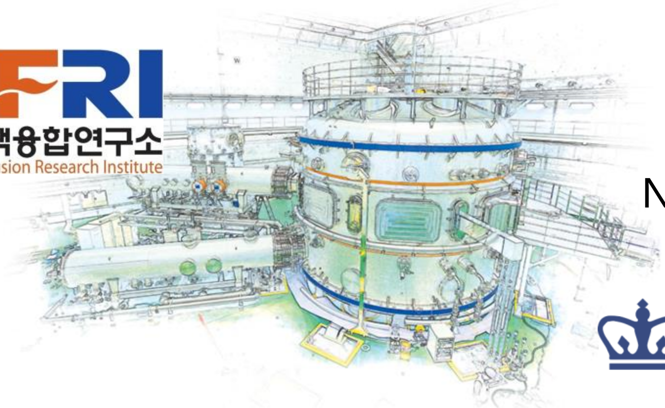
Automated Identification of MHD Mode Bifurcation and Locking in Tokamaks

S.A. Sabbagh[1], J.D. Riquezes[1], R.E. Bell[2], Y.-S. Park[1], C. Myers[2], L.A. Morton[3]

Columbia U. student

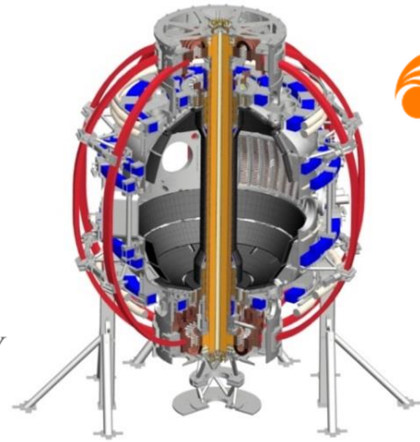
[1]*Department of Applied Physics, Columbia University, New York, NY, USA*
[2]*Princeton Plasma Physics Laboratory, Princeton, NJ, USA*
[3]*Oak Ridge Associated Universities, Oak Ridge, TN, USA*

NSTX-U Physics Meeting



PPPL

November 30th, 2017
Princeton, NJ



Supported by US DOE grant DE-SC0016614

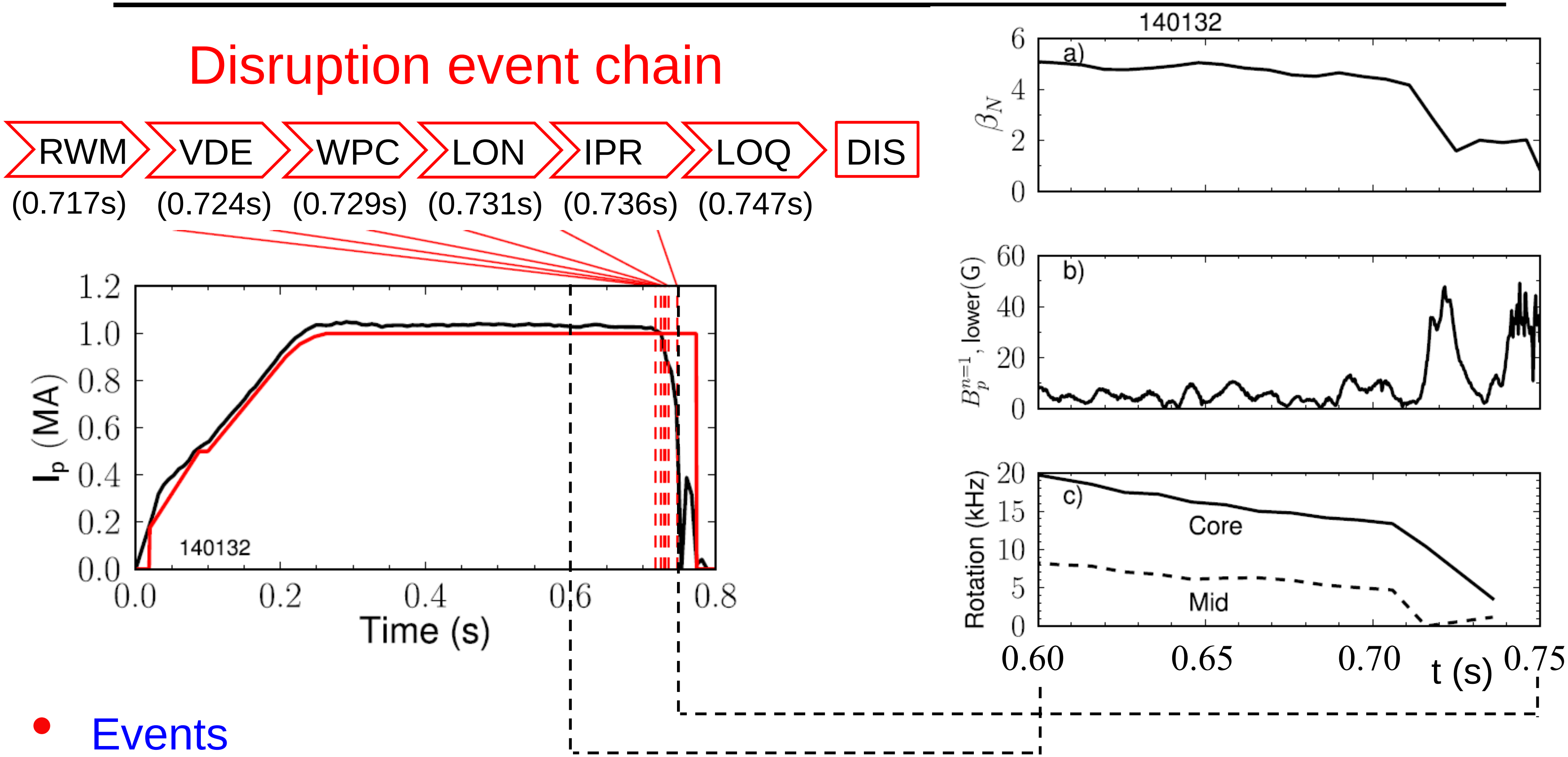
An algorithm has been created to automatically identify aspects of MHD activity supporting disruption prediction

- Motivation
  - Identify time-evolving rotating MHD instabilities in a tokamak plasma
  - Automate detection of key mode characteristics with the purpose of connecting them to plasma disruptions
  - Create portable code for general use on tokamaks as a module for the disruption event characterization and forecasting code (DECAF)

- Outline
  - Standard analysis of rotating MHD modes by FFT
  - Automation of MHD characteristics analysis for DECAF
  - Testing on various plasma scenarios
  - Simple torque balance model of bifurcations to test in DECAF

