IFS Presentation to CSEPP meeting

IFS PLAN

Presented by

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Reasons for CSEPP

- Determine Feasibility of Various Burning Plasma Scenarios

  1. Alfven waves can resonate with alpha particles which may induce stochastic radial motion and even parasitic loss

     a. Where is the parameter space boundary for stable Alfvenic excitations

     b. Where is the upper boundary for benign plasma excitations

     c. Predict the relaxed energetic particle distributions

     and where energy and momentum is deposited

     d. What are the characterizations of waves in the benign excitation regime and its transition to global loss

Burning Plasma Scenarios (cont)

2. What is the consequence that energetic particles change basic MHD properties of plasma, especially near ideal beta thresholds?
   - a. Suppresses the usual MHD instability limits and allows $\beta > \beta_{ideal}$
   - b. 'Giant' relaxation known to happen for sawteeth when modified β limit is finally reached, or energetic particle pressure gradient relaxes due to Alfvenic activity. Can be expected near other ideal beta limits.
   - c. Leads to significant background plasma response that needs investigation

3. Develop state of the art computing capability and algorithms that can be exported outside of our field

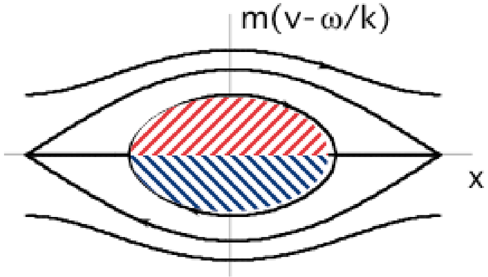
IFS program to meet required goals

1. Assist in the formulation of GKM to derive rigorous and efficient programmable equations for linear and non-linear theory. Also needed for expanded eigenvalue code with correct perturbation theory for kinetic drives and sinks
2. Work with PPPL for studying energetic particle modification of MHD modes with simulations on M3D
3. Derive and implement, with PPPL, 3.5 dimensional (E, P_ζ, μ, r) quasi-linear theory to study relaxation to accessible states
4. Study the feasibility of developing a dynamic flux tube code for high-n simulations with feedback of fluxes between tubes
5. Attempt to derive symplectic ‘mapping’ techniques in-situ with straight forward (and fast) MHD codes to capture the effect of Maxwellian tail and energetic particle response (δf algorithm likely compatible as well)

