The Dependence of Lower Hybrid Current Drive Induced Rotation Direction on Plasma Current and Magnetic Configuration

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Outline

- Motivation
- History of Lower Hybrid Current Drive Induced Rotation
- Recent Experiments on C-Mod
- Possible explanations and future experiments
- Summary

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The effects of non-inductive current drive on plasma behavior are important for tokamaks

- RF current drive systems are expected to exist on future tokamaks
- Lower hybrid current drive (LHCD) is present on Alcator C-Mod and is one possible RF system
- Rotation has been an area of active research and has a variety of beneficial effects on plasma behavior
- Sources of plasma momentum are important to understand for reactor predictability

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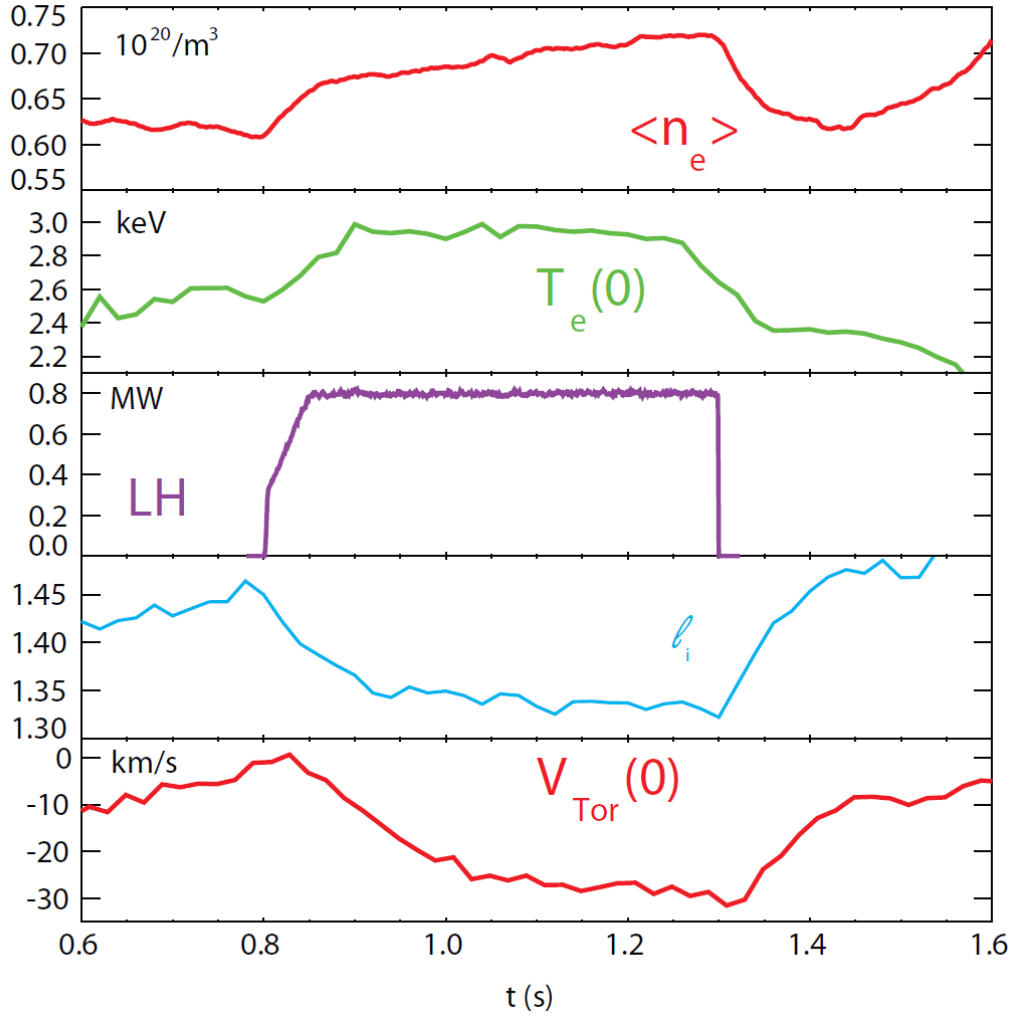
Alcator C-Mod has observed LHCD induced rotation in the past

