Non-reversed Discharges - A Tool for Understanding Reversed Field Pinch Physics

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The reversed field pinch (RFP) configuration generally supports a full spectrum of coupled magnetic fluctuations. Three-wave interactions between two m=1 modes and an m=0 mode can have a strong influence on plasma rotation and current profile evolution. By removing m=0 modes from the plasma we perform a critical test of our understanding of their role in RFP physics. In MST, we remove m=0 modes by excluding their resonant surface through edge toroidal field programming. With m=0 modes suppressed, the relaxation of the flow profile and current profile during sawteeth is greatly reduced. Anomolous ion heating is also reduced and confinement is not as good as in standard reversed discharges. A common theme emerges which links many of the global relaxations in the RFP to the extensive mode coupling mediated by m=0 modes.

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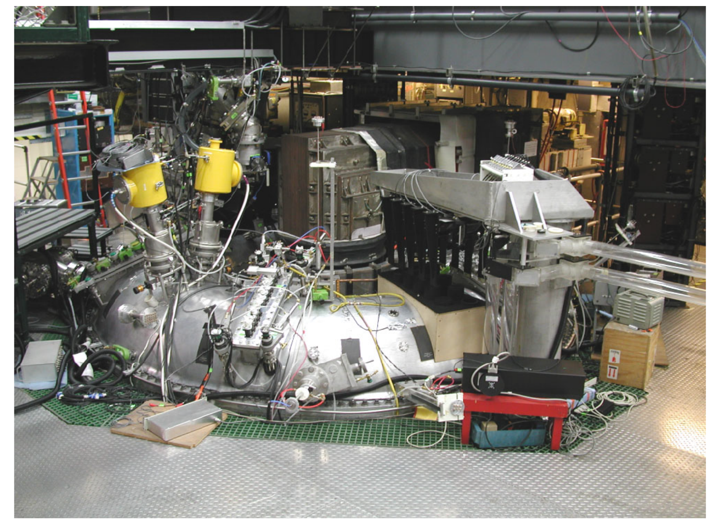
Motivation

- Fluctuations play many roles in confined plasmas.

- In Reversed Field Pinch (RFP) plasmas, magnetic fluctuations are large and are believed to strongly affect:
  - the current profile
  - particle and heat transport
  - plasma rotation
  - ion heating

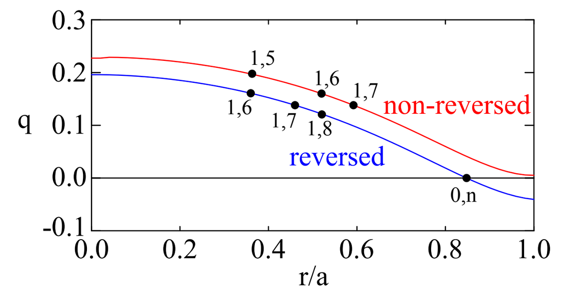
- In such a system, the ability to reliably adjust the amplitude, rotation, etc. of any subset of the fluctuations is extremely valuable for gaining physics understanding.

The Madison Symmetric Torus (MST)



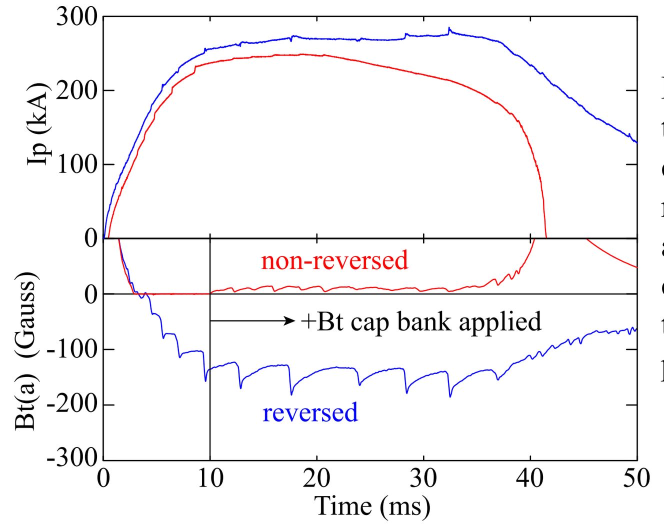
What can non-reversed discharges tell us?

