Role of fast-ion transport to sustain the high q_{min} profile in KSTAR discharges

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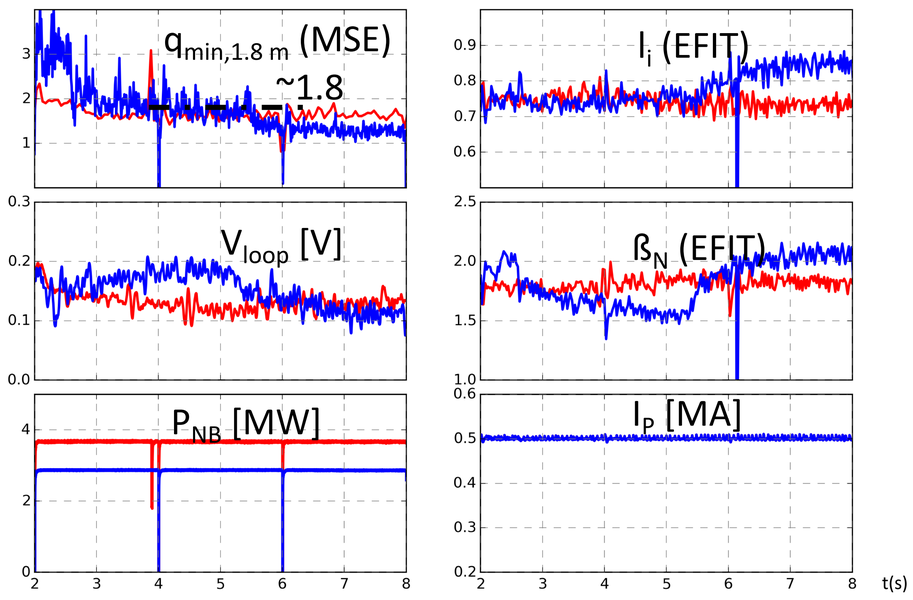
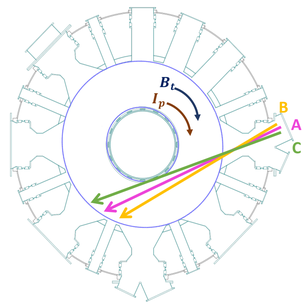
Introductions & Background

In 2018, KSTAR has achieved high q_{min} operation
1.8T 21006 (NBI1 B&C) 21695 (NBI A&B) both case shows similar results.



KSTAR NBI1 configuration



each beam has different radii of tangency
B is the most tangential, C is the most perpendicular

- Interaction between fast-ion transport(especially NBCD) and Alfvénic activties has been reported in major devices.

  DIII-D (K. L. Wong et al., NF 2005) ASDEX (S. Günter et al., NF 2007)
  NSTX (M. Podestà et al., NF 2015)

- Progress on a reduced models to contain phase space physics has been accelerated fast-ion transport study.
  (M. Podestà et al., NF 2014 NF 2017)

- Recently KSTAR observed similar phenomenon, long-pulse characteristics of KSTAR would expand research regime in a single discharge.
  - Repeated excitation / suppression of Alfvén wave.
  - Current diffusion study in 20~30 times longer than current diffusion time scale.

High q_{min} is sustained during 10 times longer than current diffusion time with V_{loop} > 0.1
→ Main research motivation.

Objective of this study

- Identify observed Alfvenic modes.
- If it is Alfvenic kinds, investigate effects of the modes on fast particles/energy transport.
- Test of fast ion transport effect on the formation of the broad current profile.

Numerical Apparatus

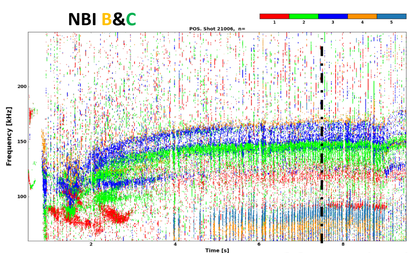
NOVA/NOVA-K: Linear stability 2D Kinetic-MHD code for tokamaks with energetic particles.
- ✓NOVA code which calculates Alfven continuum, eigenfunction and eigenvalues is used to analyze eigenmode observed in experiment by collaboration with PPPL.
- ✓NOVA-K calculates instabilities for each mode by fast-ions.