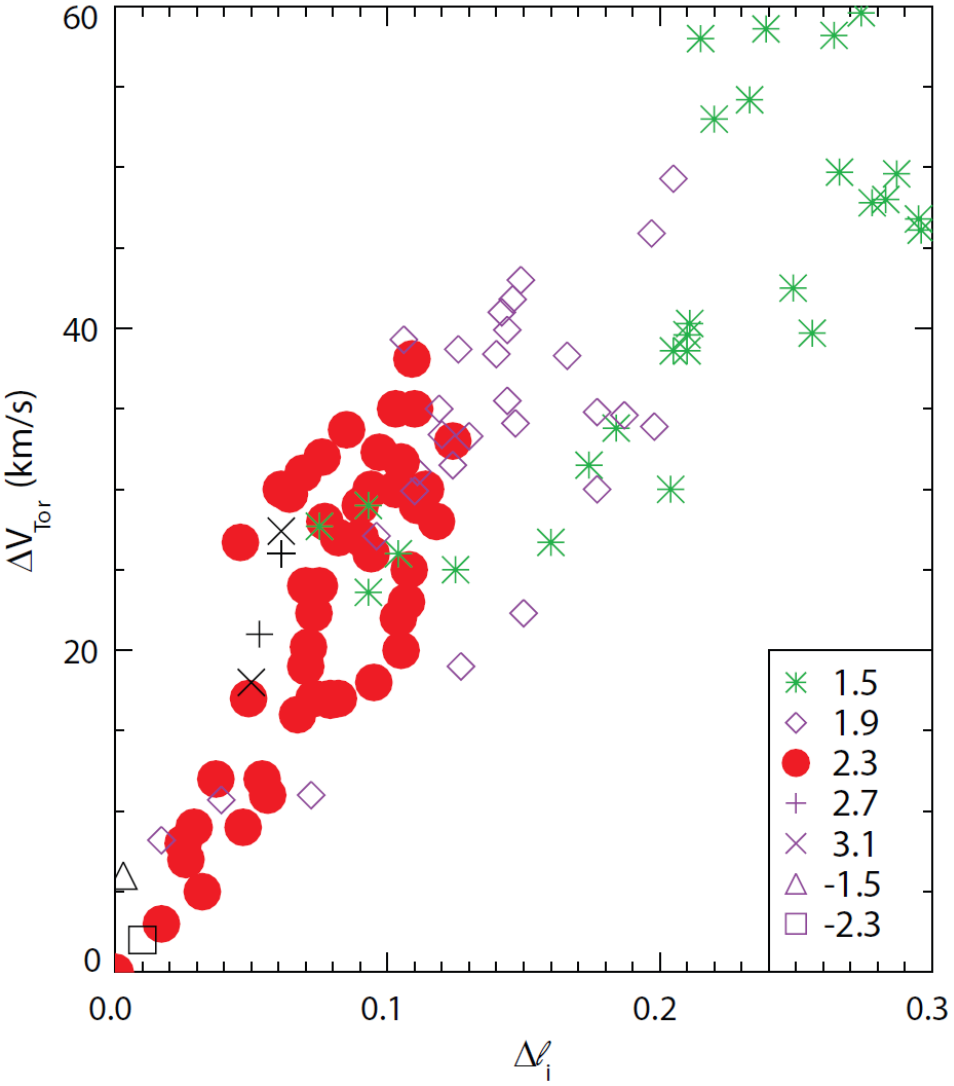


- C-Mod first observed LHCD induced rotation in 2007
- Rotation was always counter-current
- It was observed to scale with ℓ_i, P/n_e, and inversely with $n_{||}=ck_{||}/\omega$
- The effect seemingly started at the core of the plasma and diffused outward