Nonlinear Kinetic Theory for Perturbative Modes

IFS analysis focuses on the generic island

1. Weak instabilities are driven by resonant particles, which nonlinearly mix around the resonant phase space islands

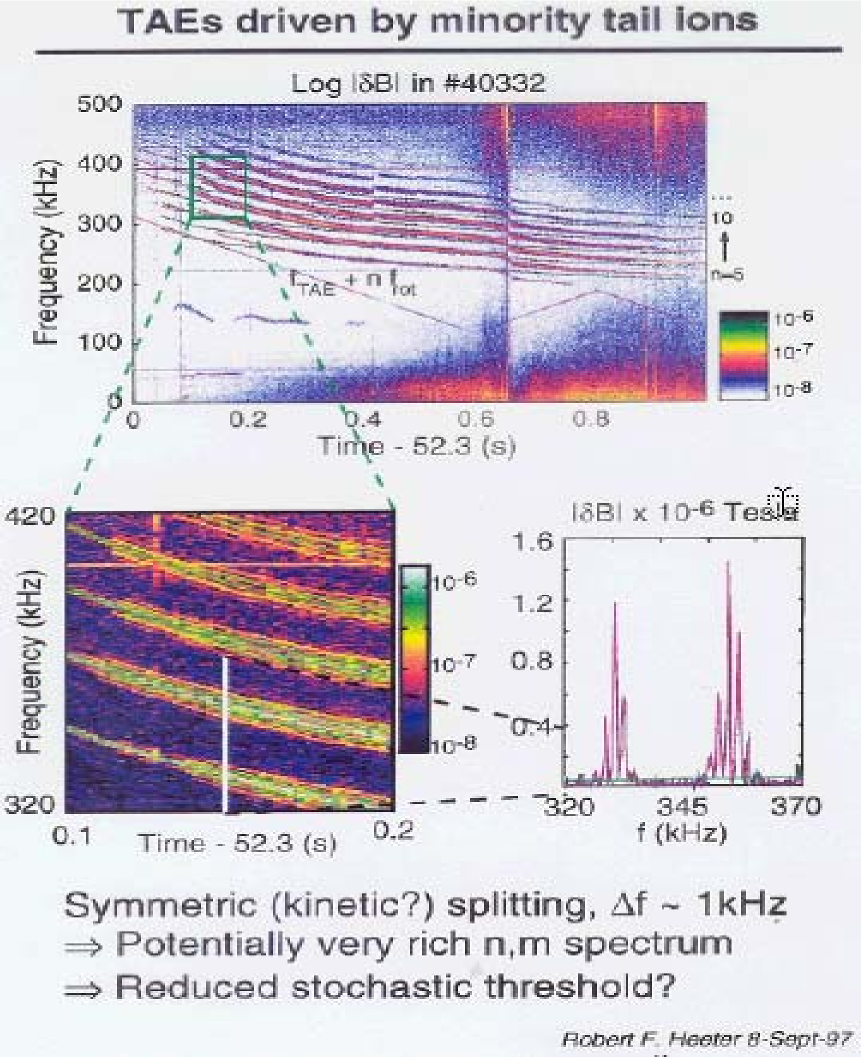


Island formation as described in 1-d problem applies to 3-d problem and basis of analytic nonlinear theory

2. Consistent theory for mode amplitude and frequency developed and studied both analytically and numerically
(a) Universal near-threshold response (Berk-Breizman model)
(b) Numerical toy models developed with analytic description
(c) Formation and evolution of phase space structures

3. Evolution from single modes to overlap of many modes, leading to global diffusion, described

Pitch Fork Biffurcations



TAEs driven by minority tail ions

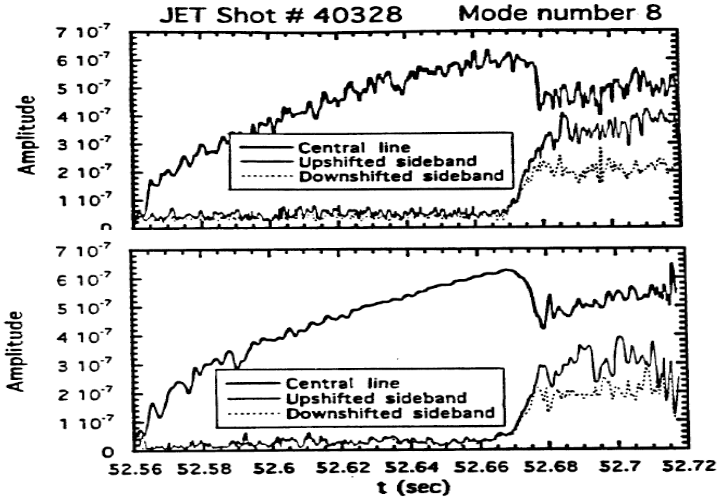
Symmetric (kinetic?) splitting, Δf ~ 1kHz

⇒ Potentially very rich n,m spectrum

⇒ Reduced stochastic threshold?

