ALFVÉN INSTABILITIES DURING ICRF MINORITY HEATING IN TFTR.

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WHY STUDY ALFVÉN INSTABILITIES?

- **ICRF minority tail ions losses due to Alfvén Instabilities melted a hole in TFTR vacuum vessel in 1994.**
- **Alpha particle losses due to same instabilities in ITER might damage the first wall.**
- **Energetic Particle Modes are more strongly correlated with losses than Toroidal Alfvén Eigenmodes (TAEs).**
- **These modes degrade the ICRF heating efficiency.**
- **Scaling for ITER has to take into account the various modes.**

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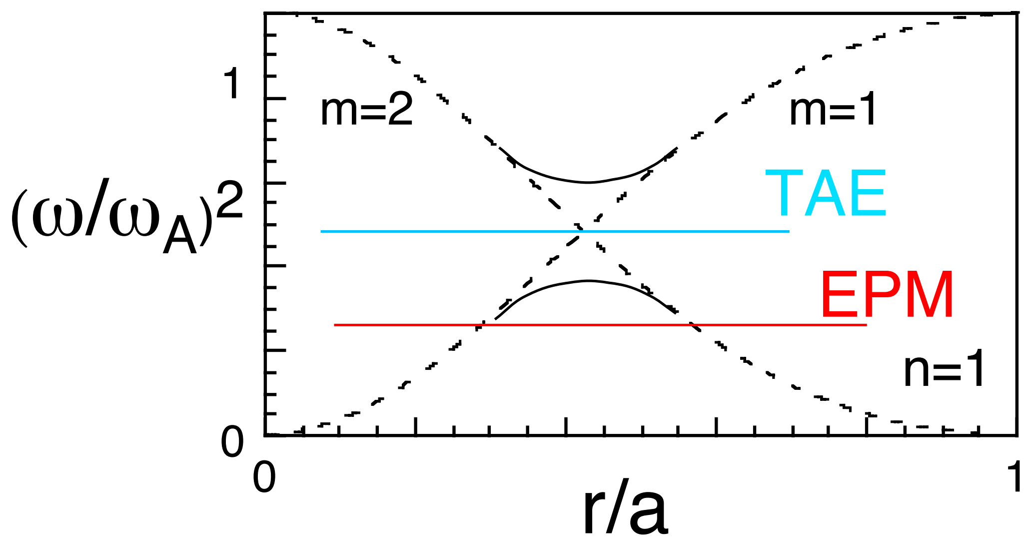
TOROIDICITY INDUCED ALFVÉN MODES

- **Toroidicity induces frequency gaps in shear Alfvén continuum.**



$$\omega_A^2 = k_{\parallel}^2 V_A^2$$

$$V_A = B/\sqrt{4\pi\rho} \approx V_{hot}$$

- Wave-particle interaction can excite discrete resonances of the background plasma inside toroidicity induced gap (TAE).

- Strong fast particle drive can resonantly excite new Alfvén modes: RTAE,EPM...

- Modes are driven by $\nabla\beta_{hot}$

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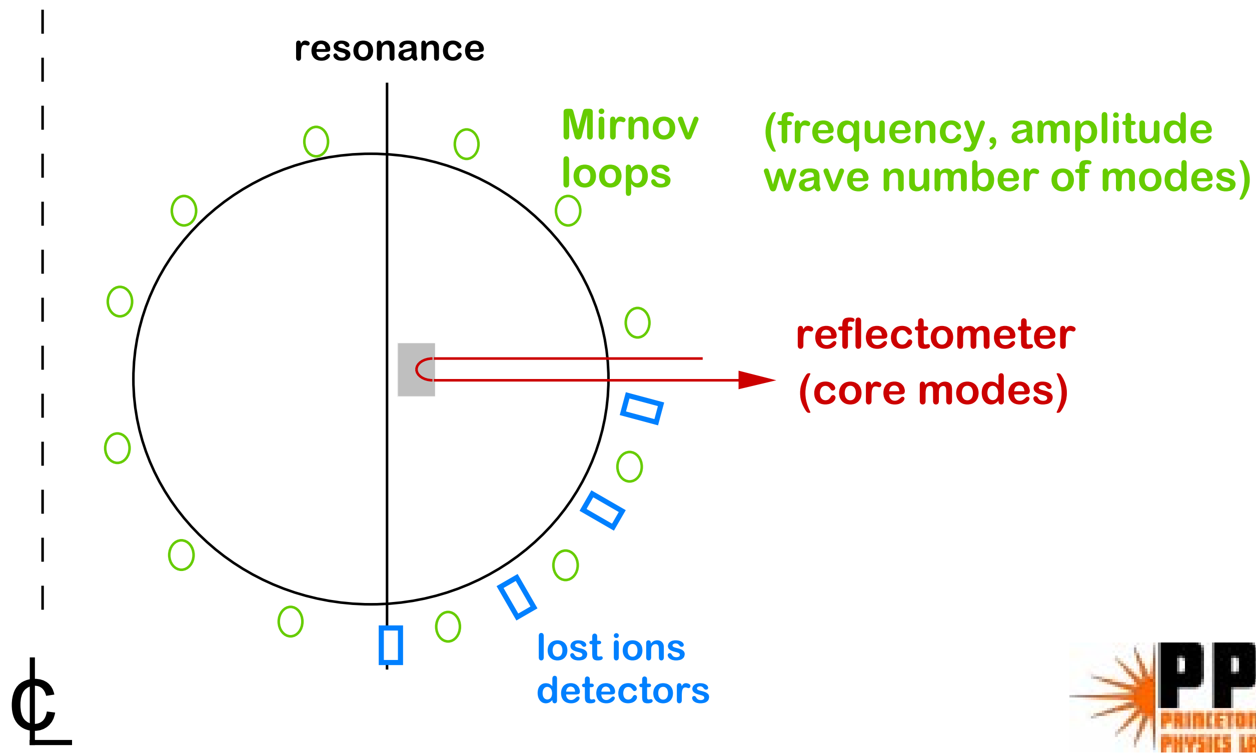
EXPERIMENTAL CONDITIONS

average density	2-4.6x10^{19} m^{-3}	frequency	43 47 63.6 MHz
current	1.2 1.8 MA	power	up to 11 MW
field	30.0 32.7 44.8 kG		