DECAF uses threshold tests and more sophisticated models to declare events and create event chains

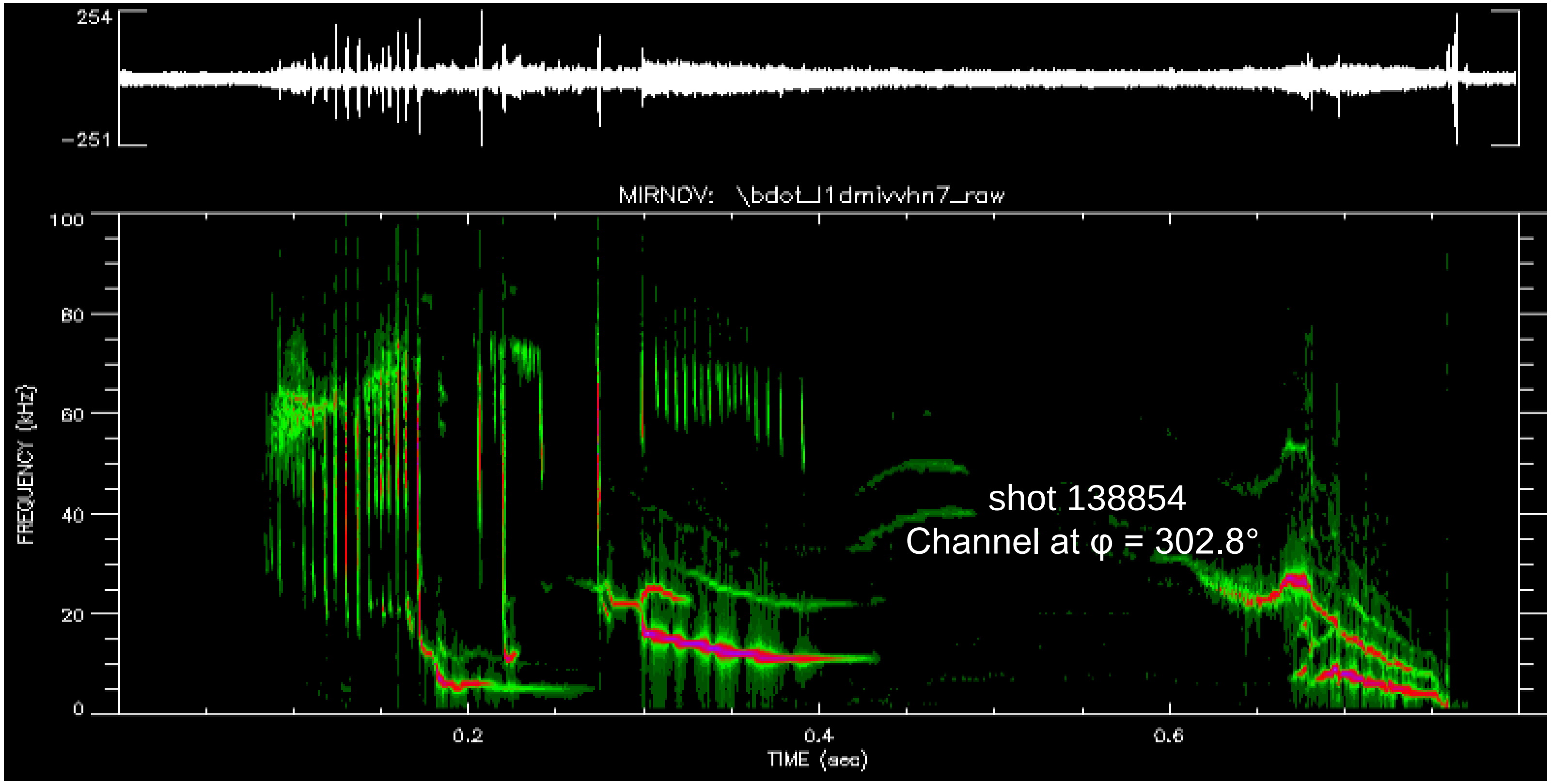
Disruption event chain



- Events
  - RWM: resistive wall mode
  - VDE: vertical instability
  - WPC: wall proximity control
  - LON: low density warning
  - IPR: not meeting Ip request
  - LOQ: low q warning
  - DIS: disruption
- Critical need for new code objects that identify rotating/locking MHD events

