Fast-ion Transport by Alfvén Instabilities in DIII-D

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Goal: Detailed measurements of fluctuations and fast ions to predict alpha transport in ITER

- Flattened fast-ion density profile
- More profile measurements
- Modeling status
Alfvén Modes Degrade Fast-ion Confinement

- Volume-averaged neutron rate is below the classical TRANSP prediction during the strong Alfvén activity

- Fast-ion $D_\alpha$ (FIDA) diagnostic measures the spectrum of fast ions with 4 cm spatial resolution*

- FIDA “density” near $\rho_{q_{\text{min}}}$ is reduced during the strong Alfvén activity

The Fast-ion Deficit Correlates with Alfven Activity

- The strength of the Alfven activity tends to increase with beam power in similar plasmas.
- The discrepancy between the classical prediction and the data is largest when the Alfven modes are strong.
- The FIDA deficit is larger than the neutron deficit.

*For this comparison, the FIDA density and neutron rate are normalized by their values at 2.0 s in the 1-source shot (when Alfven activity is undetectable).*
The Fast-ion Density Profile is Flattened

- During the strong Alfven activity, the fast-ion density profile from FIDA is nearly flat
- The fast-ion profile inferred from the equilibrium* is also very flat
- The classical profile computed by TRANSP peaks on axis

*The kinetic EFIEquilibrium uses MSE and magnetics data to compute the pressure profile. Subtraction of the thermal pressure yields the fast-ion pressure. The FIDA data are normalized to the 1.20 s pressure profile.
My Questions (as of Fall ‘06)

• The FIDA and fast-ion pressure diagnostics do not measure the same thing: should their profiles be similar?
• Are the FIDA spatial profiles valid?
• Can the measured modes explain the flattened profile?
The Pressure and FIDA techniques diagnose the same parts of velocity space

- Different fast-ion diagnostics weight velocity space differently.
- The FIDA weighting shown here is for $E_\lambda = 50$ keV.
- After averaging over the distribution function $F(E,p)$ and over wavelengths, the FIDA and pressure diagnostics have similar weightings.
FIDA relative radial profile agrees well with TRANSP prediction in quiet plasmas

- Fast-ion distributions from TRANSP are dumped to the simulation code.
- Simulated profiles are higher as expected at the later time when electron density is lower.
- At the early time, FIDA profile is normalized to the simulated profile.
- At the later time, FIDA profile agrees with the simulated profile.
- Radial profile of fast-ion pressure inferred from kinetic EFITs (MSE data) are also consistent with TRANSP.
First Try at Radial Profile in Quiet Plasma showed Disagreement

- This one-source L-mode plasma has modest Alfvén activity!
- The EFIT fast-ion pressure profile differs from TRANSP as well
Perpendicular Fast-ion Acceleration at 4th Cyclotron Harmonic

- Neutron enhancement during ICH $\rightarrow$ fast-ion acceleration
- FIDA data $\rightarrow$ distribution function distorts
- Slight increase in bulk; perpendicular tail forms
Profiles agree well during ICH acceleration

- Fast-ion pressure exceeds classical (no RF) prediction.
- FIDA profiles show similar trends.
- The FIDA data are averaged over wavelength and time, then normalized to the no-RF profile.
Reasonable values for the spatial profile of ICH acceleration

• The profile peaks ~10 cm farther out than the nominal resonance layer.
• Calculate the expected fast-ion distribution function in CQL3D, then calculate the expected FIDA spectra and profile.
• The CQL3D prediction is close to the data.
Likely Explanation for Outshifted FIDA Signal: Orbit Effects

- Launch orbits in FIDA spatial volume with values of $v_z$ that contribute strongly to the FIDA enhancement.
- Representative orbits have turning points near the Doppler-shifted resonance layer.
1. Match linear NOVA-K eigenfunctions to ECE data.

2. Insert these modes (with experimental amplitudes) into ORBIT drift orbit code. Compute fast-ion transport.

3. Dump ORBIT distribution function. Use diagnostic simulation codes to predict signals. Compare with data.
The Mode Structure agrees with linear ideal MHD Theory

n=3 RSAE

- The MHD $\delta T_e$ amplitude is scaled to match the ECE data
- Easy to match strongest TAE and RSAE modes

Modes move fast ions from magnetic axis to half-radius

- Pitch-angle scattering is included @ experimental level of ~2 Hz
- Mode amplitudes are scaled up to investigate effect.
- The change in the distribution roughly doubles for a 3.8 ms run.
Does the “Sea” of Activity Cause Diffusive Transport?

- ECE Data (Blue is strong)
- Many modes that constantly change
Can use ad hoc beam-ion diffusion in \texttt{TRANSP} to match experimental profile

\begin{itemize}
  \item Used spatially uniform $D_B$ in this initial run.
  \item Need a large $D_B$ in core, smaller outside 0.6 to match experiment.
\end{itemize}
Revised Analysis Plan for Alfven Mode Transport

1. Match linear NOVA-K eigenfunctions to ECE data. OK

2. Insert these modes (with experimental amplitudes) into ORBIT drift orbit code. Compute fast-ion transport for a few milliseconds.

3. Estimate diffusion from ORBIT run. Compare with \textit{TRANSP} ad hoc diffusion coefficient that matches the data.
• The FIDA and fast-ion pressure diagnostics do not measure the same thing; should their profiles be similar? Yes, they detect the distribution function in the same portion of velocity space.

• Are the FIDA spatial profiles valid? Yes, profiles analyzed the same way in quiet and ICH-heated plasmas make sense.

• Can the measured modes explain the flattened profile? I don’t know yet.
Backup slides
My Questions (as of 11/06)

• Are the FIDA spatial profiles valid?
• The FIDA and fast-ion pressure diagnostics do not measure the same thing: should their profiles be similar?
• Can the measured modes explain the flattened profile?
Fast-ion $D_\alpha$ (FIDA) Diagnostic

- A type of Charge Exchange Recombination Spectroscopy
- Use vertical view to avoid bright interferences
- Exploit large Doppler shift (measure wings of line)

- Background subtraction usually dominates uncertainty
- Achieved resolution: $\sim 5$ cm, $\sim 10$ keV, 1 ms.