Hydrogen minority in Deuterium plasma

No NBI

$q(a)_{cyl} = 3.2$



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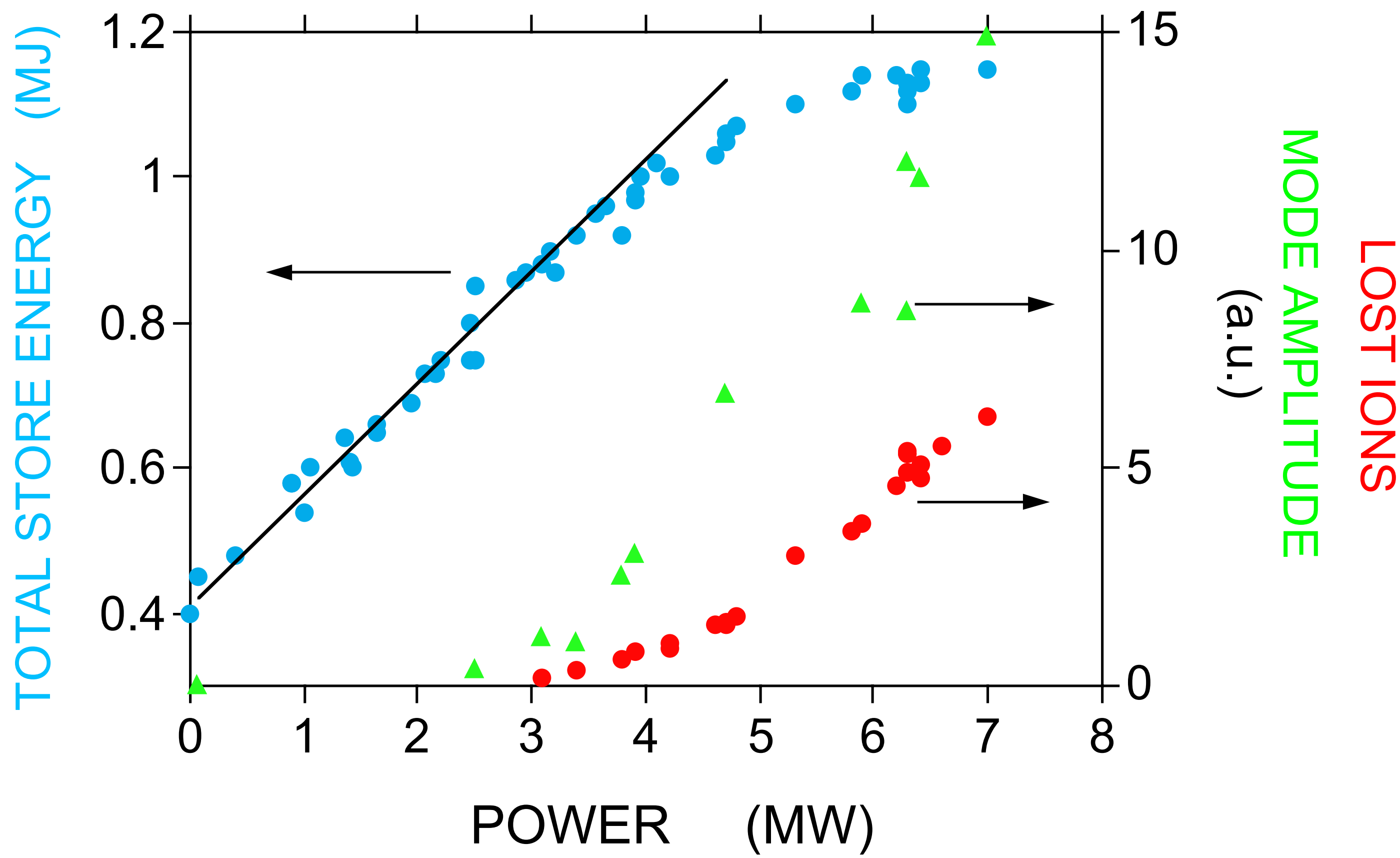