A. Ince-Cushman et al. PRL 102:035002. 2009

J. E. Rice et al. Nucl. Fus. 49:025004. 2009.

Very strong dependence seen with internal inductance and $n_{||}$



- The behavior seemed fairly straightforward
- The effect was explained by accounting for the direct momentum input from the wave
- Possible explanation also was the fast electron pinch

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Other machines have also observed LHCD induced plasma rotation

- **Co-current** rotation was observed, however, on both JT-60U and Tore Supra
- The effect was suggested to be due to ripple losses of electrons
- C-Mod has a much smaller ripple, so this seemed to explain the issue
- Still this was a wide open question on the rotation

Y. Koide et al. IAEA-CN-56/E-3-11. 1993.
P. Platz et al. 22nd EPS Conf. Proc. 19C. 1995.

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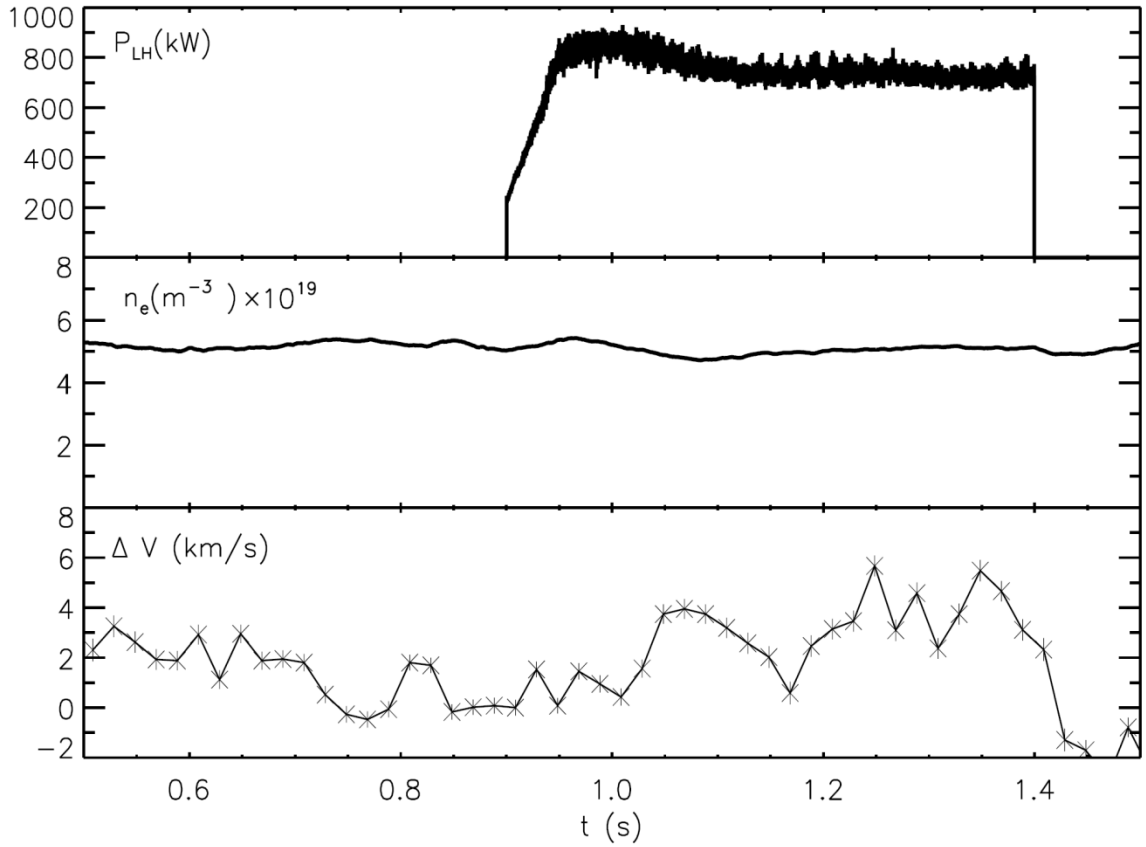
Slight co-current rotation was observed for the first time during the 2010 campaign on C-Mod



