Workshop on Burning Plasma Science

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DISCUSSION OF NONLINEAR ENERGETIC PARTICLE ISSUES

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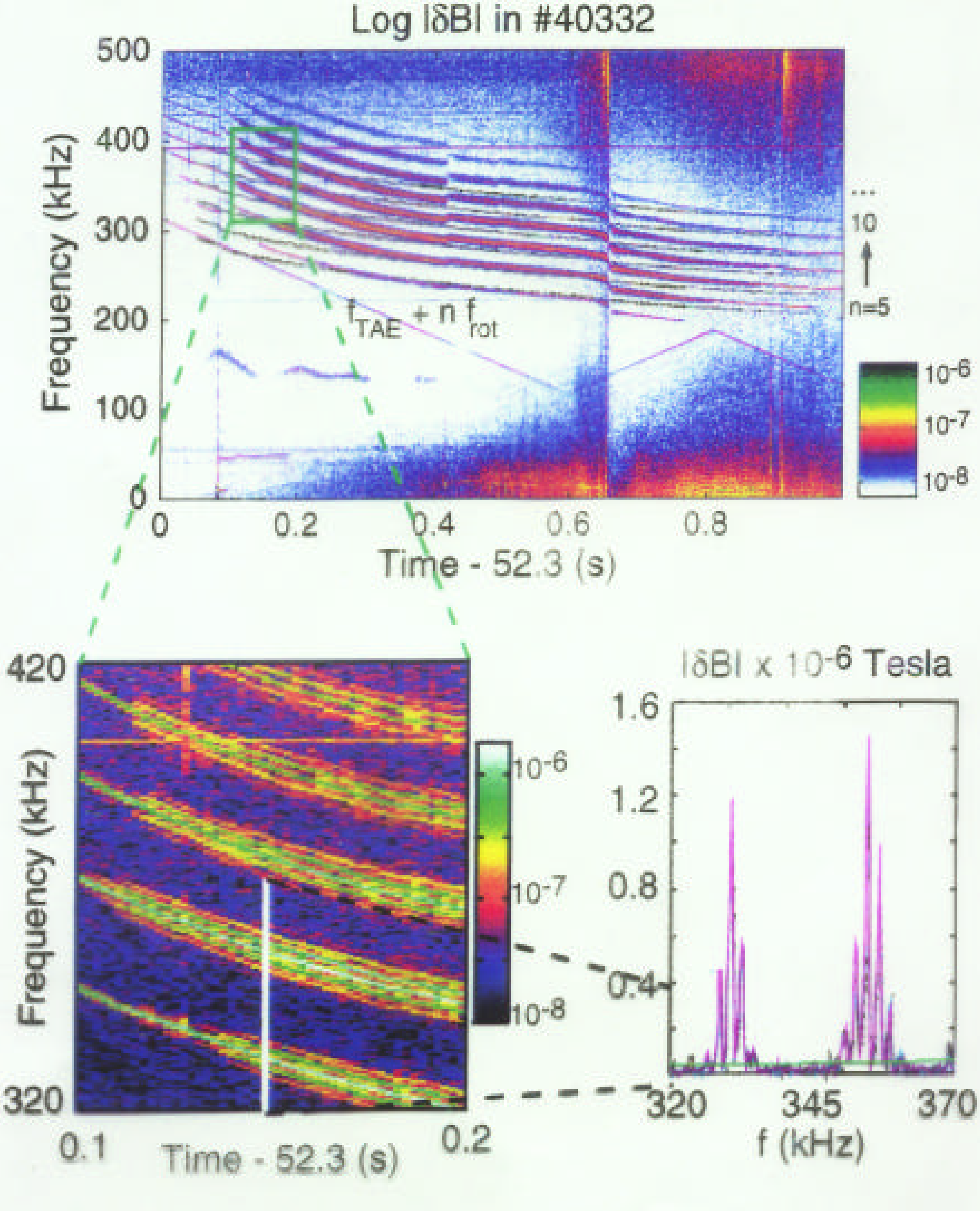
A population of energetic particles in plasma can excite instabilities with potentially adverse consequences for particle and energy confinement. The related theoretical picture has to be intrinsically nonlinear since instability growth times are typically much shorter than the plasma lifetime. There has been a significant progress in recent years in understanding key physics elements that control the nonlinear evolution of unstable modes. This understanding has been instrumental in the interpretation of challenging observations made on JET and TFTR. It has also led to the development of first-principle reduced numerical models. It is quite possible that, with this background, the nonlinear studies will raise to the level of credible assessment of collective effects associated with energetic particles in burning plasma. This will require a substantial expansion of numerical work to accomplish a transition from idealized models that focus on the essential physics to fully realistic modeling relevant to specific fusion devices.