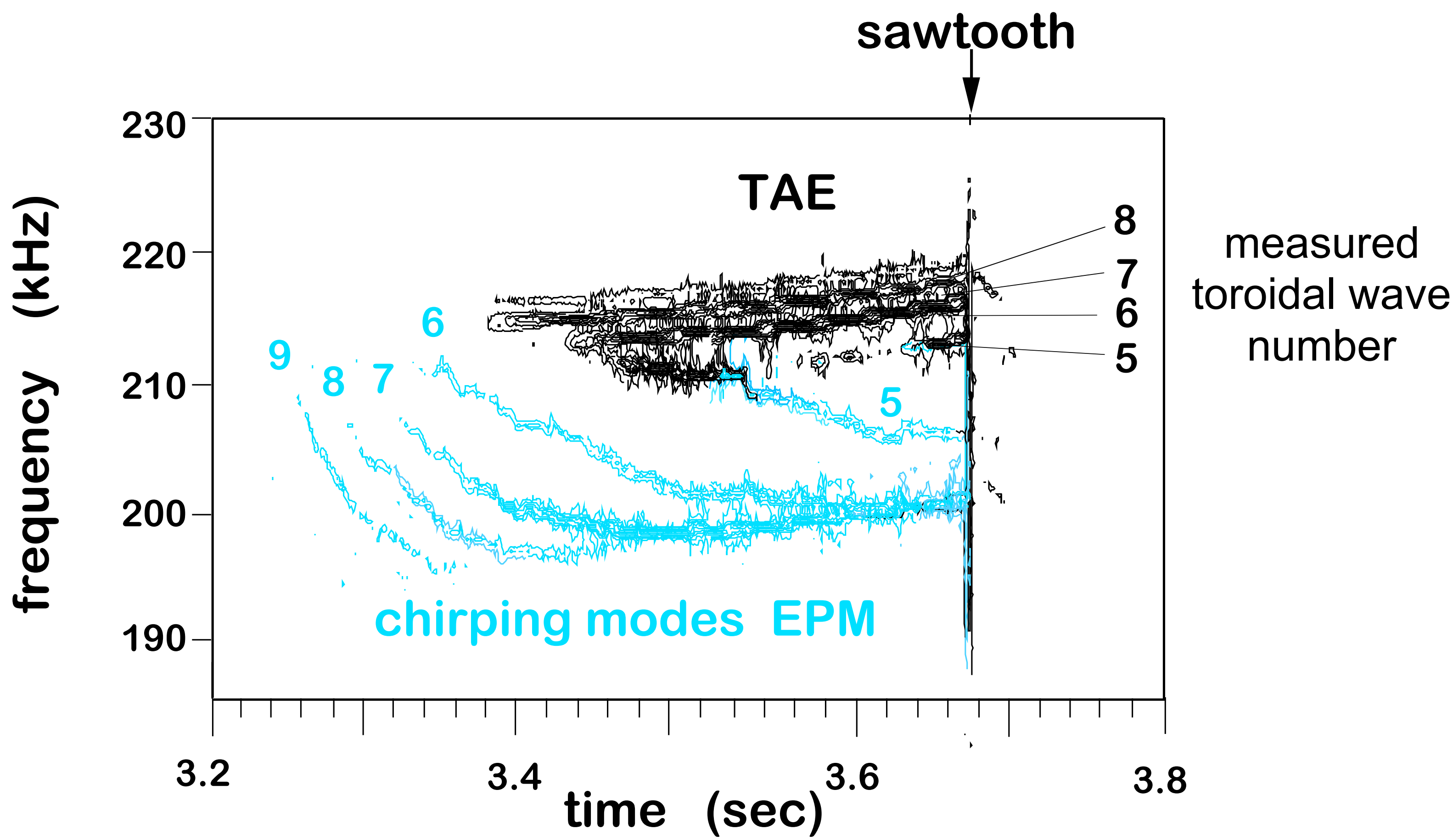
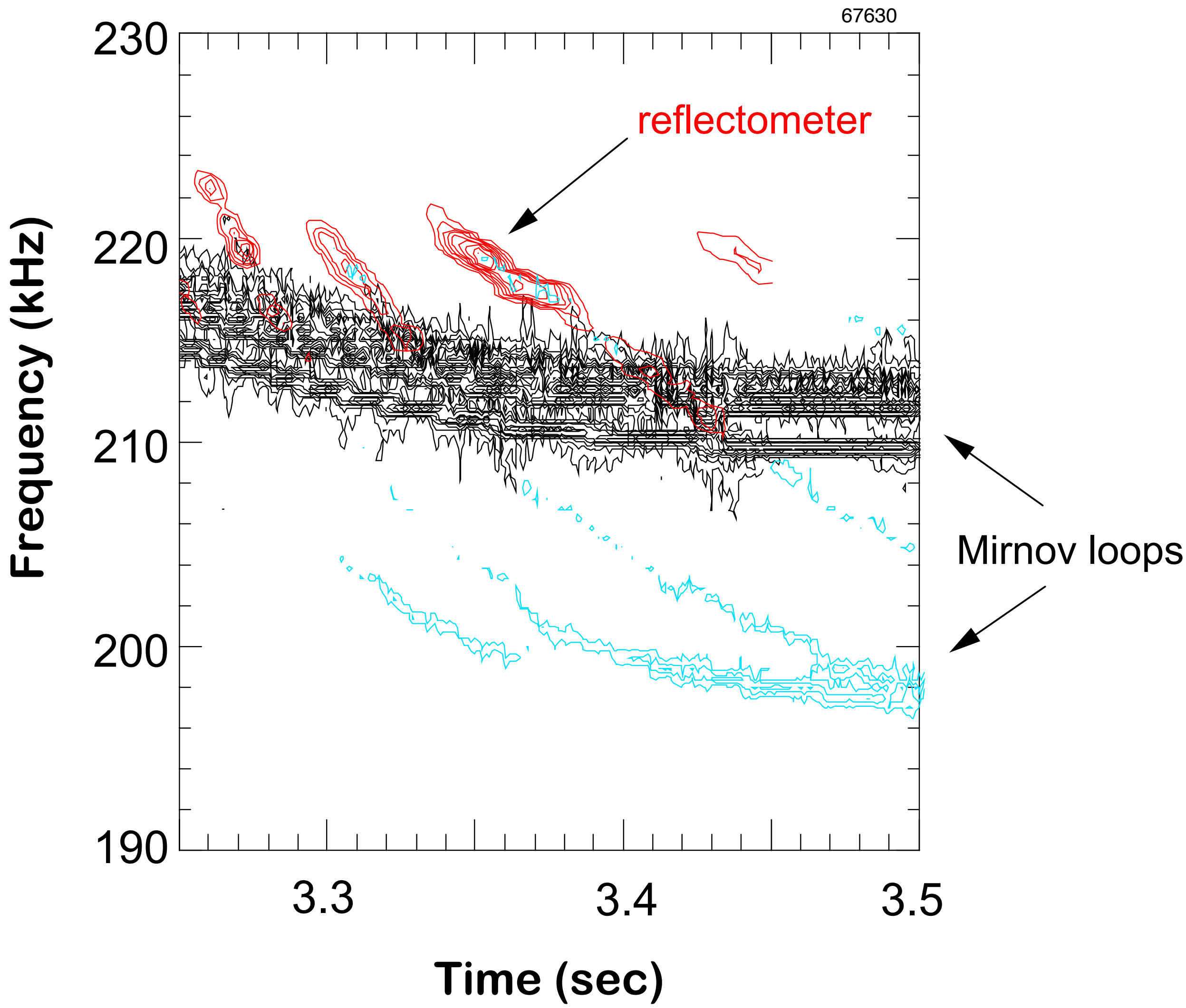
STORED ENERGY INCREASES LINEARLY WITH ICRF POWER UNTIL THE ONSET OF ALFVÉN INSTABILITIES