- Started observing little rotation during shots
- On certain shots even observed slight co-current rotation

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LHCD induced rotation was only observed in USN plasmas and was proportional to I_P

- Towards the end of 2010, it was observed that current appeared to be influencing the amount of **co-current** rotation
- Co-current rotation was observed in Upper Single Null (USN) plasmas only
- A dedicated experiment was performed in early 2011 to test this connection in USN and LSN plasmas

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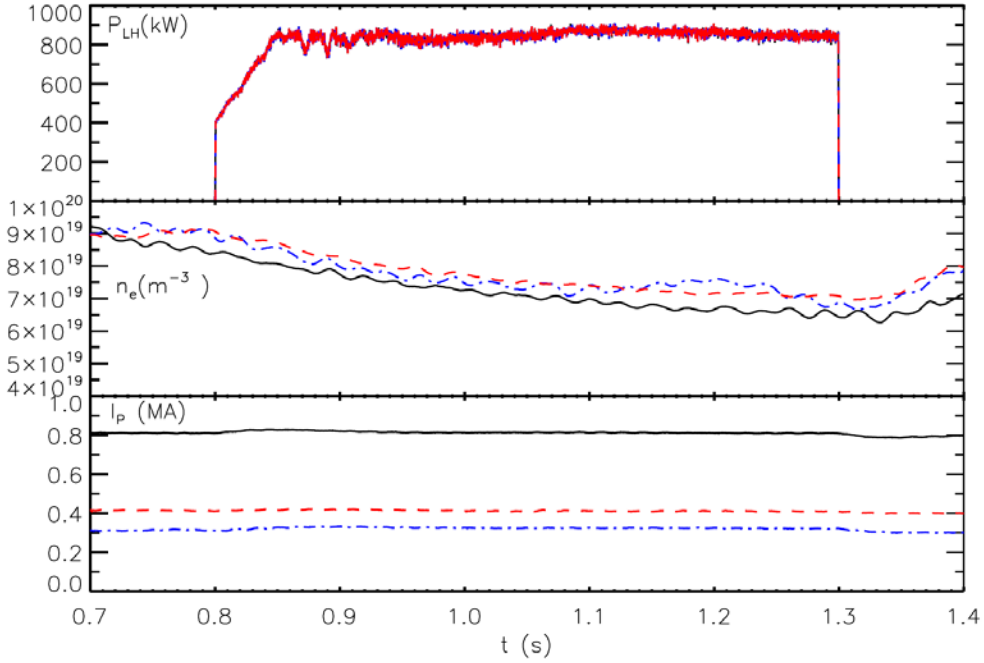
Experimental Set-up

- Ip scan at fixed
  - B_T=5.4 T
  - n_e = 0.66E20 m-3
  - $n_{||}$ =1.6
  - P_{LH} = 800 kW
- Deuterium main ion
- Rotation profiles measured by argon impurity spectroscopy (HiReX Sr)