TAEs driven by minority tail ions



Symmetric (kinetic?) splitting, $\Delta f \sim 1\text{kHz}$

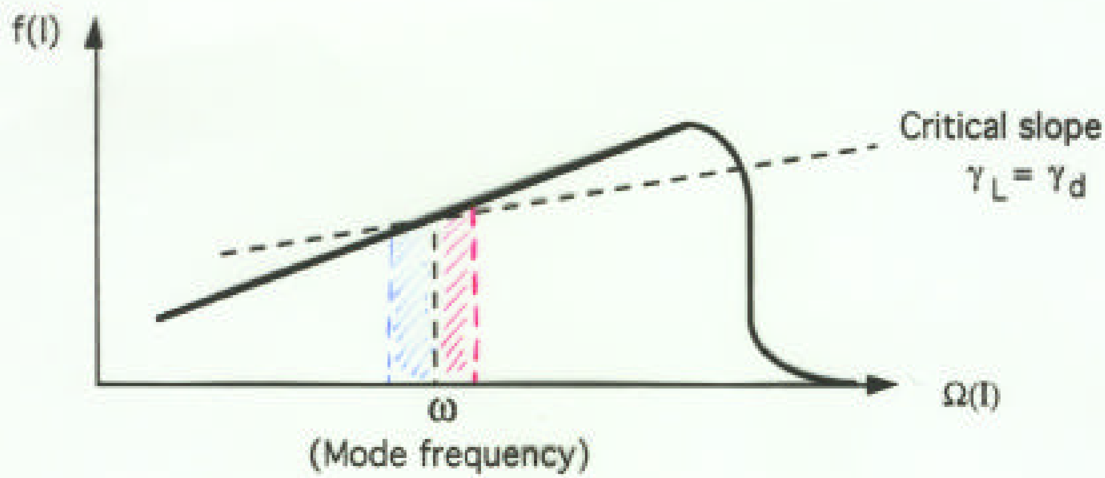
⇒ Potentially very rich n,m spectrum

⇒ Reduced stochastic threshold?

Robert F. Heeter 8-Sept-97

BASIC INGREDIENTS

- Instability drive, γ_L, due to particle-wave resonances.
- Background dissipation rate, γ_d, determines the critical gradient for the instability.
- Discrete spectrum of unstable modes.
- Source and effective collisions, ν_{eff}, for energetic particles.



- Growth rate near instability threshold: $\gamma \equiv \gamma_L - \gamma_d << \gamma_L$.
- Motivation for near-threshold analysis: In most experiments, the energetic particle population builds up slowly compared to the time scale for the instability.

NONLINEAR EQUATION FOR MODE AMPLITUDE

- Near the instability threshold $(\gamma_L - \gamma_d << \gamma_L)$ the saturation time is shorter than the trapped particle bounce time in the mode.

- Kinetic equation with collisions included solved with perturbation technique.