TWO TYPES OF MODES ARE USUALLY EXCITED IN THE ALFVÉN FREQUENCY RANGE



THE CHIRPING MODES ARE DETECTED IN THE CORE BY THE REFLECTOMETER BEFORE BEING DETECTED BY THE MIRNOV LOOPS



- **The chirping modes (EPM) move radially**

CHIRPING MODES CONSISTENT WITH THE ENERGETIC PARTICLE BRANCH OF THE ALFVÉN MODES

- **Perturbative analysis (NOVA-K code) finds no mode in the toroidal Alfvén gap due to high central pressure.**

- **Non-perturbative, high-n, fully kinetic code (HINST*) finds modes in the Alfvén continuum driven by strong fast ion pressure gradient.**

  - **Mode frequency chirps with small change in q(0).**

  - **Mode initially core localized and moves out radially.**

  - **Decreasing mode numbers with decreasing q(0).**

- **Guide center ORBIT code modeling predicts large fast ion redistribution for $\approx \Delta B/B \sim 10^{-4}$.**

*** Gorelenkov *et al*. Phys.Plasmas 5 p.3389 (1998)**

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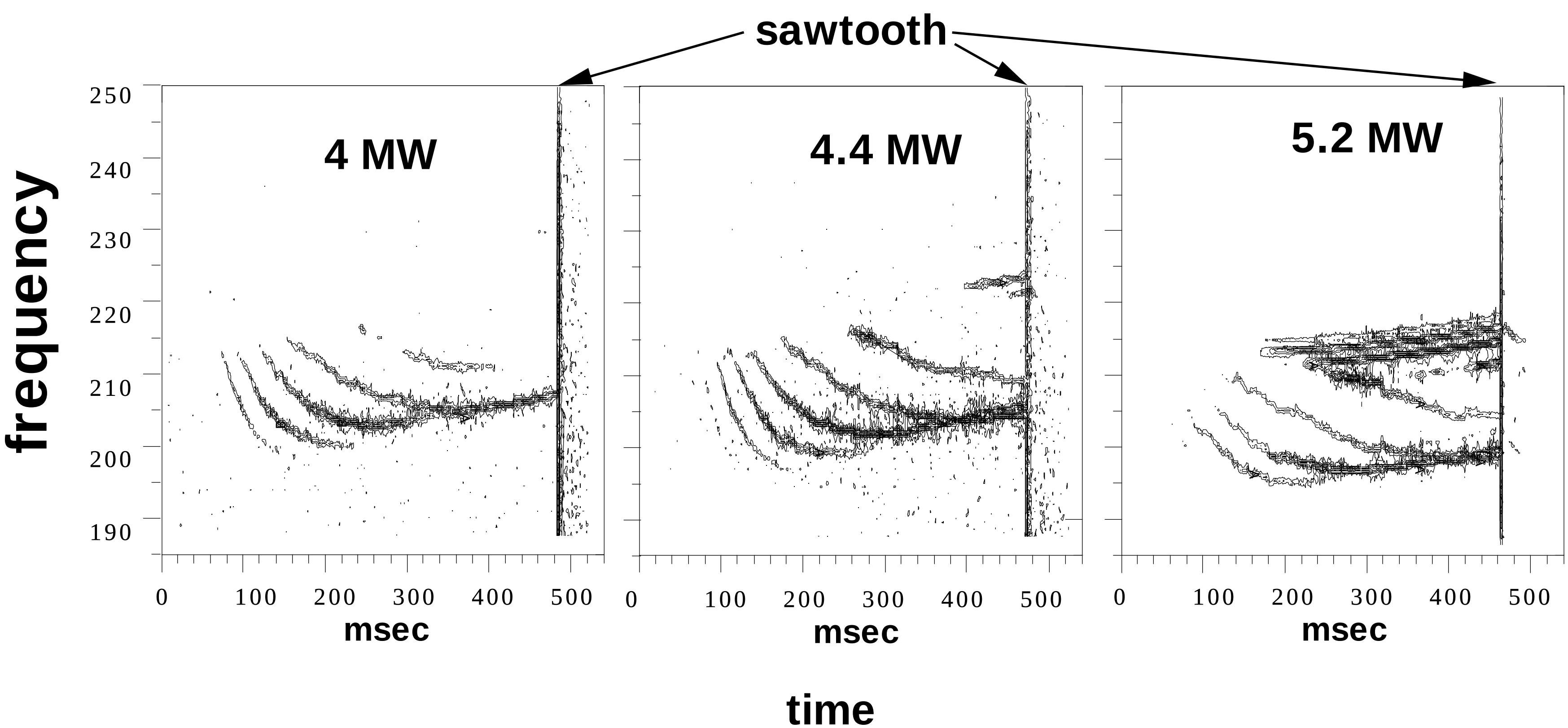
THE EPMs ARE DESTABILIZED BEFORE THE TAEs



- Fast ions in the core destabilize EPMs
- The fast ions, displaced by EPMs, move outward in minor radius and excite TAEs