- Standard RFP q profiles support many resonant modes
- Core resonant m=1 and edge resonant m=0 are largest
- Modes are global and coupled in 3-wave interactions
  - e.g. m,n=1,6 and 1,7 couple through 0,1
- Excluding q=0 from the plasma causes a discontinuous change in the configuration and should single out the role played by m=0 modes



How do we make non-reversed discharges?

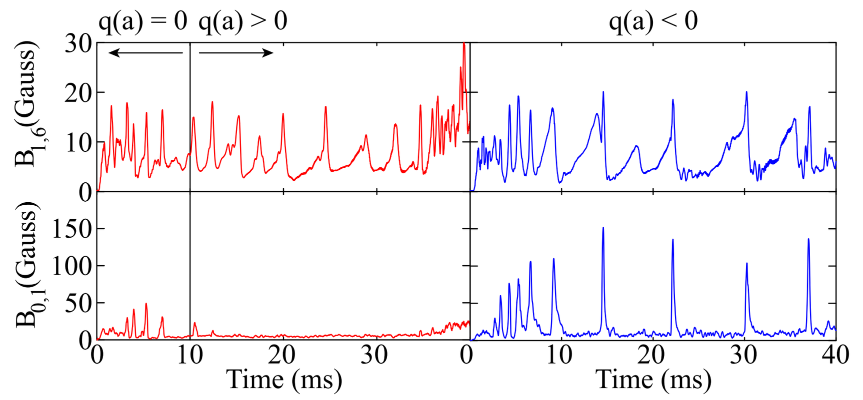
- In standard RFP plasmas, the current in the toroidal winding becomes negative in response to toroidal flux generation in the plasma.



Here, we open the toroidal field circuit to prevent reversed current and use a small capacitor bank to drive Bt(a) positive at 10 ms.

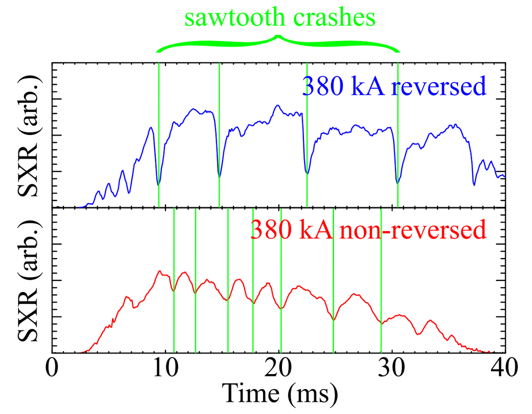
Mode behavior in non-reversed discharges

- Core m=1 modes have similar amplitude and time dependence
- Edge m=0 are strongly suppressed



Sawteeth still present without reversal

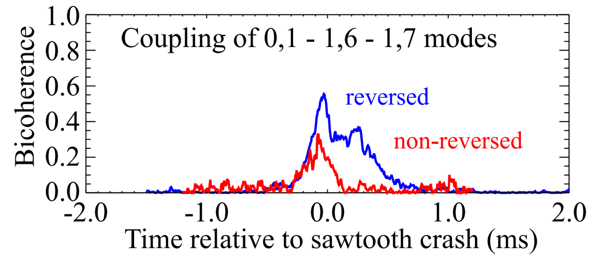
- Sawtooth cycle in RFP involves many coupled modes
- In MHD computation, suppression of m=0 removes sawteeth
- In experiment, sawteeth still present but weaker and more closely spaced



Conclusion: m=0 modes are not necessary for sawteeth but may play a role in the sawtooth period