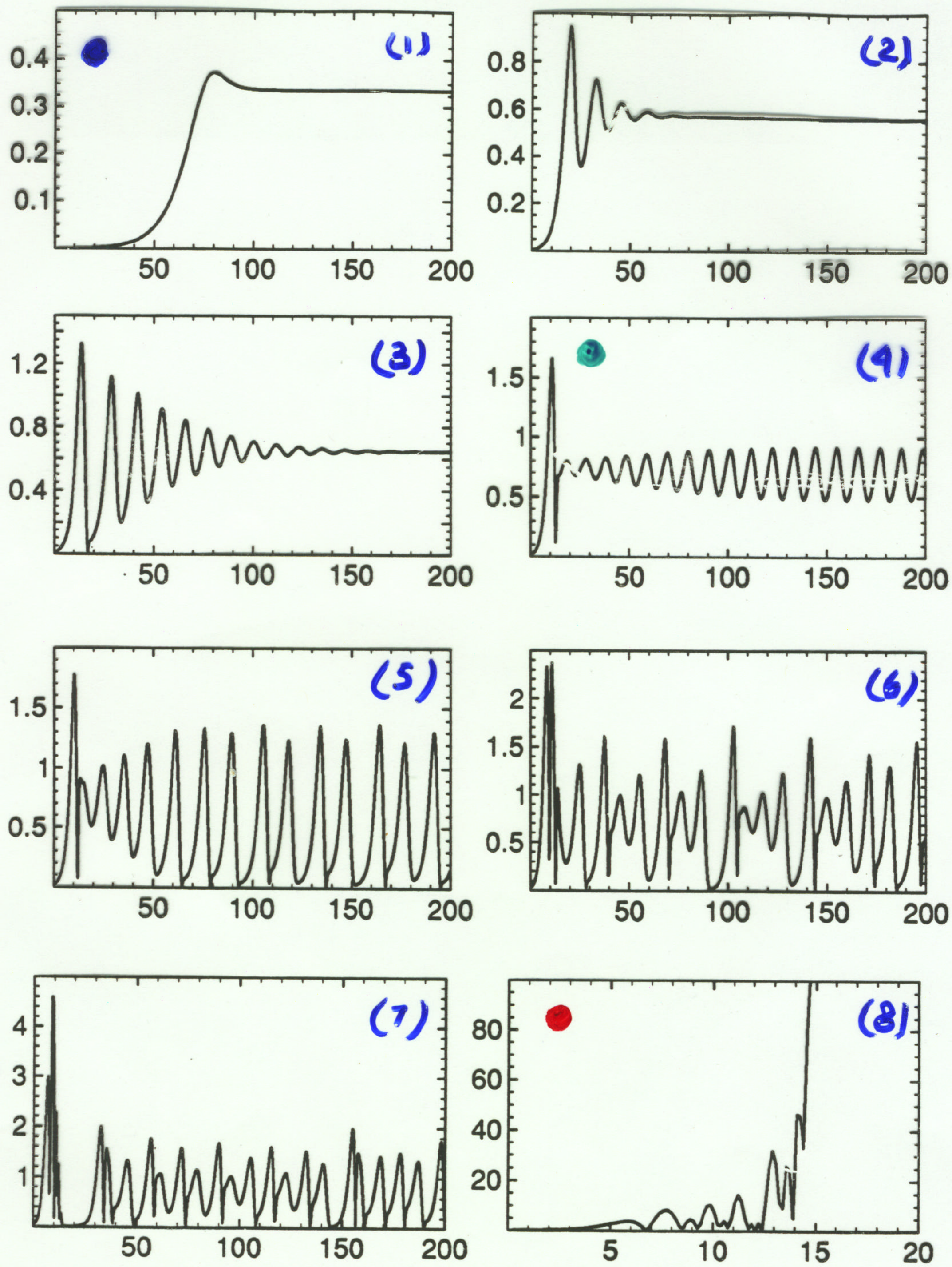
- Equation for the mode amplitude reduces to

$$e^{-i\phi}\frac{dA}{dt} = \frac{\gamma}{\cos\phi}A - \frac{\gamma_L}{2}\int_0^{t/2}\tau^2 d\tau \int_0^{t-2\tau} d\tau_1 \exp[-\nu_{eff}^3 \tau^2 (2\tau/3 + \tau_1)]$$
$$\times A(t-\tau)A(t-\tau-\tau_1)A^*(t-2\tau-\tau_1)$$

- The amplitude $|A|$ equals the square of the nonlinear bounce frequency, ω_b^2, for a typical resonant particle.