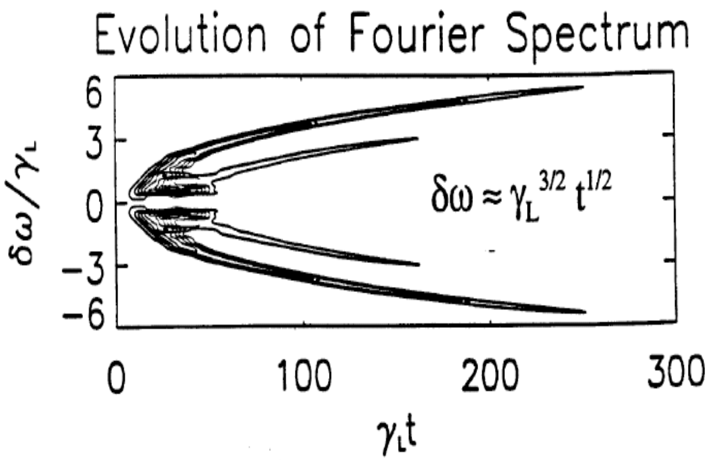
Robert F. Heeter 8-Sept-97

Comparison Jet Shot and Theory

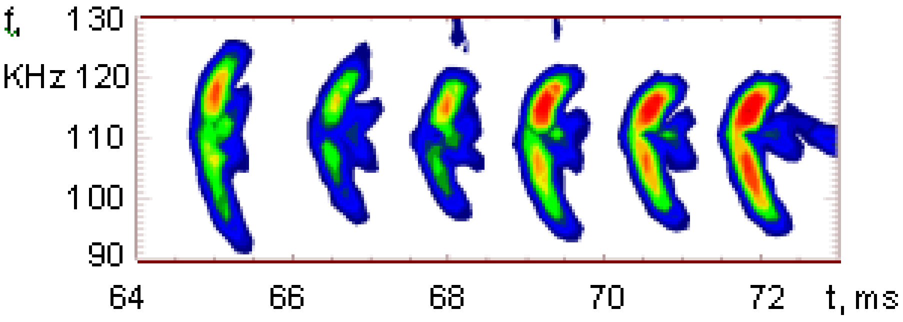


DETERMINATION OF INTERNAL FIELDS BY FREQUENCY SWEEPING

numerical simulation (N.Petviashvili)



TAE modes in MAST (M. Gryaznevich)

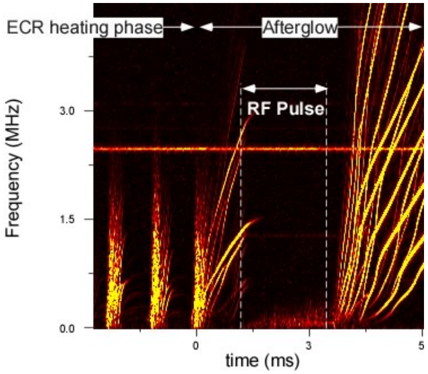


$\gamma_L \equiv$ linear growth without dissipation; for spontaneous hole formation; $\gamma_L \approx \gamma_d$. $\omega_{\square} = (ekE/m)^{1/2} \approx 0.5\gamma_L$ enables inferring mode amplitude from frequency sweeping rate

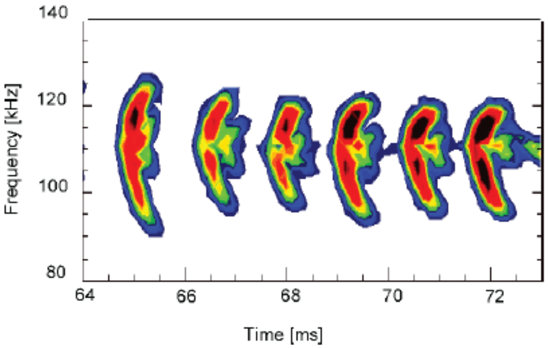
With geometry and energetic particle distribution known internal perturbed fields can be inferred

Using same logic of simplified simulation gives internal prediction of internal field that is about a factor of two of internal field inferred from magnetic probe signals (S. D. Pinches, et. al.)

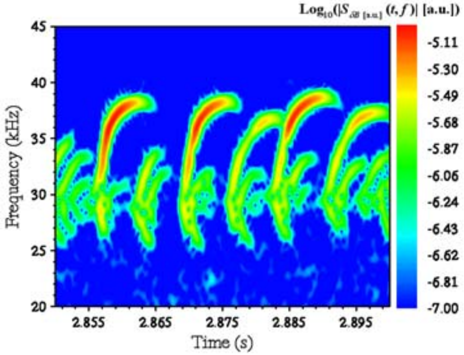
Examples of Fast Chirping Events



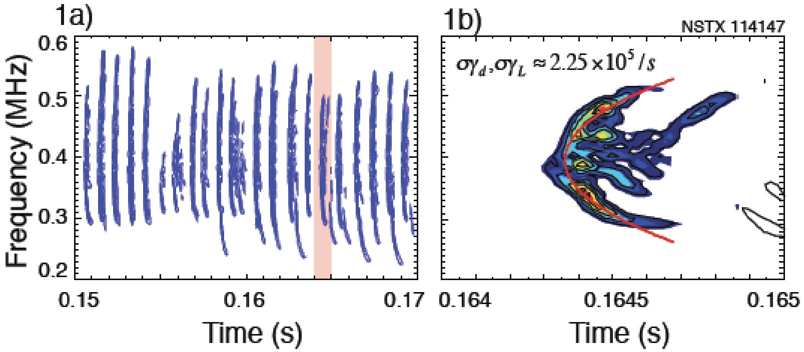
TERELLA Hot Electron Interchange
(electron drift resonance)