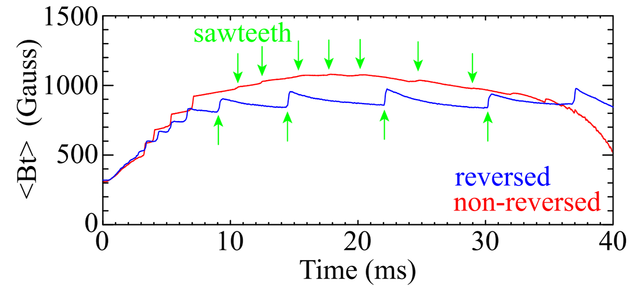
Residual m=0 modes are still coupled to core m=1 modes without q=0 in plasma

- Use bispectral analysis to identify mode coupling (*see poster by S. Choi in this session*)
- Coupling is weaker in non-reversed plasmas but still exists
- Shows that non-resonant modes can couple with resonant modes



Discrete flux generation events small in non-reversed plasmas

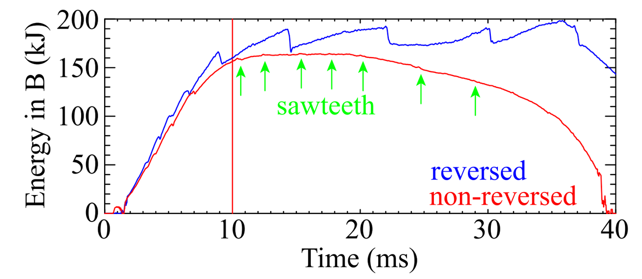
- Strong fluctuations can drive poloidal current during sawteeth
- Although m=1 modes have similar amplitude in non-reversed plasmas, they do not generate much toroidal flux
- Flux decay between sawteeth is also reduced



Conclusion: m=0 modes are necessary for strong flux generation. Flux decay may be enhanced by m=0 modes.

Magnetic energy change during relaxation is small in non-reversed plasmas

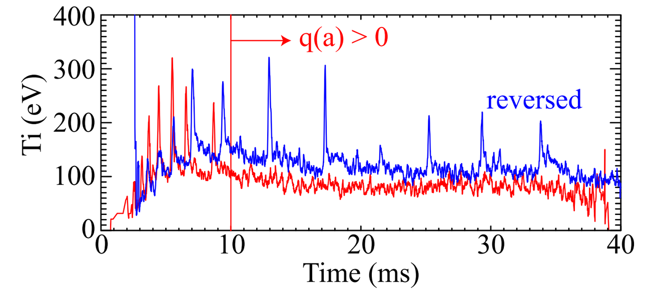
- In standard discharges, relaxation toward a state of minimum magnetic energy occurs at each sawtooth crash
- Relaxation is due to current redistribution by fluctuations
- Without reversal, magnetic energy does not drop at the crash
- Strong increase between crashes is also absent with q(a)>0



Conclusion: m=0 modes facilitate release of magnetic energy.

Anomolous ion heating reduced in non-reversed plasmas

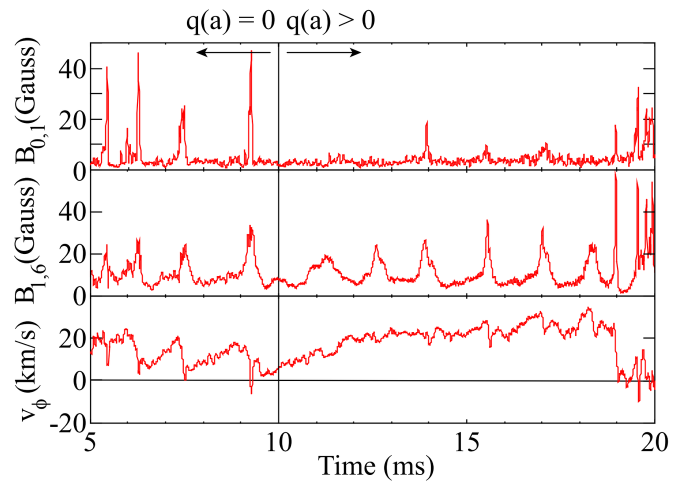
- Ions are heated by an unknown fluctuation mechanism in the RFP (*see poster by J. Reardon in this session*)
- Strong heating during sawtooth crashes in reversed plasmas
- Without reversal, mean Ti is lower and heating at sawteeth is not present