A. Ince-Cushman et al. RSI **79**, 10E302. 2008

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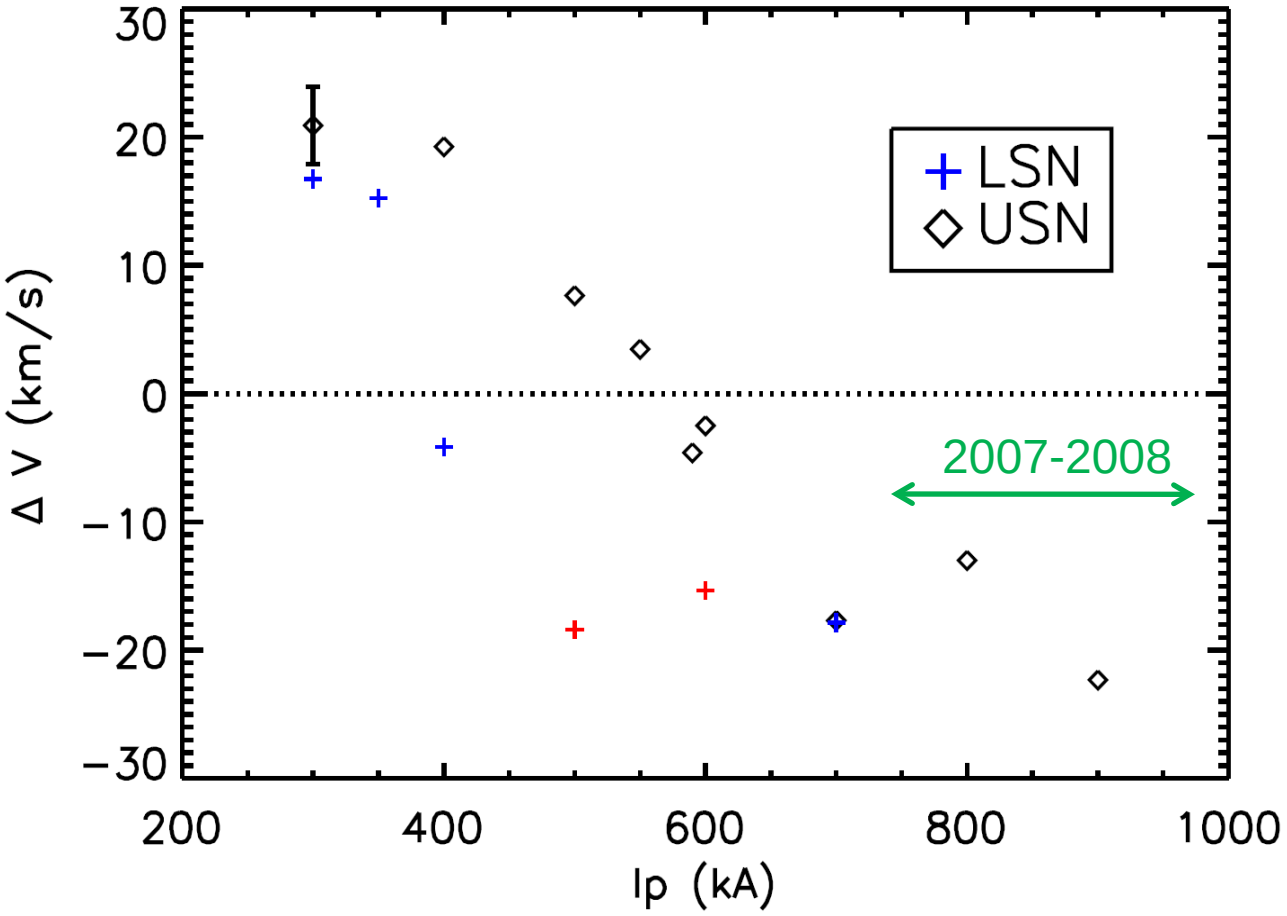
Change in rotation depends strongly on Ip and magnetic configuration



- Red points have higher (~15-20%) density
- USN zero rotation: ~550 kA
- LSN zero rotation: ~400 kA