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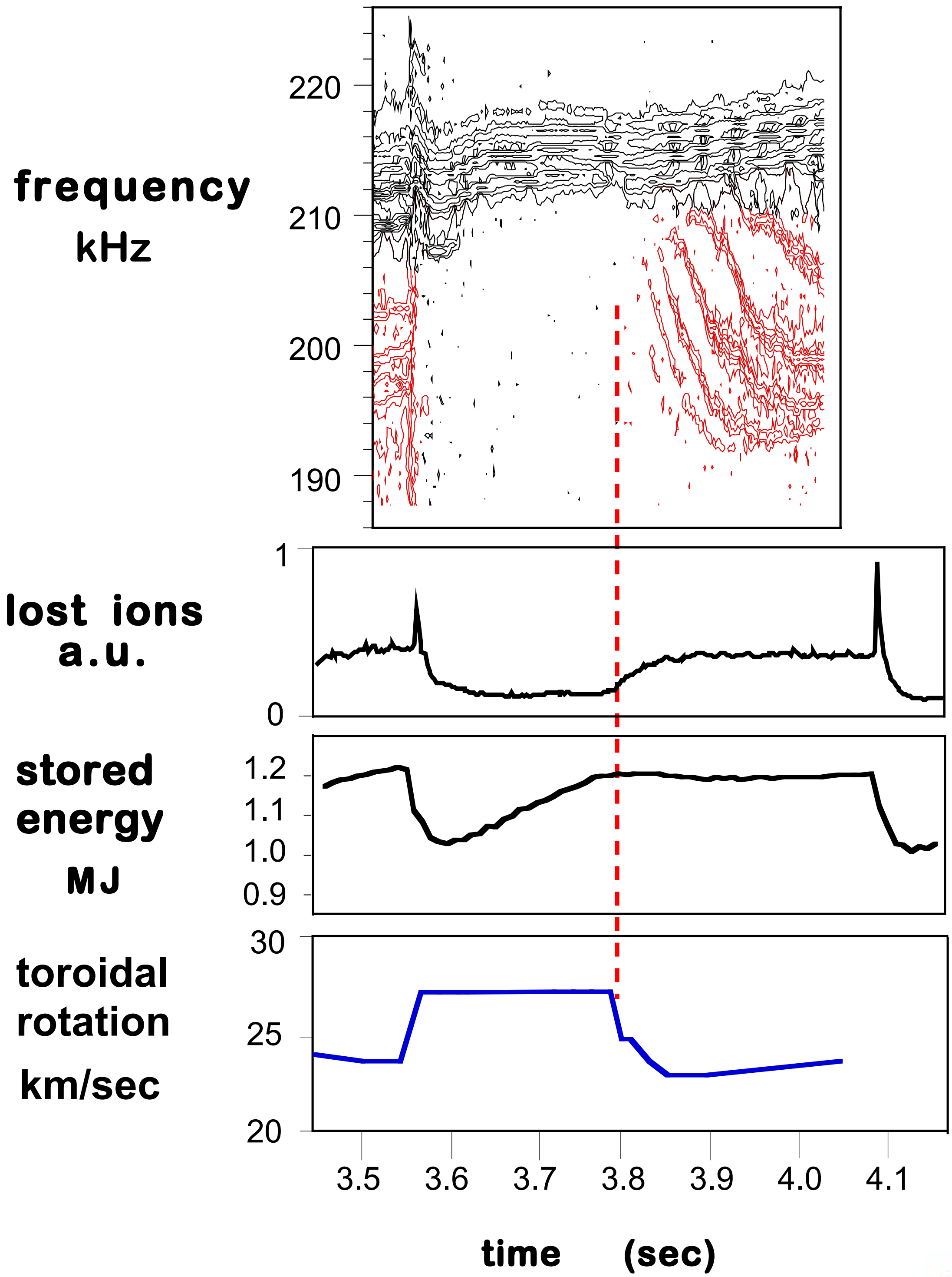
LOSSES ARE ASSOCIATED WITH EPMs



