Waves (IBW) [2, 3, 4]. A TFTR experiment on flow drive indicated that mode conversion process may also drive flow [5]. In this experiment, a poloidal flow correlated with the launched RF power was observed in between the mode conversion layer and $^3$He ion cyclotron layer in a D($^3$He) plasma [5]. Recent experimental observation and confirmation of the MC ion cyclotron wave (ICW) [6, 7, 8] made the MC flow drive picture more complicated, but also opened a new window for mode conversion experiments. In retrospect, the experimental observation in TFTR may be interpreted as a consequence of MC ICW flow drive. More studies on the flow drive is necessary to understand the physics.
Recent simulation result from the RF Sci-DAC efforts indicated that the RF-driven flow is strongly affected by the direct RF wave momentum input, or the momentum transfer caused by the RF wave (through a mechanism equivalent to Reynolds stress) when there is no net momentum input [9]. However, the uncertainty of the predicted flow magnitude, based on neoclassical flow damping rate, is very high. The flow can be in the order of $10^2$ to $10^3$ m/sec level. The general recipe from this study [10], and from some preliminary modeling using TORIC, suggested that a short-wavelength wave absorbed at an IC layer may be the best scenario for flow generation. The physics behind the recipe is that the mode converted waves mostly exert force on electrons before reaching an IC layer. Deposition of the MC ICW at the IC layer should exert force on ions and drive plasma flow. The scenario is in consistent with direct launch IBW experiments, in which the flow was observed near the IC layer where the IBW is absorbed.

In Alcator C-Mod, we can produce plasmas with minority concentration in-between minority heating and strong mode conversion. The MC ICW, propagating to the low field side from the MC layer, may be able to reach the IC resonance, and deposit its power to the ion species. We also need the MC layer not too far away from the magnetic axis, so that the plasma volume is small and the power density is high for flow generation. Modeling based on TORIC suggests that we may be able to observe significant flows near the $^3$He IC layer in D($^3$He) plasma. The other scenario is MC at high $^3$He concentration in D($^3$He) plasmas. In this case, the MC layer is close to the D IC layer so that the MC IBW can potentially propagate up to D IC layer and drive the plasma flow. We can also produce similar scenarios with $^3$He-H-D plasmas. This scenario has been tried in JET, but no conclusive result has been obtained [11]. We will focus on the first scenario in this experiment.

Sheared poloidal flow has been thought to suppress the turbulence and enhance plasma confinement in some RF-driven flow experiments. General observation from the literature is that no confinement enhancement was observed for experiments with RF-driven flow measurement [4, 5]; on the other hand, no RF-driven flow was directly measured in experiments with confinement enhancement [2, 3]. As a result, the effect of the RF driven poloidal flow to the confinement enhancement is still barely a speculation. Because of the high power density, it is possible in Alcator C-Mod to test the causality of flow shear and confinement enhancement. The flow predicted from SCI-DAC simulation is only an order of magnitude smaller than the level that can significantly affect the confinement. This experiment will also try to determine whether MC plasma flow drive can act as a knob for the plasma confinement in Alcator C-Mod.

If no flow is observed in usual heating phasing, we may also do experiment using the current-drive phasing of J-antenna, $[0, \pi/2, \pi, 3\pi/2]$. In the the current drive phasing, the possible average-out of poloidal flow due to positive and negative toroidal modes can be minimized.

3. **Approach**

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.
The flow is expected to maximize in-between the mode conversion layer and the IC layer. The flow will be measured by HIREX, which can scan the viewing location shot by shot. The $^3$He concentration can be estimated by comparing the density rise with gate valve open and close. It can also be estimated from the mode conversion heating profile from ECE measurement. Detailed core temperature and density profile measurements are crucial for this experiment.

Favorable plasmas conditions will be higher current (high $B_{pol}$), lower density (easier to have flow) and higher temperature (larger IC damping region).

If significant flow is observed, we will continue the study and determine the flow shear and its effect on plasma confinement.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field:** $\sim 7.3$ T ($^3$He cyclotron layer off axis on the high field side) for D-$^3$He plasmas, $\sim 5.1$ T for $^3$He-H-D

- **Plasma Current:** 1 MA or higher.

- **Working gas species:** D, $^3$He, H

- **Density:** $n_l04 \sim 0.8 \times 10^{20}$ m$^{-2}$

- **Equilibrium configuration** (if possible, refer to database equilibria): Usual single null diverted.

- **Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms; Refer to recent successful D$^3$He heating shots.

4.2 Auxiliary Systems

- **RF Power, pulse length, phasing:** 1 – 4 MW

- **Pellet Injection (species):** none.

- **Impurity blow-off injection:** none.

- **Diagnostic Neutral Beam:** not required.

- **Special gas puffing:** $^3$He and H if needed.

- **Other:**

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

- HIREX and HIREX jr (configured for poloidal velocity measurement), FRC-ECE, GPC, GPC2, Core Thomson, Visible Bremsstrahlung, TCI.
5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period (10 hours maximum), etc.

One run day.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

The following is for D-\(^3\)He plasmas operation. It is similar for \(^3\)He-H-D plasmas.

2 ohmic shots. One without \(^3\)He puff, the other with \(^3\)He. Obtain the \(^3\)He concentration profile by comparing the density profile from the two shots.

If the \(^3\)He concentration is ideal at a level about 10-20\%, continue with RF shots, otherwise change the gas valve time to get \(^3\)He concentration in this range.

5 shots: ramping up RF from 0.5 to 1 MW. Vary HIREX viewing locations shot by shot, starting from the expected MC location. Check any flow that is correlated with RF power.

If flow is observed:

9 shots: we will fix the HIREX view location and do RF power scan (3 shots), density scan (3 shots). We will also do RF power modulation to see flow damping rate and obtain mode conversion heating profile (3 shots).

If the observed flow velocity is higher than 5 km/sec, we will try higher RF power to see evidence of confinement effect of the flow shear (all the rest shots).

If no flow is observed: Repeat at a different \(^3\)He level.

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

If significant flow is observed (and the effects on confinement is demonstrated), the study will lead to a publication. The experimental result will provide concrete data for further physics study on the RF flow drive.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.


[6]. F.W. Perkins, Nucl. Fusion 17(1977), 1197