Automated mode identification starts with FFT analysis of magnetic probe data

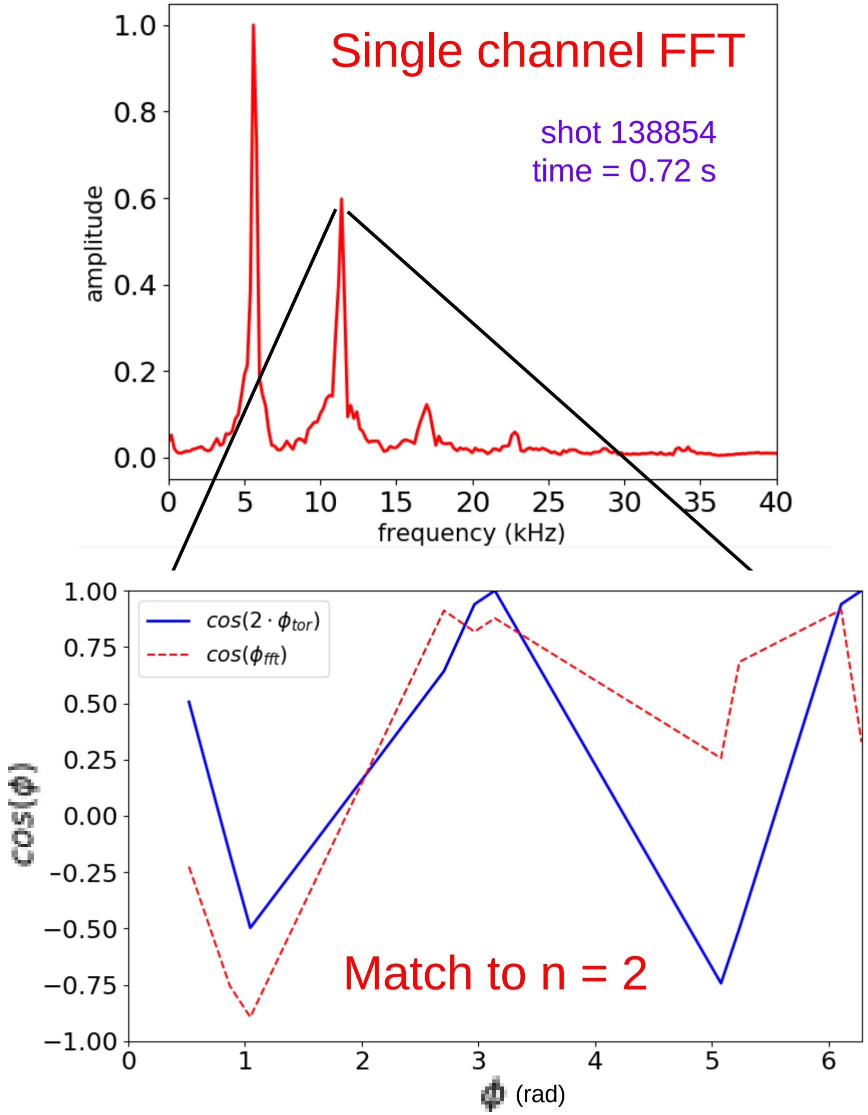
Mirnov signal & FFT amplitude



- Consecutive FFTs give the phase and amplitude of a signal in frequency and time

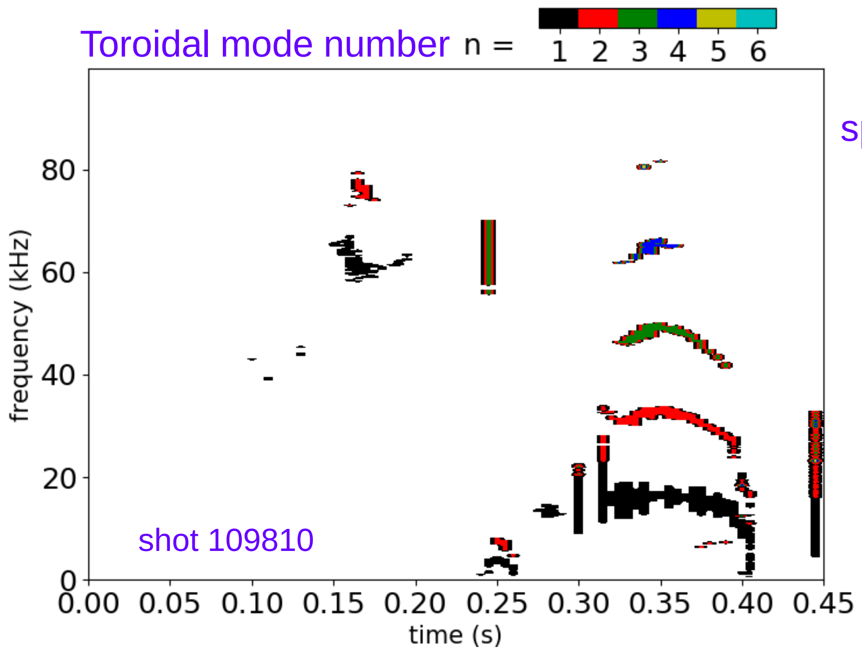
Toroidal mode numbers are determined by toroidal phase matching of peaks in FFT

- Input data from a toroidal array of magnetic probes
- Toroidal mode number determined by best match to measured phase
- Created a portable Python code for general use in tokamaks (e.g. NSTX/-U, KSTAR, etc.)
  - Diagnostic configuration files allow easy setup for any tokamak

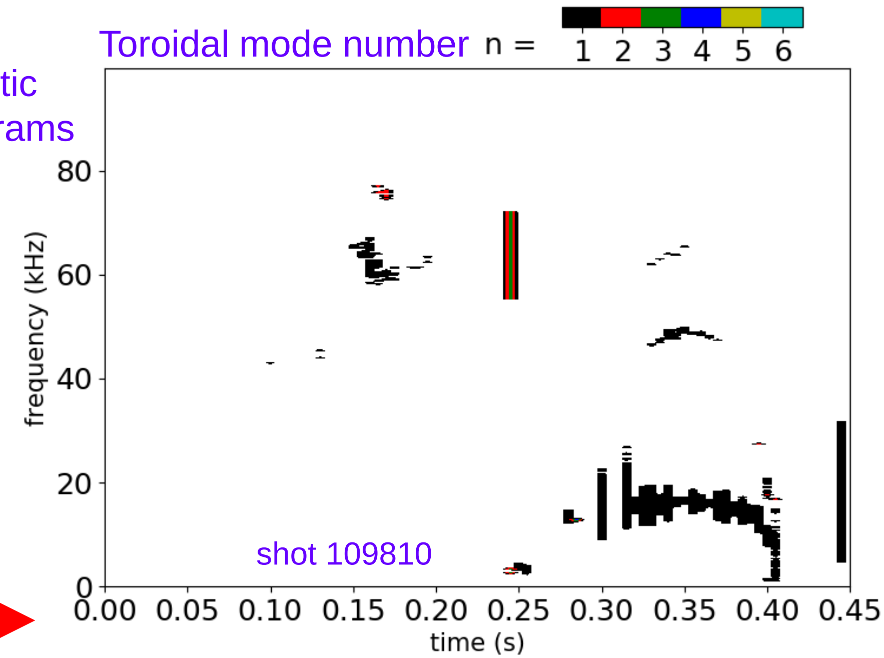


Principal components can be optionally selected by SVD

- SVD allows for decomposition of signals into principal components
  - Can be used to pre-condition data for analysis (e.g. noise reduction, or to analyze dominant activity
  - Capability to be tested in DECAF to determine advantages