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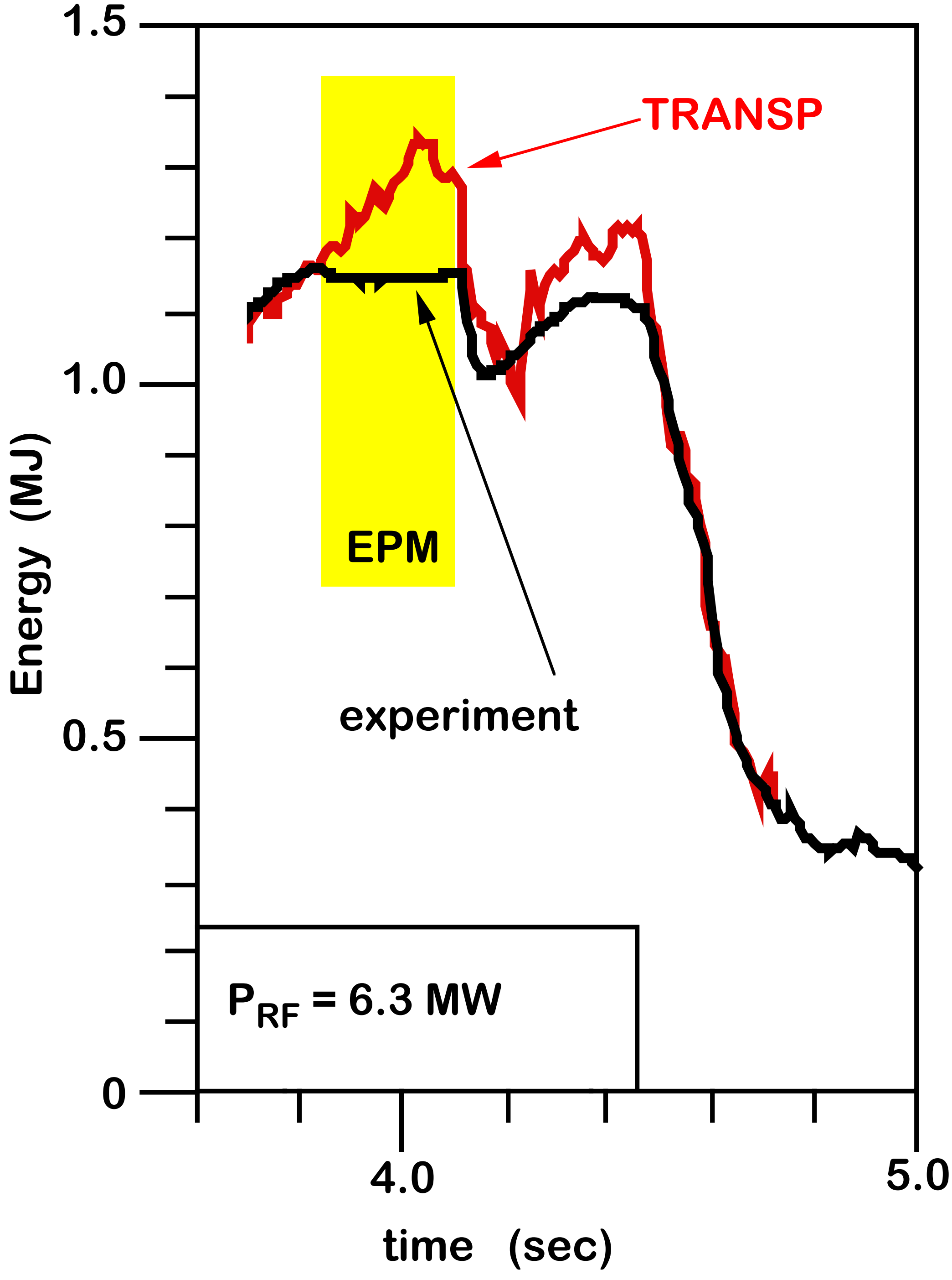
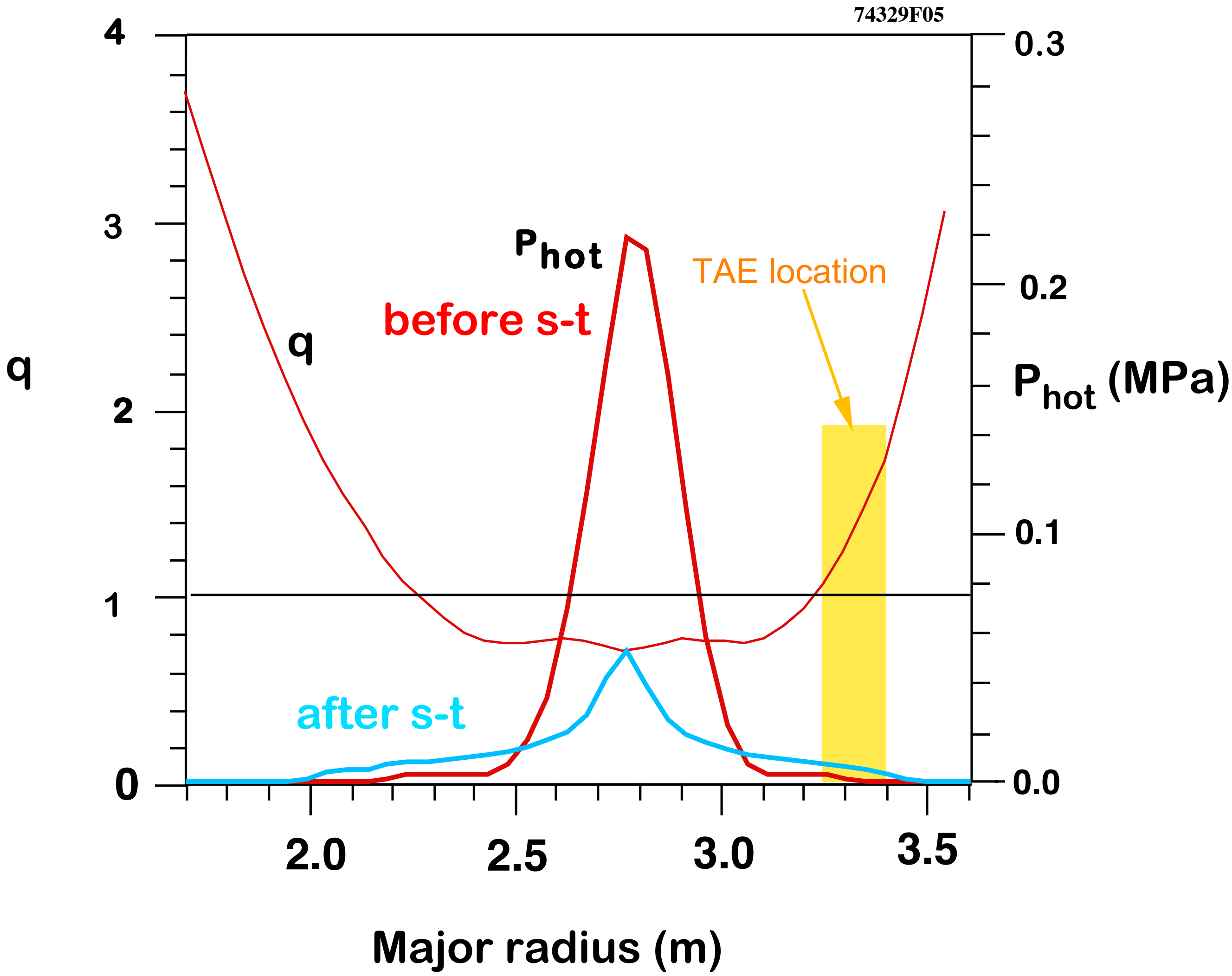
STORED ENERGY FALLS BELOW CLASSICAL PREDICTION DURING EPMs



EXCITATION OF TAEs DEPENDS UPON FAST ION RADIAL TRANSPORT DUE TO SAWTOOTH OR EPMs

See S. S. Medley, paper K6Q.09



- Initial fast ion distribution is entirely within q=1
- Sawteeth can move ions radially
- EPMs can do the same (ORBIT code)