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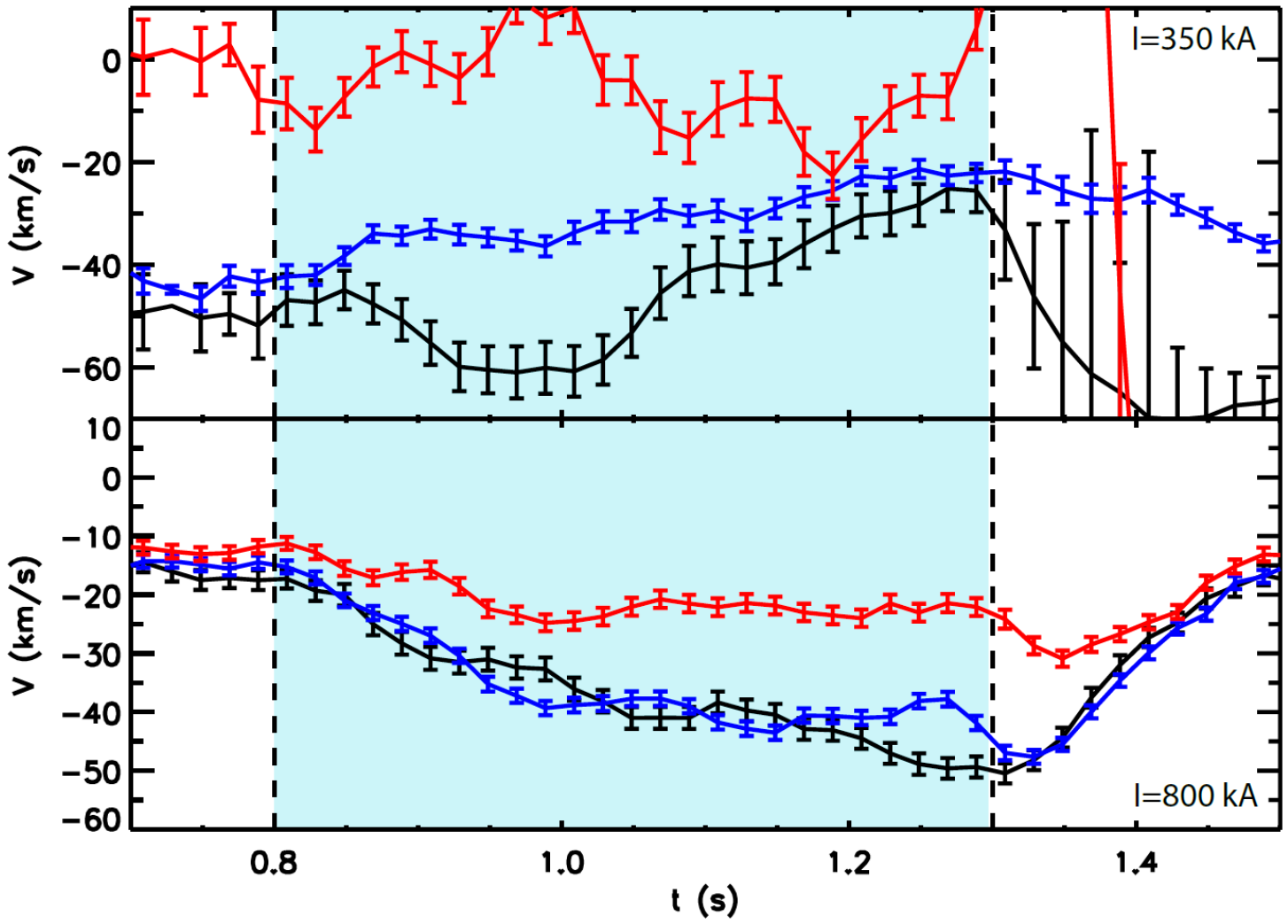
LSN: rotation from LHCD appears to start near the core