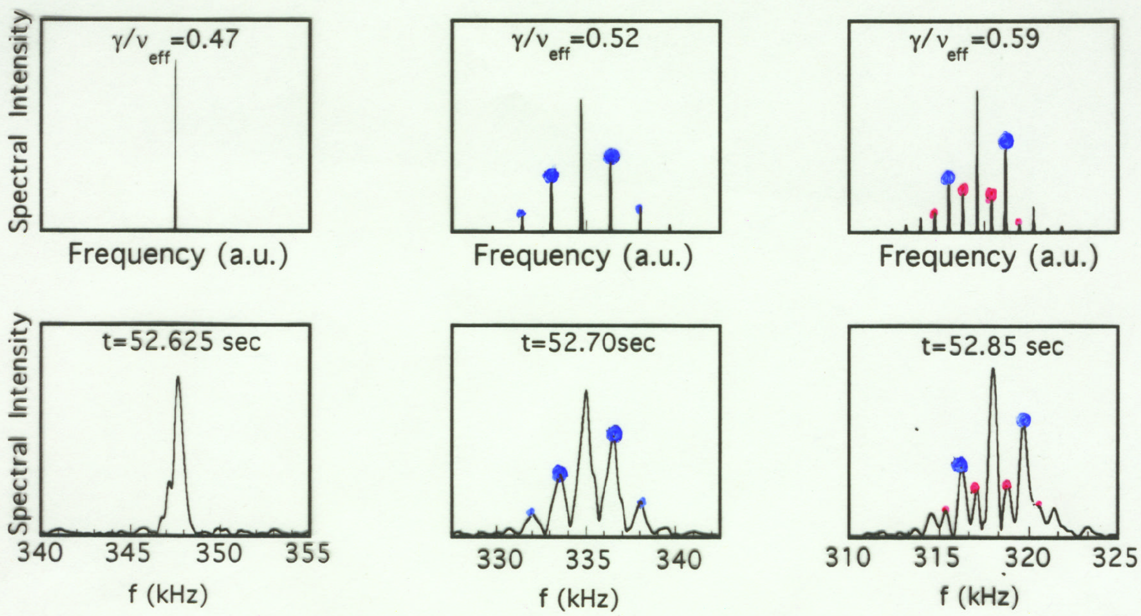
- Parameter ϕ characterizes linear contribution of hot particles to the real part of the mode frequency.

