Effects of Magnetic Shear on Toroidal Rotation in C-Mod Plasmas with LHCD

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with thanks to

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Motivation

Rich phenomenology exhibited in intrinsic rotation:

Rotation reversals in Ohmic plasmas triggered by changes in density, $I_p$, $B_T$, magnetic configuration.

Reversals occur at a critical collisionality.

Results indicate role of the residual stress: intrinsic torque $= \nabla \cdot \Pi^{\text{res}}$.

$\Pi^{\text{res}}$ depends on underlying turbulence, can change sign if mode propagation direction changes.

Both co- and counter-current rotation changes seen in LHCD plasmas.

Present results demonstrate role of current density profile in driving intrinsic rotation.

$\Pi^{\text{res}}$ is a function of $s$.

Unifies rotation observations in LHCD plasmas from many devices.
C-Mod

Counter-current rotation, \( q \approx 4.5 \)
J.E.Rice et al., Nucl. Fusion 49 (2009) 025004

EAST

Co-current rotation, \( q \approx 10 \)
Comparison of LHCD ‘Induced’ Rotation at High and Low Current

Counter-current rotation change at high plasma current, co-rotation at low \( I_p \).


0.91 MA, \( q_{95} = 3.7 \)

0.42 MA, \( q_{95} = 7.7 \)
LHCD Causes Core Rotation Changes in Both Directions
Rotation increment direction depends upon magnitude of plasma current.

J.E. Rice et al., Nucl. Fusion 53 (2013) 093015

Plasma current scan

Change in Rotation with LHCD

Target plasmas in different $v_*$ regimes
Rotation Profile Changes with LHCD Occur Only in the Core Region

Similar behavior observed in Ohmic rotation reversals

(pre LHCD (low \(v_*\))

with LHCD

(pre LHCD (high \(v_*\))

0.71 MA

0.42 MA

TEM

ITG

with LHCD

\(0.2 \quad 0.4 \quad 0.6 \quad 0.8\)

\(0.70 \quad 0.75 \quad 0.80 \quad 0.85\)

\(0.0 \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.7\)

\(r/a\)

\(V_{\text{Tor}} \text{ (km/s)}\)

\(0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1 \quad 3/2 \quad 2\)

\(0 \quad 10 \quad 20\)

\(0 \quad 10 \quad 20 \quad 30\)

\(V_{\text{Tor}} \text{ (km/s)}\)
Rotation Reversal through Changes in Current Density Profile (LHCD)

\[ s = \frac{r}{q} \frac{dq}{dr} \]

\[ L_s = R_0 \frac{q}{s} \]

\[ \langle n_e \rangle = 0.7 \times 10^{20} / m^3 \]

5.4 T

Ohmic target plasma

ITG

TEM

sawteeth

no sawteeth

co-

counter-

0 discharges

146 discharges

89 discharges

8 discharges


for details, see R.T. Mumgaard, next talk
Rotation Increment Direction (w/ LHCD) Depends on q Profile


Magnetic Shear Scale Length

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\[ \text{change in } V \text{ (km/s)} \]

\[ \text{change in rotation frequency (kRad/s)} \]

Is it \( q \) or \( \nabla q \) that matters?

Unifies results from several devices.
Completely Different Rotation Behavior with LHRF at Higher Density

At high density the LH waves do not penetrate to the plasma core, and there is no current drive. Unlike the lower density cases, the rotation evolves on a time scale similar to the energy and momentum confinement times. The rotation initiates at the edge and propagates inward. The rotation change is in the co-current direction for this 0.8 MA discharge, and is observed over the entire cross section.

see J.L. Terry talk 13 this session
LHCD Rotation Summary

Rotation changes in both co- and counter-current directions observed with LHCD.

Rotation evolves on a current relaxation time scale.

Profile changes only in the core plasma.

Rotation direction depends on core magnetic shear and/or $q_0$.

Unifies results from multiple devices.

Rotation changes through $\Pi_{\text{res}}$ dependence on $q$ profile.

Is it possible to distinguish between dependence on $q_0$, $\hat{s}$ or $q^\prime$?

J.M.Kwon et al., Nucl. Fusion 52 (2012) 013004

related theory talk:  J.P. Lee  PI2.00005  Wed. P.M.