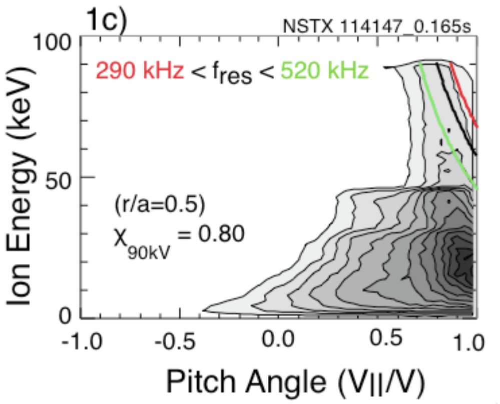


MAST: TAE (ion bounce resonance)



JET: GAM (trapped ion bounce resonance)

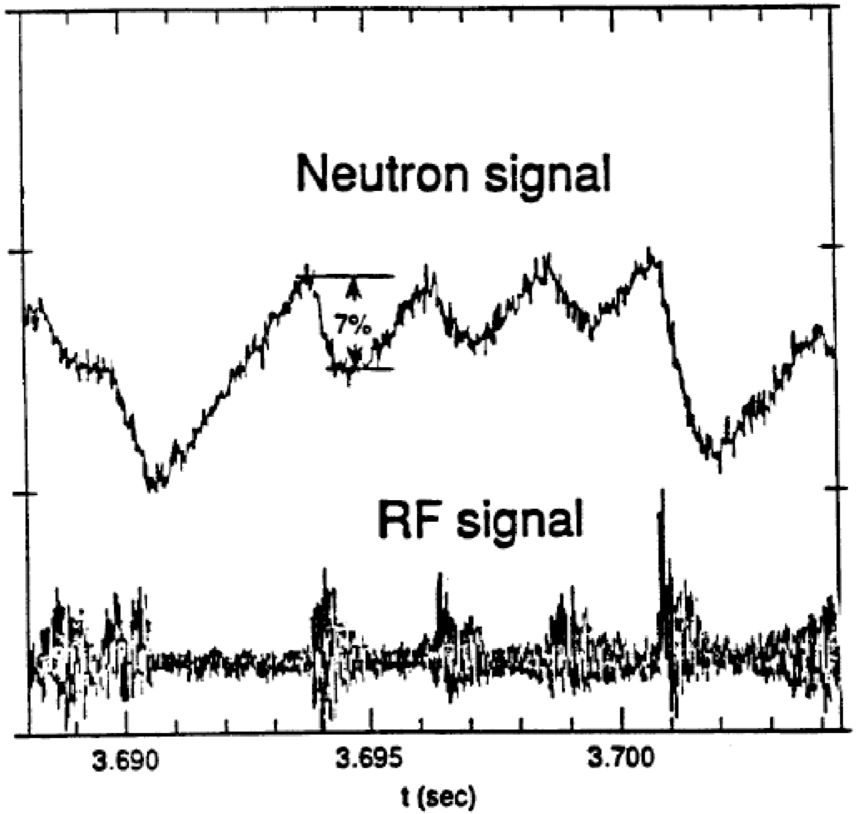




NSTX; Compression Alfven Wave
(doppler shifted cyclotron resonance)

TAE's May Lead to Alpha Loss

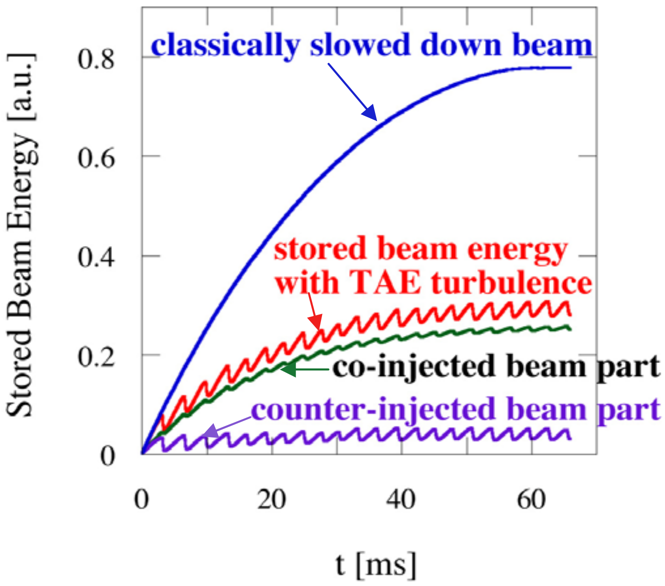
- **Experiments show both benign and deleterious effects**
- **Rapid Intermittent losses in early TAE experiments:**
  - Wong (TFTR)
  - Heidbrink (DIII-D)
- **Simulation of rapid loss:**
  - Todo, Berk, and Breizman,
  - Multiple modes (n=1, 2, 3)