TRANSITION FROM STEADY STATE SATURATION TO THE EXPLOSIVE NONLINEAR REGIME

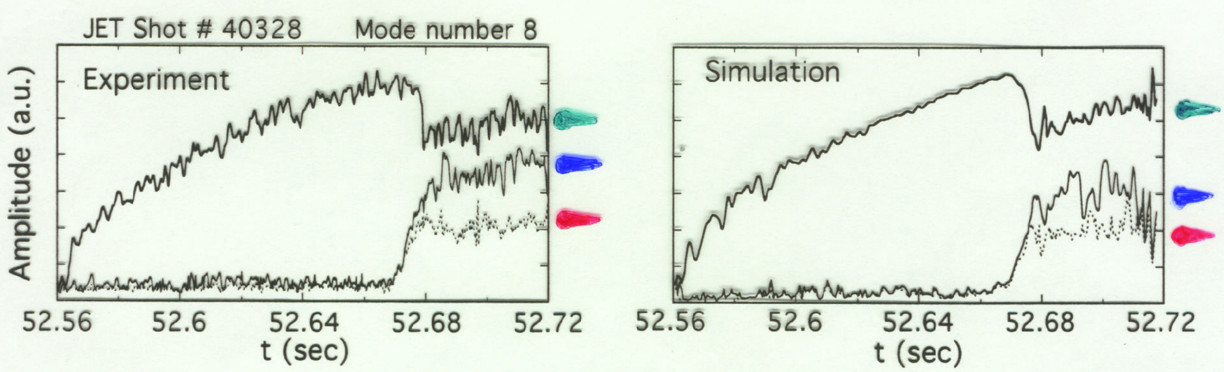


THEORETICAL FIT OF THE PITCHFORK SPLITTING EXPERIMENT

Saturated mode • First bifurcation • Period doubling



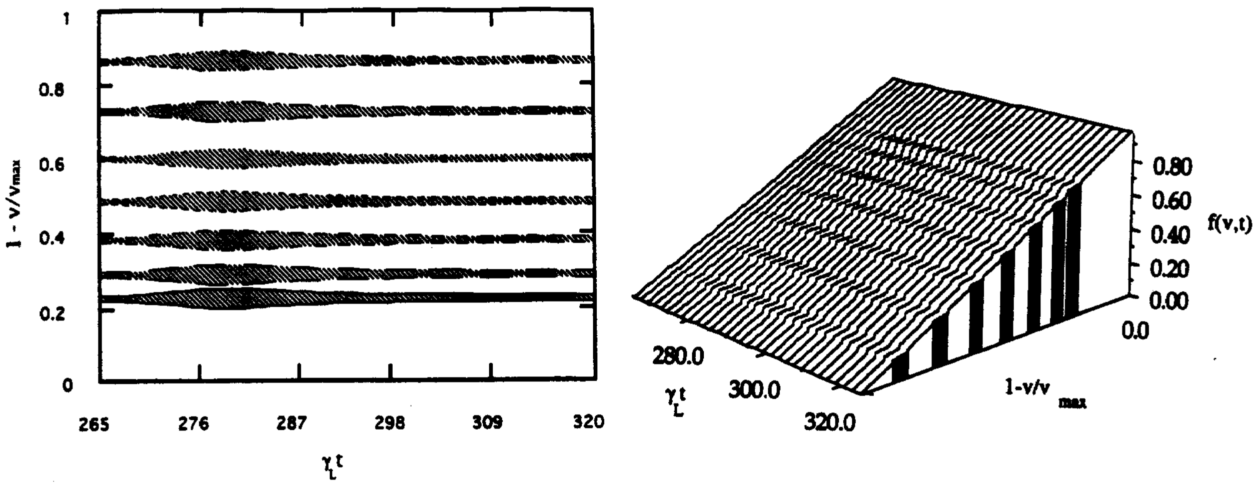
TIME EVOLUTION OF THE BIFURCATING MODE



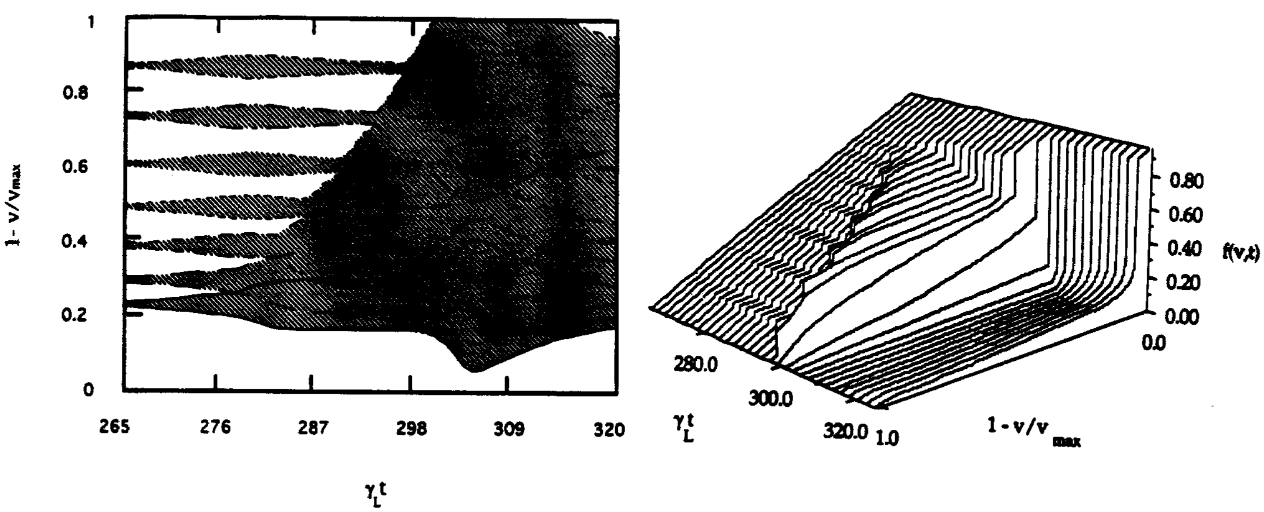
- central spectral line
- upshifted sideband
- downshifted sideband

WHAT HAPPENS WITH MANY MODES?