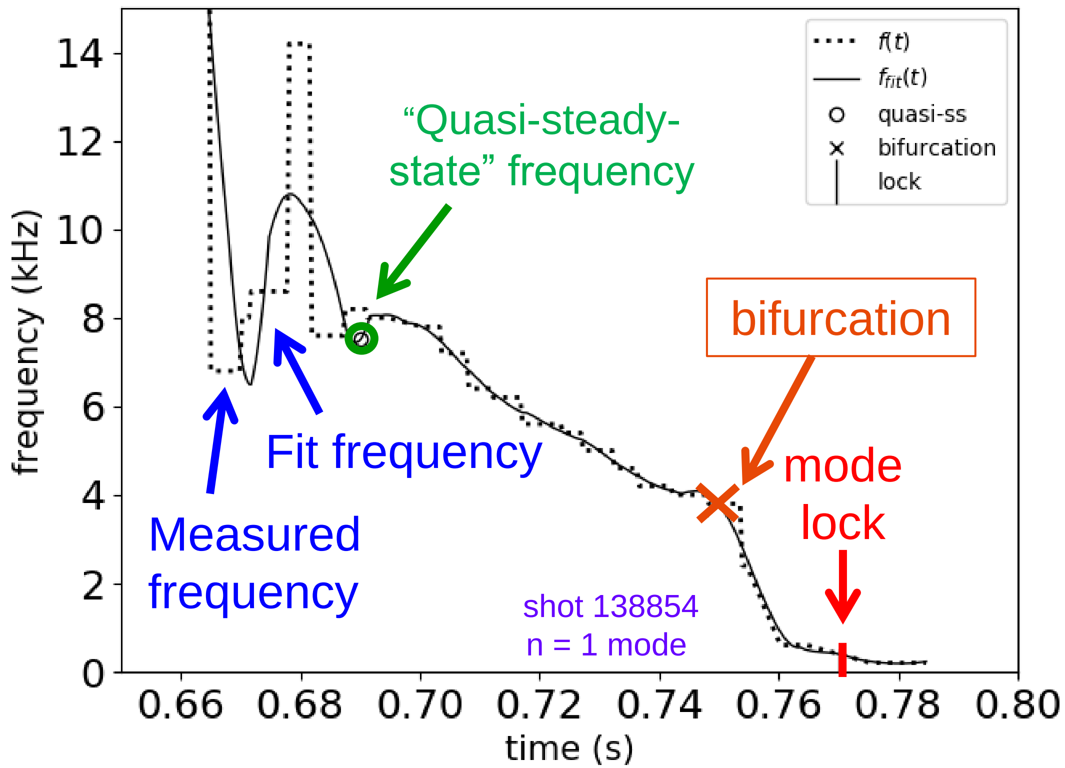


Magnetic spectrograms



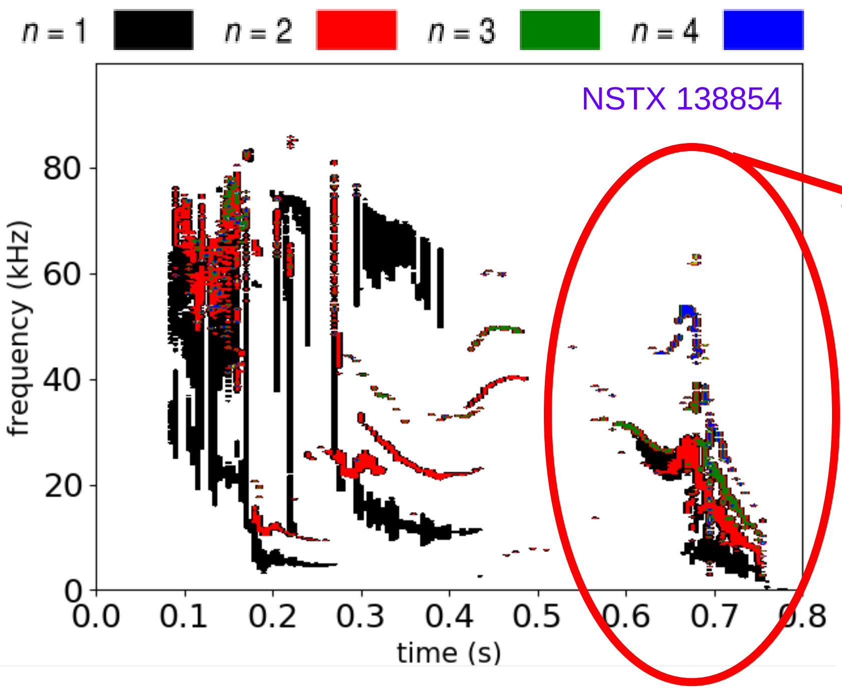
Choosing only first two principal components

Discrete modes are processed as objects, key mode characteristics are determined and tracked

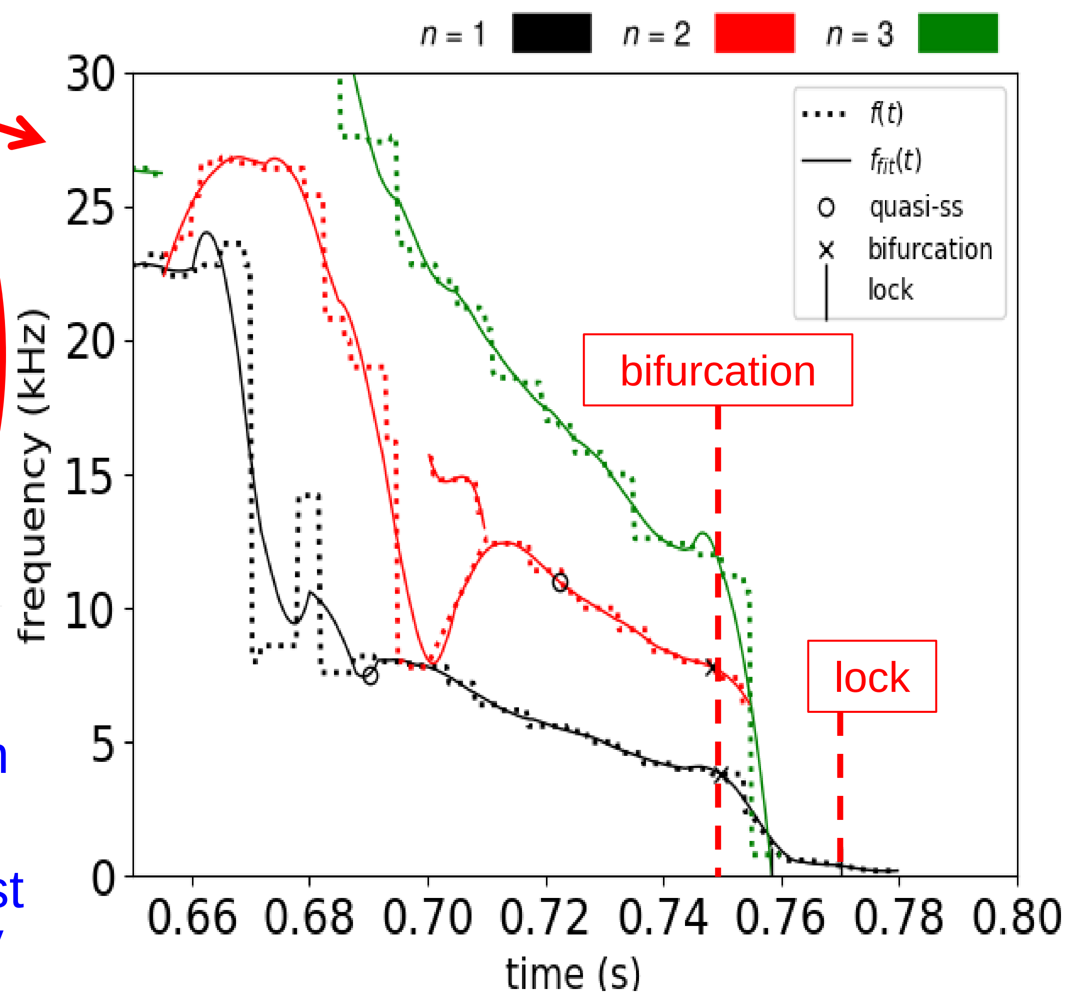


- Frequency vs. time determined for continuous mode activity defines an object, fit for analytic determination of f'(t)
- Quasi-steady state, rotation (bifurcation), and mode locking are automatically flagged for use by the DECAF code