r/a~0.5
r/a~0.3
r/a~0.0



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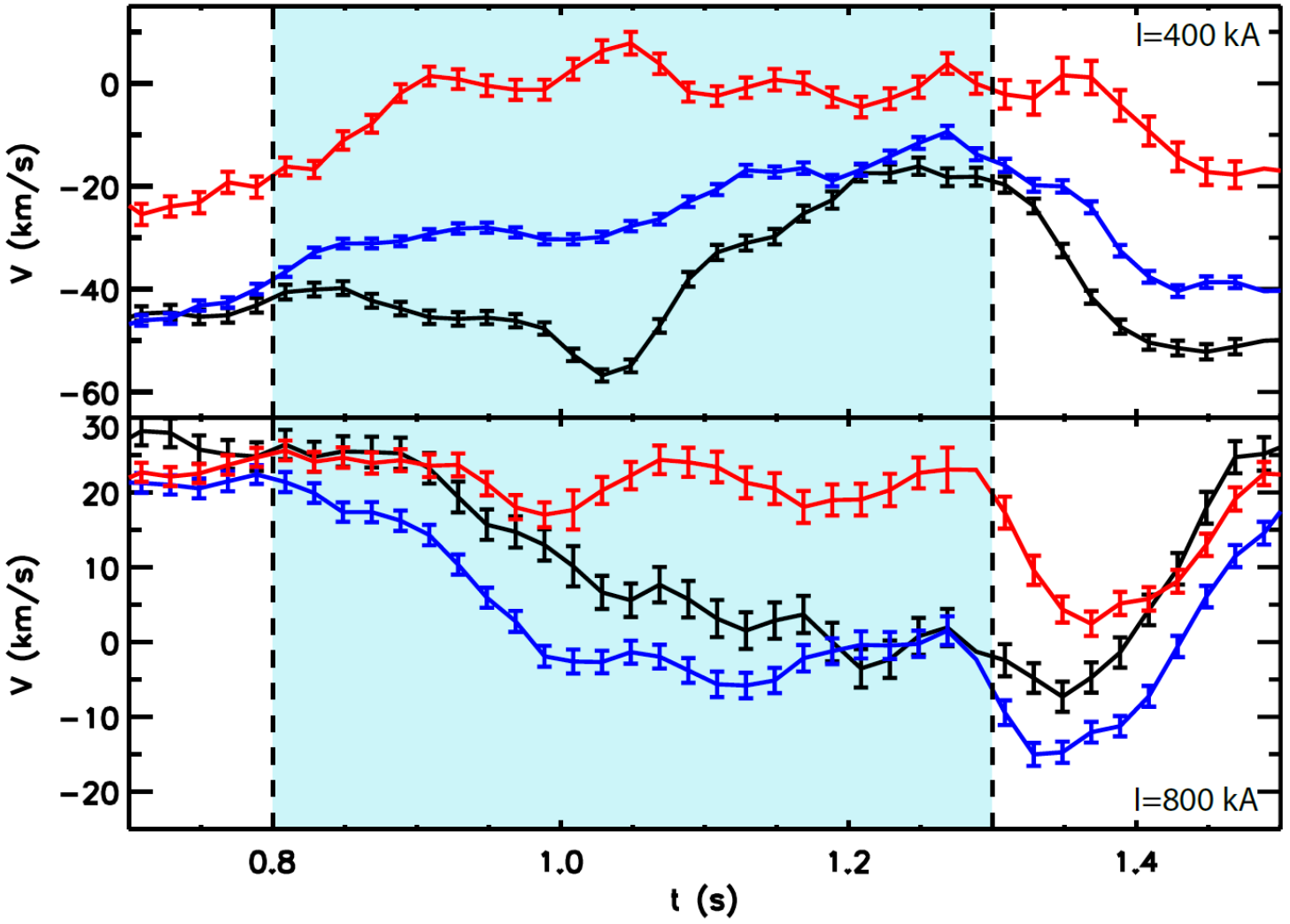
USN: rotation from LHCD appears to be strongest near the core region as well