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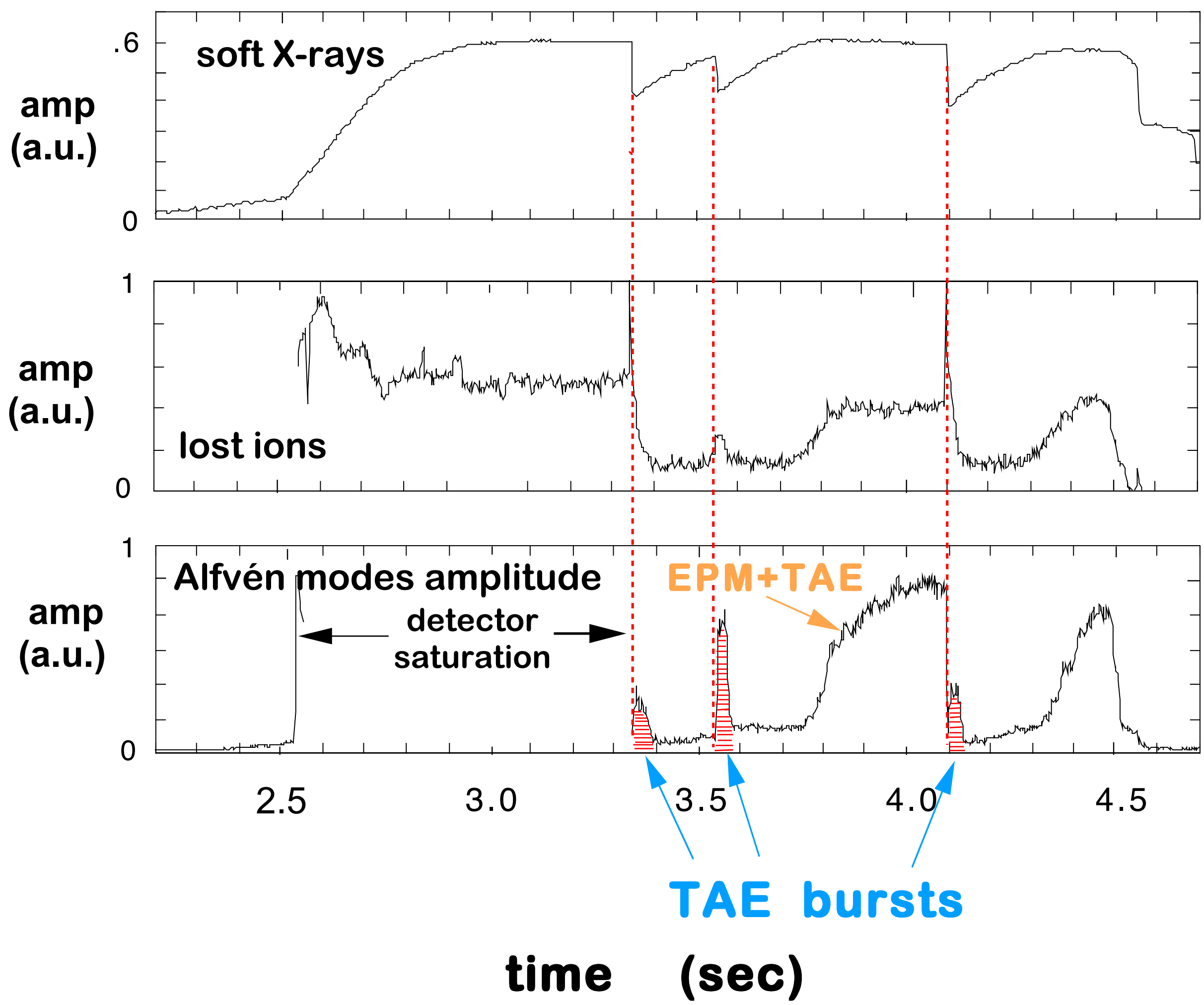
THE DISPLACEMENT OF FAST IONS BY SAWTEETH OR BY THE EPMs, EXCITES TAEs



MODELLING

is done by

1. **extracting the fast ion distibution function from TRANSP modelling of ICRF heating**
2. **then evolving this distribution function with the ORBIT code in the presence of modes.**

CONDITIONS NECESSARY FOR INDUCED DIFFUSIVE PARTICLE LOSSES ARE MET:

1. **Local resonant wave-particle interaction, consistent with experimental mode frequency;**
2. **significant mode amplitude, $\Delta B/B \approx 10^{-4}$;**
3. **broad radial extent of the modes OR radially sweeping modes**