Algorithm tracks each mode as desired, searching for bifurcations, locking

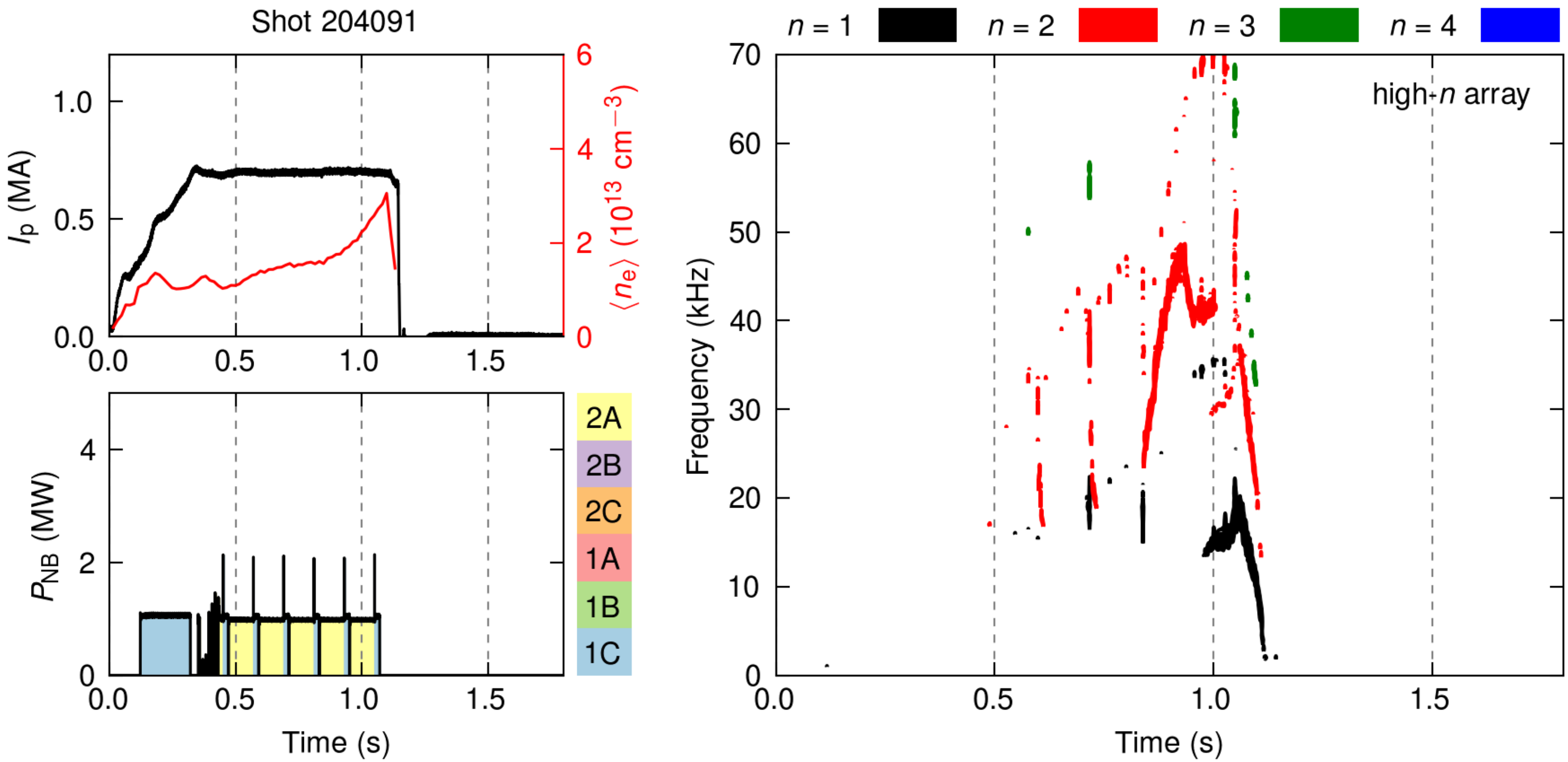


Zoomed-in View



- Each "separate" mode considered a separate object in DECAF
- Ongoing work to determine best ways to fully distinguish activity

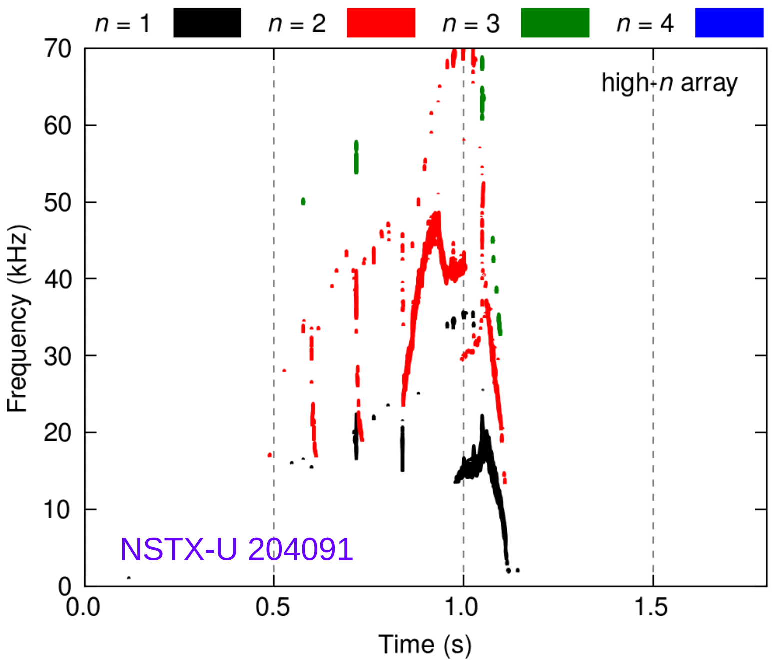
Examine mode locking in NSTX-U H-mode plasma