r/a~0.5
r/a~0.3
r/a~0.0



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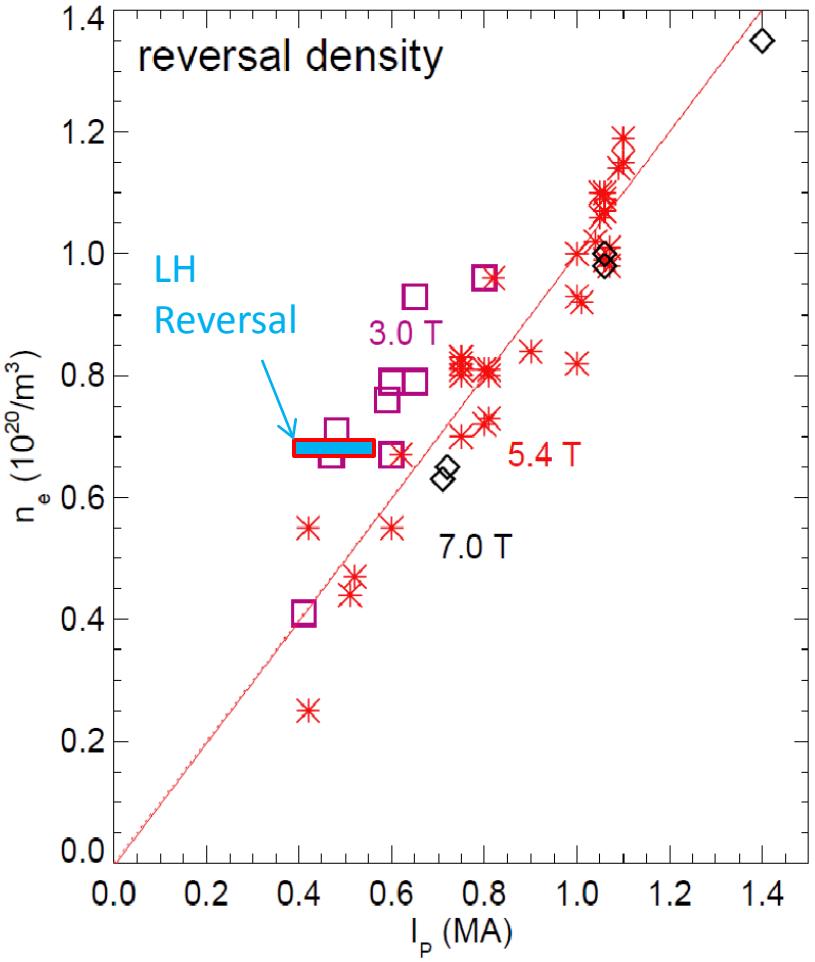
LHCD Rotation Reversal occurs in a similar parameter space as the Intrinsic Rotation Reversal



- Rotation reversal involves an intrinsic momentum transport change
- Reversal effect appears in a similar regime as the LHCD reversal
- Perhaps LHCD is modifying the plasma transport directly

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Some empirical observations exist as well

- Rotation direction seems to depend on plasma density
- Poloidal rotation change is not outside of the instrumental sensitivity (~1km/s)
- LHCD induced rotation was not observed in helium main ion plasmas

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Several ideas have been proposed to explain LHCD rotation but they are still incipient

- This is unfortunately still not fully developed
- Proposed ideas
  - Direct momentum input from LH waves[1]
  - Fast electron losses/fast electron pinch leading to an E_r
  - Changes in the plasma transport

[1]J. P. Lee et al. APS Poster. 2010

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Summary and future work

- Co- and counter-current LHCD driven rotation has been observed in Alcator C-Mod
- Direction depends strongly on plasma current
- Many ideas about what is causing this exist, but they are still incomplete
- In the future, we will test LHCD dependence on density and magnetic field

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Open Questions and Requests for Collaboration

- Why are the LSN and USN plasma reversals different for a core oriented phenomenon?
- Is this one effect (e.g. transport) or multiple effects (e.g. wave momentum versus fast electron losses)?
- Can we come up with a testable theory for this effect?
- All collaborations are more than welcome: www.psfc.mit.edu/research/alcator/index.html

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Thank you for your time

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