KICK/TRANSP: a reduced fast ion transport model containing phase space effects

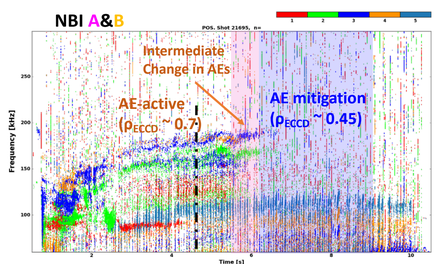
Spectrogram Observation

Various high frequency MHD modes (>100kHz) has been observed

Mirnov spectrogram shows activities of the modes of Alfvénic frequency



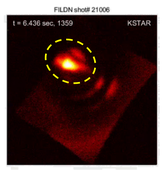
6.8s analysis point



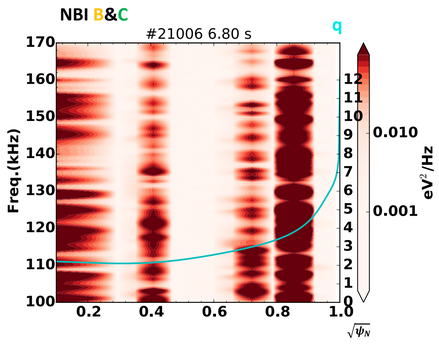
4.45s analysis point

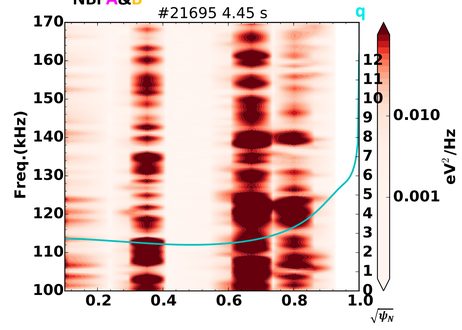
- Mainly n=2,3,4 around 150kHz modes are observed from edge Mirnov.
- When performance is increased, those patterns disappear.
- Two shot has been adopted the same operation scenario.(shape/heating timing)

High q_{min} scanerio: Inter-ELM fast-ion loss is strong even in the H-mode.



ECE Spectogram guides its radial position

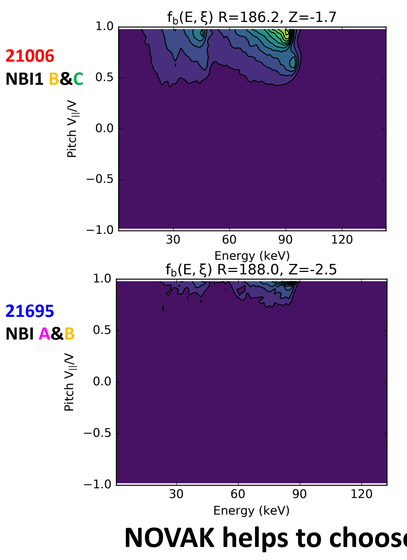




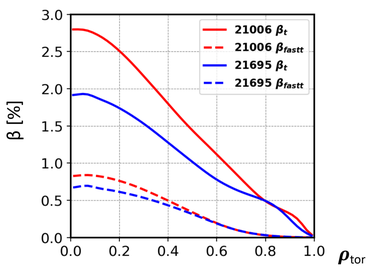
- Those could be internal modes.
- Both shots suggest that strong off-axis modes could be responsible for fast-ion transport

Numerical Modeling Results [NOVA / NOVAK / ORBIT / Kick-model]