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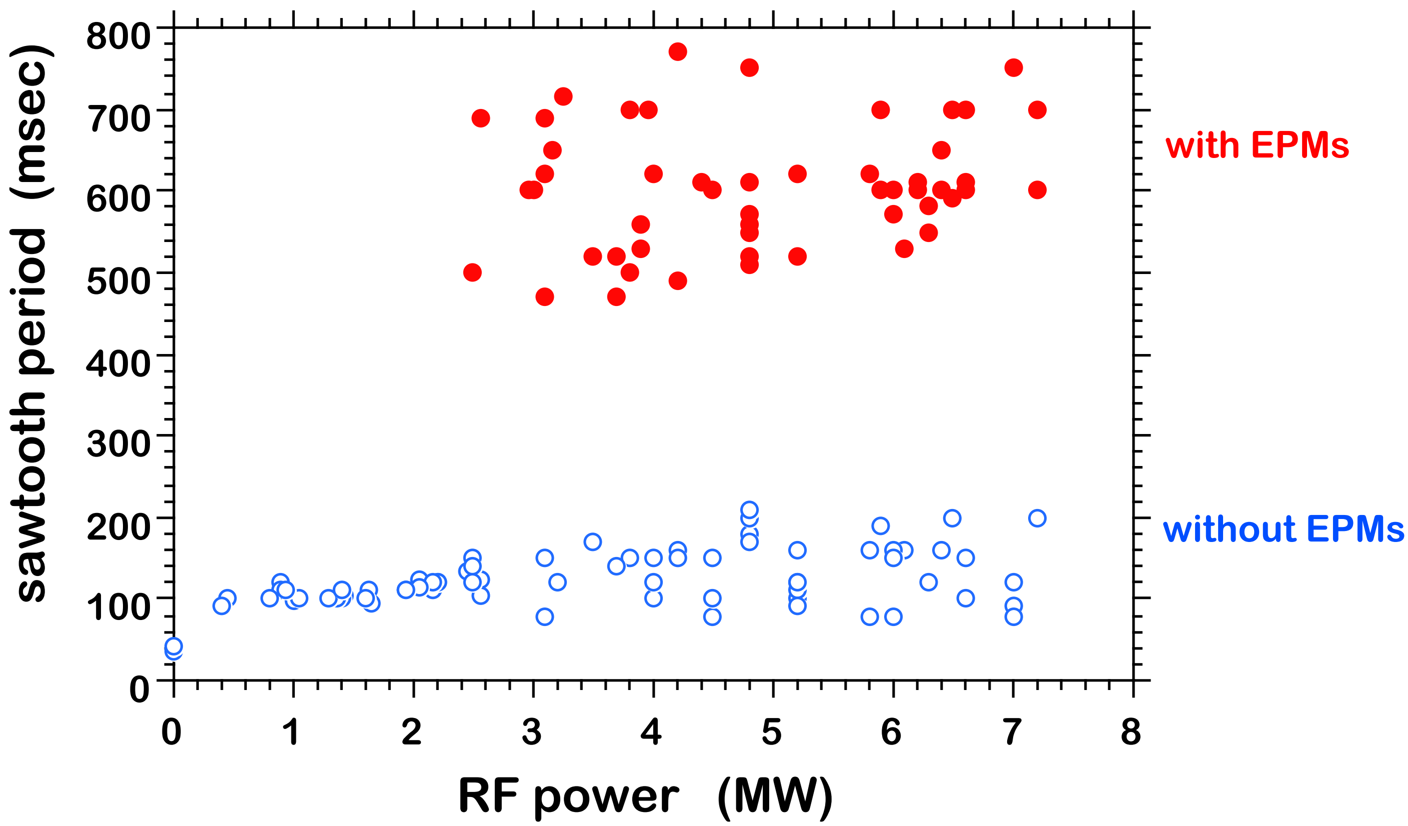
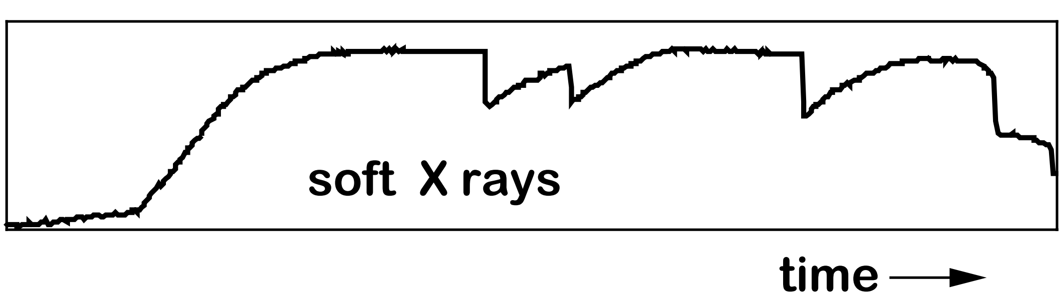
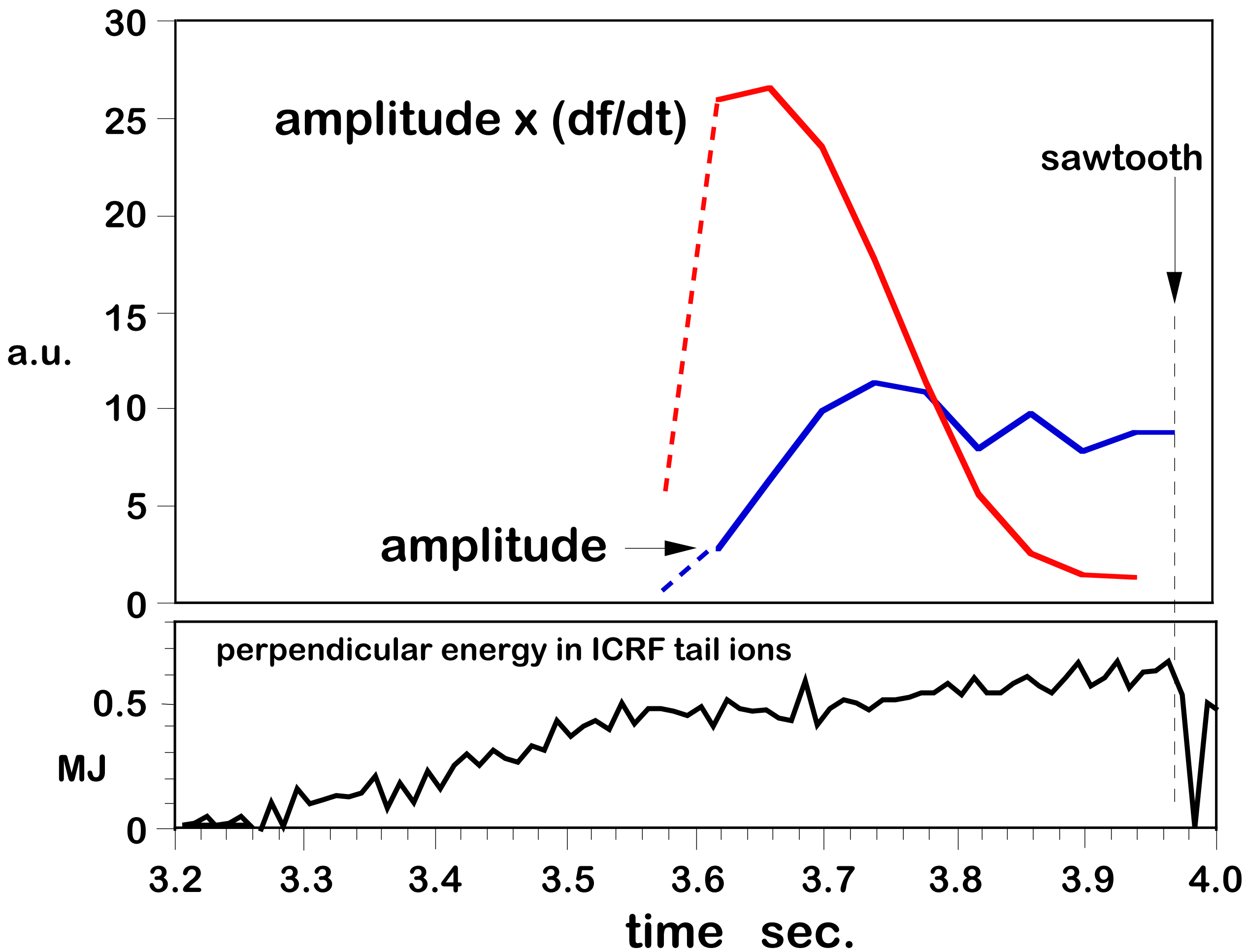
SAWTOOTH PERIOD SHOWS "BIFURCATION" CORRELATED WITH EPMs





FAST ION LOSSES ARE ASSOCIATED WITH THE FREQUENCY CHIRPING OF THE EPMs



- Sawtooth crashes after chirping stops and frequency locks

ROLE OF EPMs IN GIANT SAWTOOTH STABILITY

- always present before crash
- crash occurs when chirping ceases

action of EPMs		effect upon sawtooth
increase loss of ions	=	destabilizing
broaden distribution of heating	=	stabilizing
reduce rotation (electric field)	=	stabilizing (?)
increase radius of q=1 surface	=	destabilizing

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CONCLUSIONS

- Alfvén instabilities degrade the ICRF heating efficiency
  - TAEs
  - EPMs
- Energetic Particle Modes are more strongly correlated with losses than TAEs
- Giant sawteeth are correlated with Energetic Particle Modes
- Extrapolations to ITER should take into account Energetic Particle Modes