Conclusion: m=1 modes alone are not sufficient for ion heating at sawteeth but must be accompanied by m=0 modes

Core plasma rotation is unaffected by sawteeth in non-reversed discharges

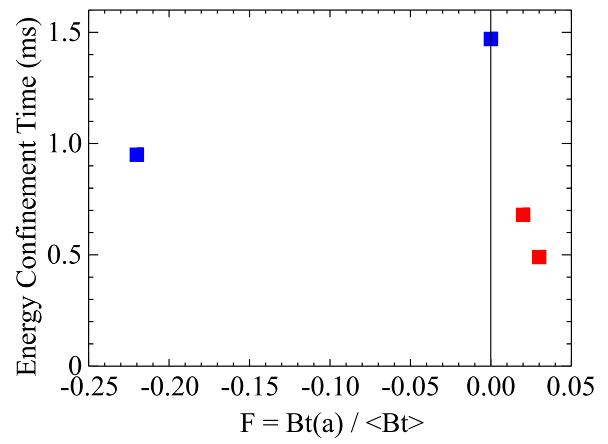
- In reversed shots, 3-wave coupling produces torques at resonant surfaces which rapidly change core plasma rotation



- When m=0 modes are suppressed these torques are reduced

Energy confinement degrades as discharges become more non-reversed

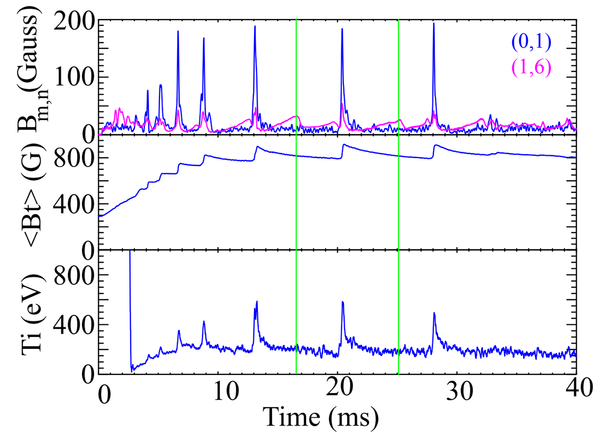
- Beta decreases and input power increases slightly with q(a)>0
- New fluctuations appear which might play a role in transport in these discharges



(see poster by T. Biewer in this session for more on confinement in MST)

m=0 importance in these phenomena verified in special cases of reversed discharges

- Occasional events with large m=1 but small m=0 are observed in reversed plasmas and confirm our conclusions
- Non-reversed plasmas offer a method for achieving this in a controlled way



Future plans for non-reversed experiments

- Improve power supply for better control of discharges with slightly positive q(a)

- Determine the source of confinement degradation with q(a)>0

- Measure the MHD dynamo with m=0 absent

- Investigate source of sawtooth oscillation with m=0 absent

- PPCD application to q(a)>0 target plasmas to suppress m=0 during PPCD startup

- Repeat confinement measurements with less gas puffing during non-reversed phase

Summary

- Non-reversed discharges allow us to controllably suppress m=0 modes without strongly changing m=1 modes.

- Comparing reversed and non-reversed discharges shows that large m=0 amplitudes coincide with:
  1. Toroidal flux generation at sawteeth
  2. Magnetic energy release and relaxation
  3. Anomolous ion heating
  4. Rapid momentum transport

- The tight correlation of these phenomena with one another and the modes indicates that a broad, coupled spectrum is probably very important for many of the global relaxations ascribed to fluctuations in the RFP

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