Each NBI combination leads different fast ion distribution function

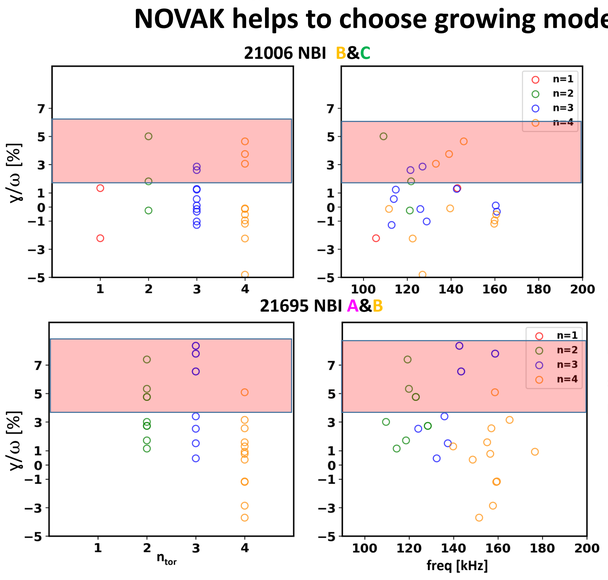


Here, ad-hoc method of NUBEAM is adopted.



Even 21006 has more NB power, its perpendicular components could lead an ineffective NBCD.
→ Total beta is bit different, fast ion beta is similar

NOVAK helps to choose growing modes



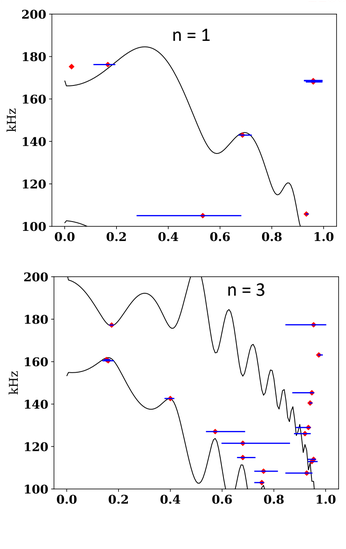
Like local map, more unstable modes are expected in 21695 case.

Mostly n=2,3,4 modes are unstable

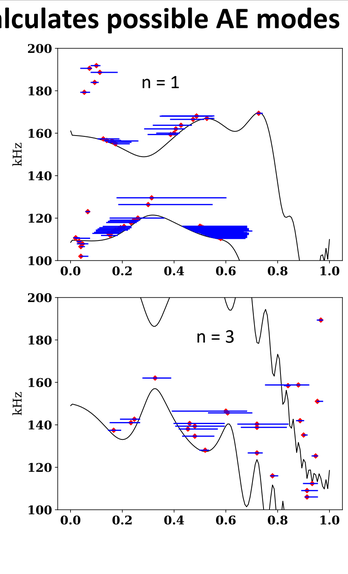
~120 to 160 kHz are unstable

Shaded modes are chosen to run orbit and compute probability matrix for kick-model.