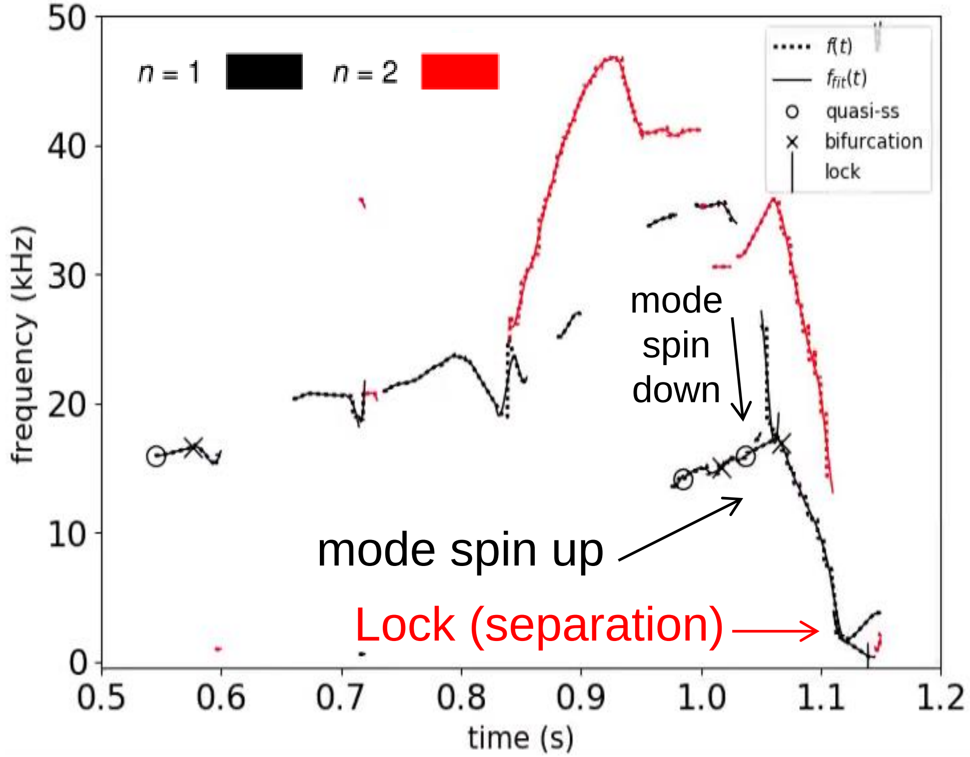
- Experiment switching NBI and using beam blips leads to mode lock at insufficient plasma rotation

Mode bifurcation and locking identified well in NSTX-U H-mode plasma

Magnetic spectrogram

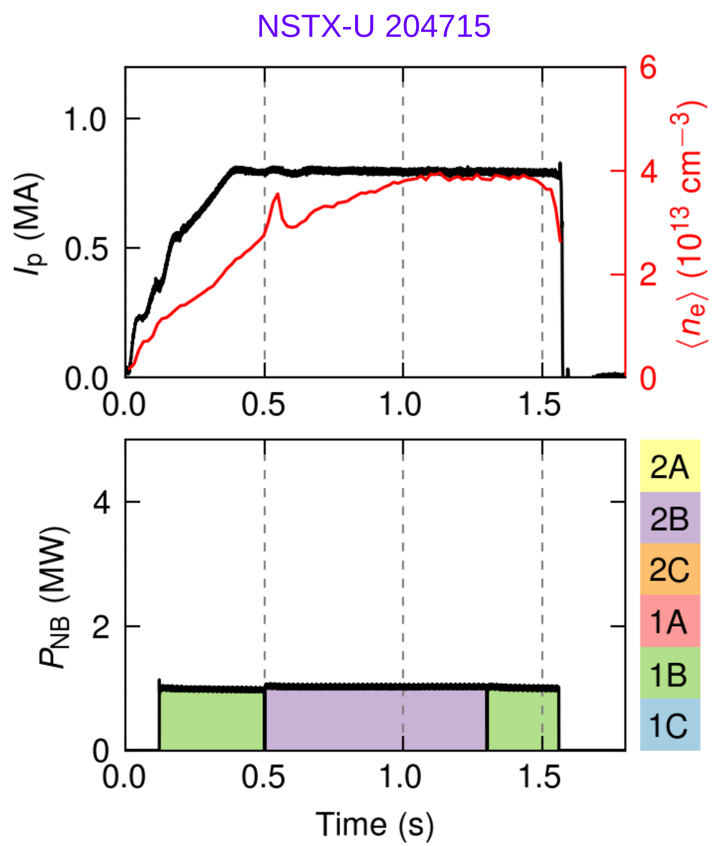


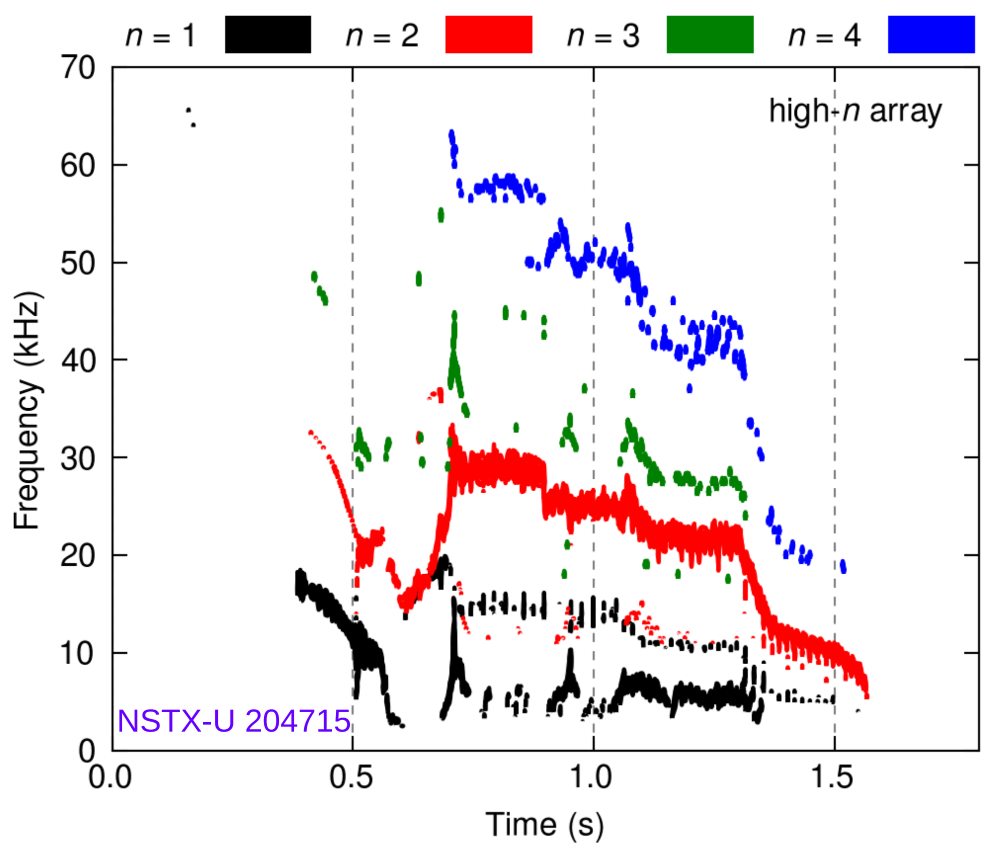
Mode object and event analysis



- Code shows two n = 1 modes match frequency near time of bifurcation, apparently separate at mode lock