K.L. Wong et al

SIMULATION OF INTERMITTENT LOSSES (Todo and IFS)

- **“Reduced” Simulations have reproduced NBI beam ion loss in TFTR**
- **Synchronized TAE bursts:**
  - At 2.9 ms time intervals (2.2ms in experiments) – max stored energy comparable to experiment
  - Beam energy 10% modulation per burst (cf. 7% in experiment)
- **TAE activity reduces stored beam energy from classical slowing-down prediction**
  - 40% for co-injected ions while larger reduction (by 88%) for counter-injected beam ions
  - Co-orbits stick out, have difficulty reaching limiter even with high fields



However field amplitude too high!

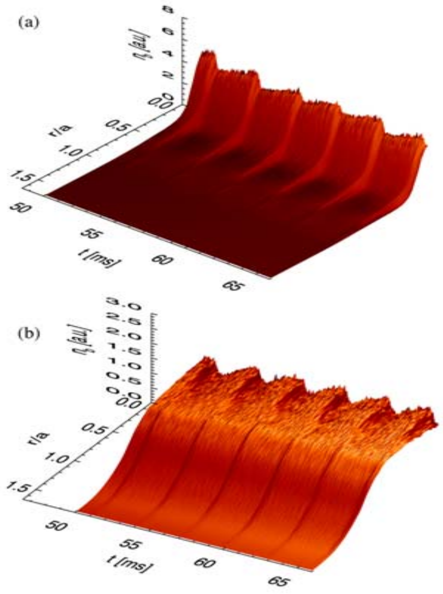
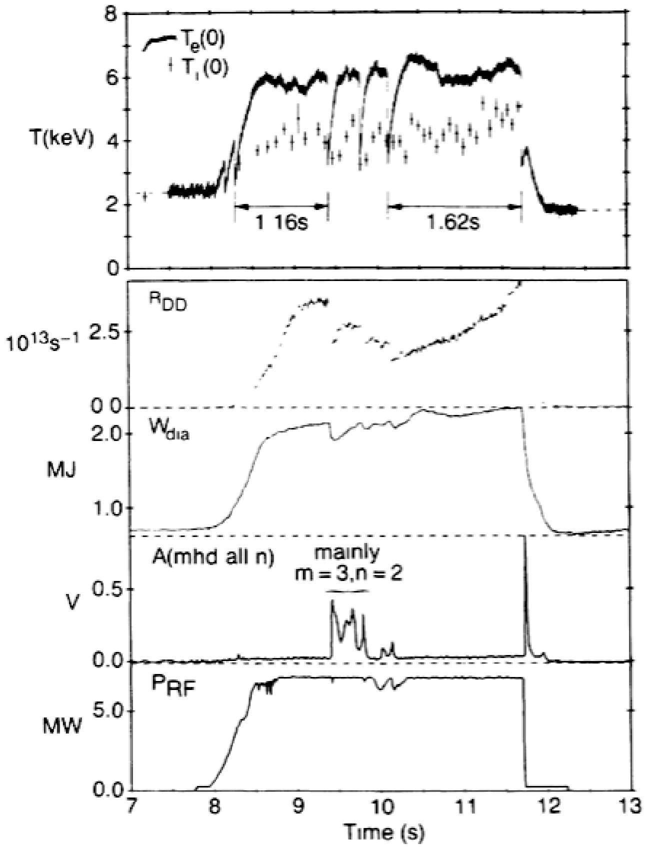


Figure 8 (Y. Todo et al.)

Sawtooth Suppression and Monster Relaxation JET (Campbell, et. al.)