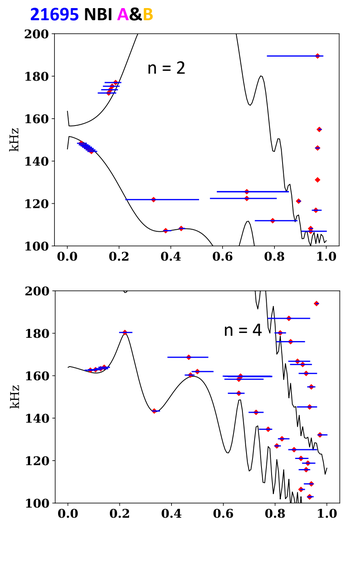
21006 NBI B&C

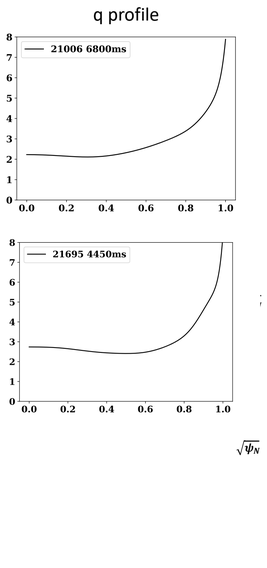


NOVA calculates possible AE modes



21695 NBI A&B

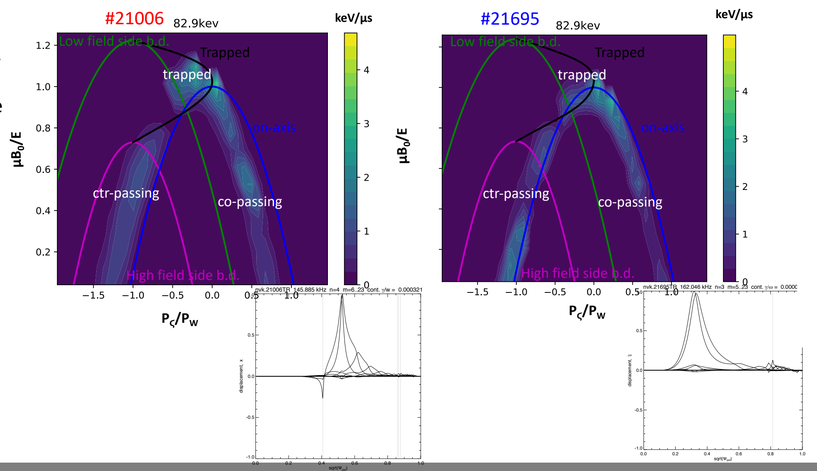




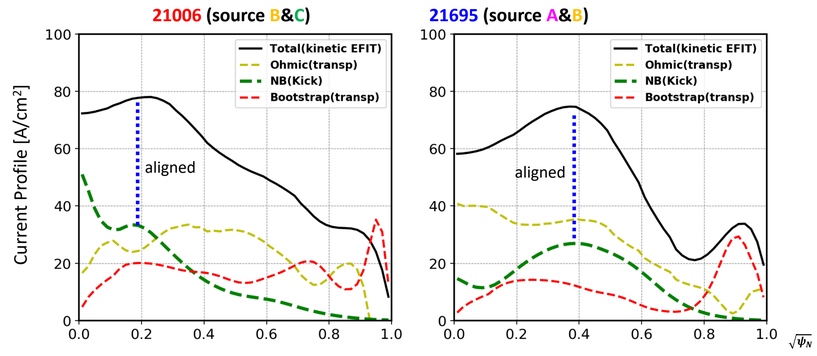
ORBIT reveals phase space transport of fast ions by TAEs

Interaction between co-passing fast particles (NBCD main contributor) and TAE is strong.

< Selected eigenfunction and root mean square of the energy kicks in the (P_ζ,μ) plane>



➢ **On-axis KSTAR J_{NB} becomes like off-axis NBCD profile with strong AE activities**



Beam is the main non-inductive current driver for this shot.
It suggest that J_{NB} with active Alfvenic activity would be the candidate to sustain high q_{min}.
In 21695, inward modes make strong fast-ion transport in core region → more hollow current profile.

Summary & Future Work

Summary
A high q_{min} scenario has been developed in KSTAR and a steady-state high and broad q profile has been sustained even without strong off-axis current drive scheme.
Measured spectrogram and NOVA analysis suggest that there could be Alfvénic activities
- The frequency of the magnetics/ECE spectrogram and the electron temperature fluctuation pattern of the ECE were compared with the NOVA analysis..

Phase space effect on NBCD has been shown with ORBIT/Kick-model
- high and broad q profiles are obtained in the KSTAR plasma with a moderate non-inductive fraction when off-axis NBCD profile is produced from the fast-ion transport due to by Alfvenic modes.
- A positive aspect of Alfvenic mode driven fast ion transport in the KSTAR is the generation of favorable q-profile modification.

Future Work

In 2019, experiments on fully non-inductive discharges to isolate J_{oh} effect.
+ Interaction of ohmic current diffusion vs Alfvènic activities.
Cross-check with FIDA fast ion pressure profile.
Role of ASEs on NBCD current profile modification.