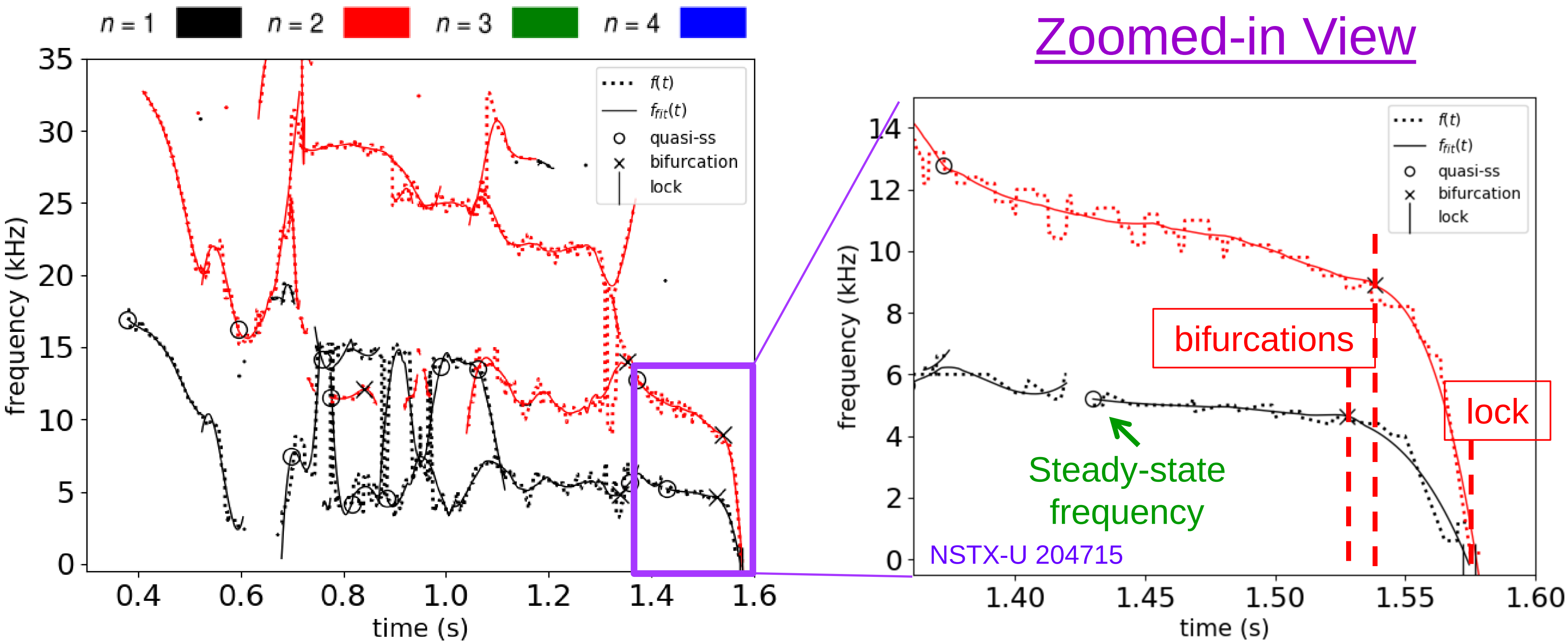
Richer mode activity somewhat more difficult to handle – concentrate on most dangerous modes





- Code to ignore n = 3, 4 modes here due to high frequency, discontinuity
- What will happen to frequency-separated n = 1 activity?

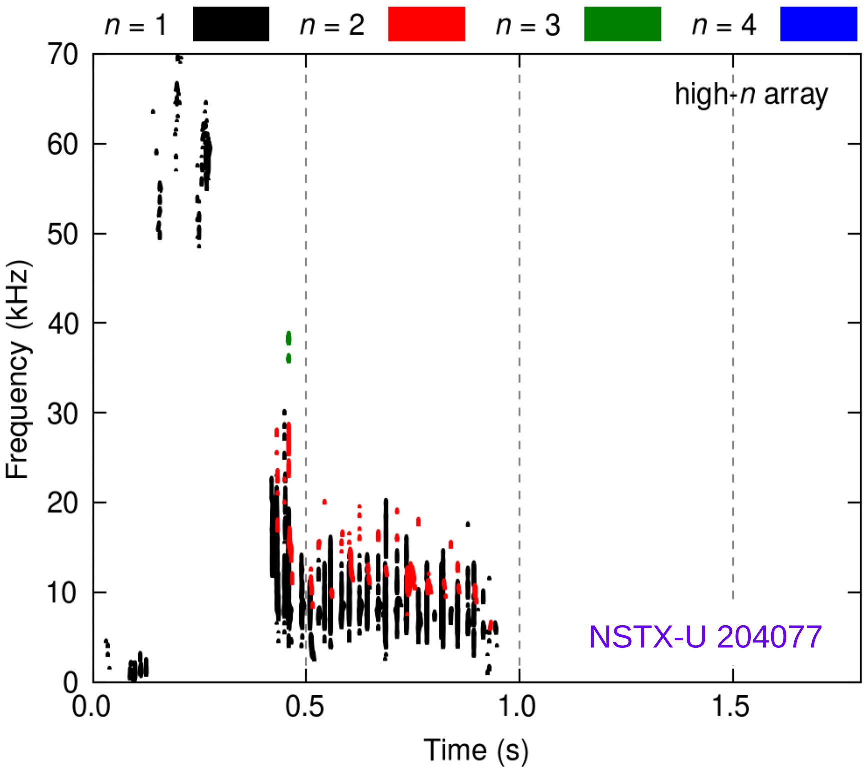
n = 1, 2 modes are tracked, bifurcations and locking identified