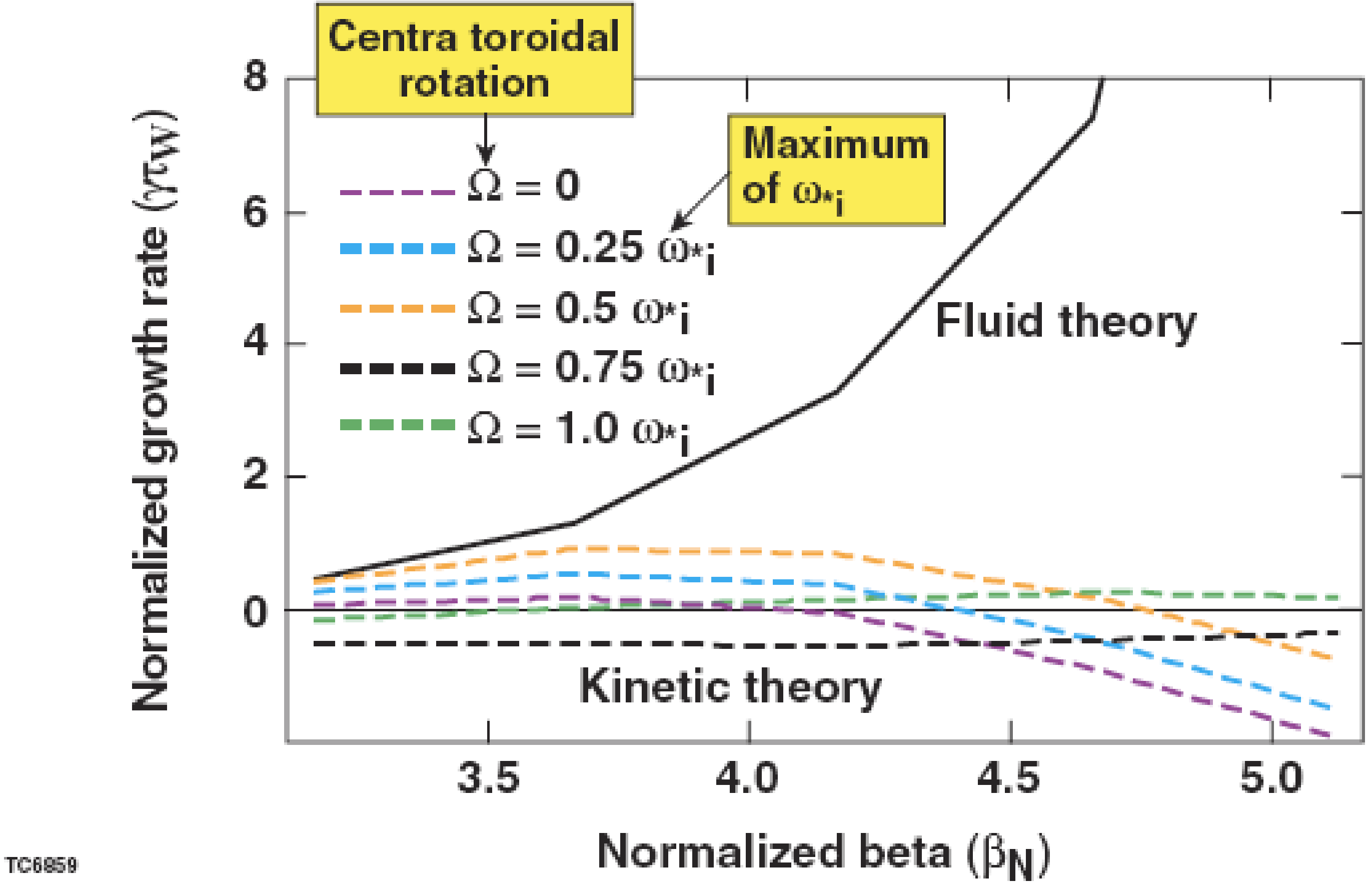


Proves sawtooth activity can be suppressed but then relaxation more severe!

Increased β limits then expected from other MHD modes with similar severe relaxation

Undoubtedly we will attempt to take advantage of the allowable increased beta that a burning plasma will allow, but we then must learn how prevent hard disruptive relaxation

- RWM normalized growth rate with and without kinetic effects and varying plasma rotation frequencies Ω(0).



- for low flows $\Omega/\omega* = 0.75$ most stable
- for high enough b_N faster flows are destabilizing
- alpha particle pressure contribute to half of the stabilization effect

(R. Betti)

IFS Methodology and GKM

- Attempt to simplify problem to its essentials to explain underlying physics
- Apply theoretical models to real experimental world in an effective way
- Apply theoretical models to kinetic- simulation output to explain data
- Sufficiently energetic particle dynamics have been shown to be nearly decoupled from background turbulence
- Use models that are not overly complex (we will deal with MHD, with some essential additions; should be suitable for Alfvenic activity and give a reasonable turnaround time)
- For this computational intiative we are Interested in developing fundamental algorithms for the general scientific community (developing an interactive non-passive tracer using mapping scheme could have wide applications)
- We seek success for this upcoming intellectual challenge