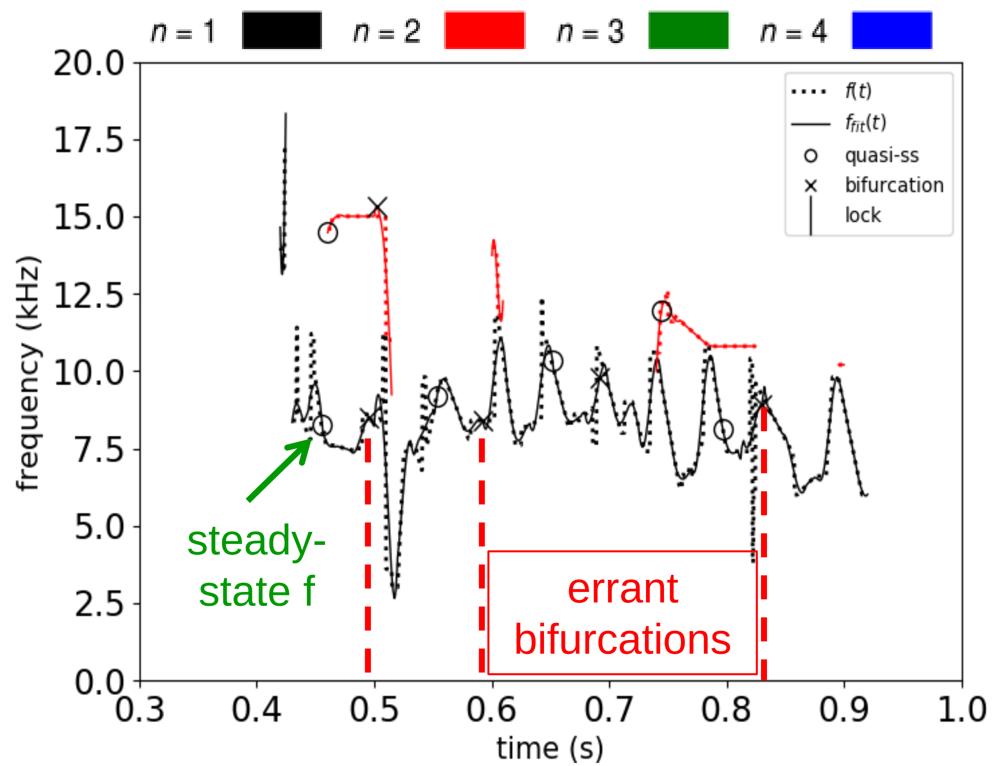
- Frequency separated n = 1 modes ~ 0.8s – 1.0s sometimes joined
- Good identification of bifurcation and lock (most important)

Sawteeth reveal that bifurcation algorithm needs somewhat greater intelligence

Spectrogram



Automated processing



- Algorithm does identify sawtooth activity as continuous
- Inflections in frequency presently interpreted as bifurcations (to be fixed)

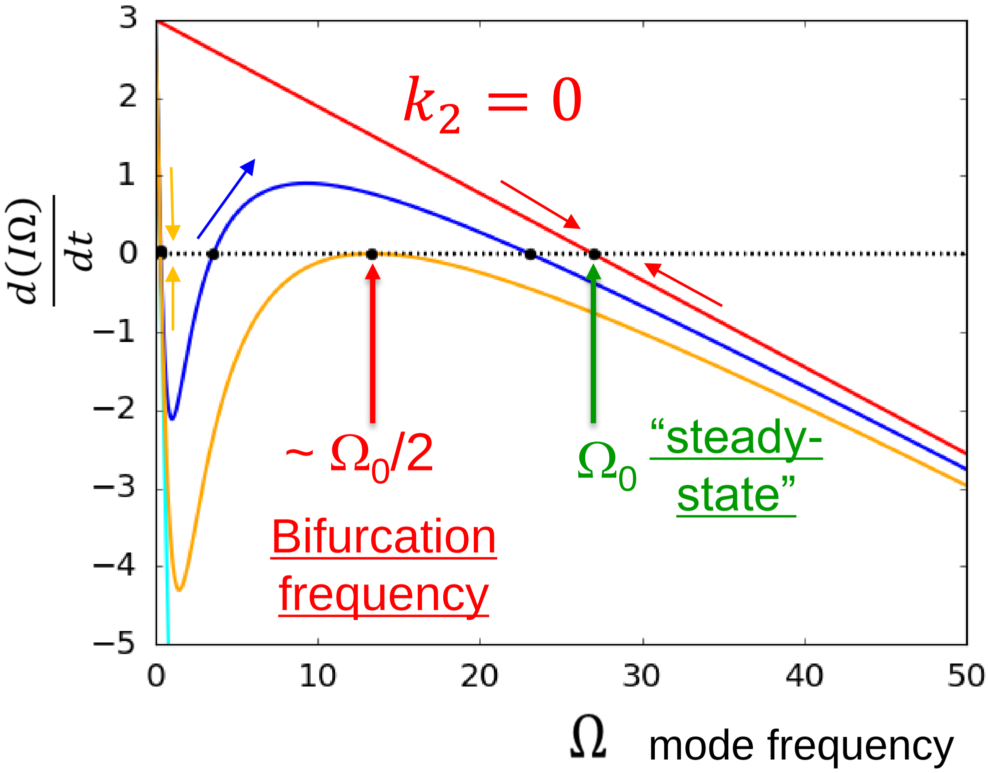
Simple physics model for mode rotation evolution / mode lock forecasting derived, can be tested in DECAF as next step

- Model derived to allow island drag for both "slip" and a "no slip" condition

$$\frac{d(I\Omega)}{dt} = T_{aux} - \frac{k_2\Omega}{1 + k_3\Omega^2} - \frac{(I\Omega)}{\tau_{2D}}$$

$$T_{mode} = \frac{k_2\Omega}{1 + k_3\Omega^2}$$

Model based on
R. Fitzpatrick et al., NF **33** (1993) 1049



- Simple "Ω_0" defines steady state
  - Robust way to define this using the automated code?
- Simple "Ω_0/2" defines bifurcation point

Automated characterization of rotating MHD modes is a key capability for disruption analysis, forecasting goal

- Automated algorithm developed to characterize rotating MHD modes, spot their bifurcation and locking
  - A critical capability to process general tokamak databases (ubiquitous rotating MHD activity)
- General algorithm in portable Python code discriminates toroidal mode number, tracks modes as objects for DECAF
- The algorithm was tested on a set of expected plasma scenarios in NSTX/-U
- Code reads and can process KSTAR data. Needed next step to improve reading speed for long pulse data with high sampling rate