- Benign superposition of isolated nonlinear modes when resonances do not overlap

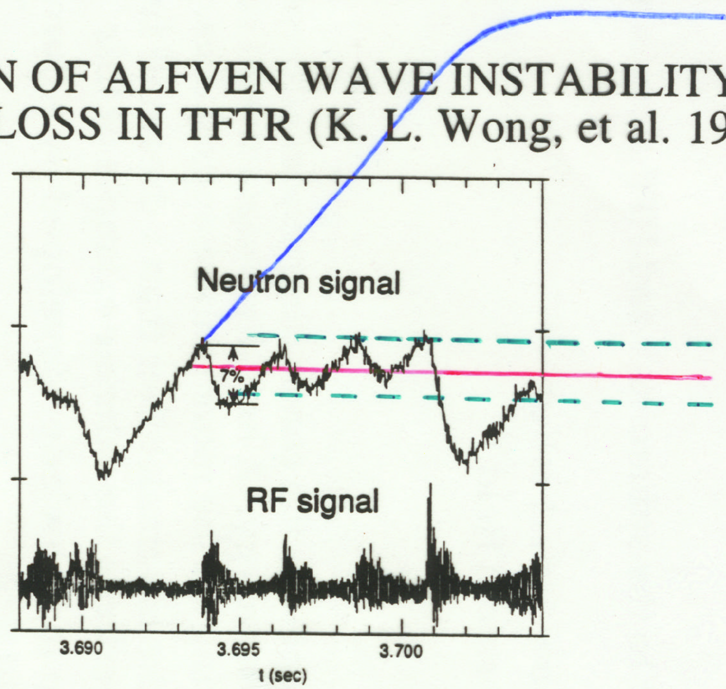


- Enhanced energy release and global quasilinear diffusion when resonances overlap



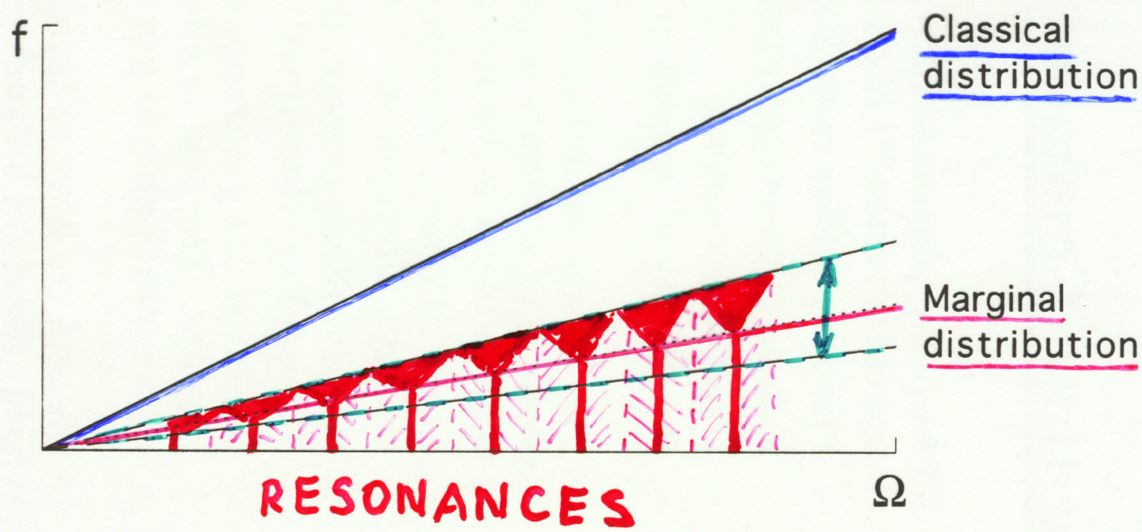
INTERMITTENT QUASILINEAR DIFFUSION

CORRELATION OF ALFVEN WAVE INSTABILITY AND PARTICLE LOSS IN TFTR (K. L. Wong, et al. 1991)

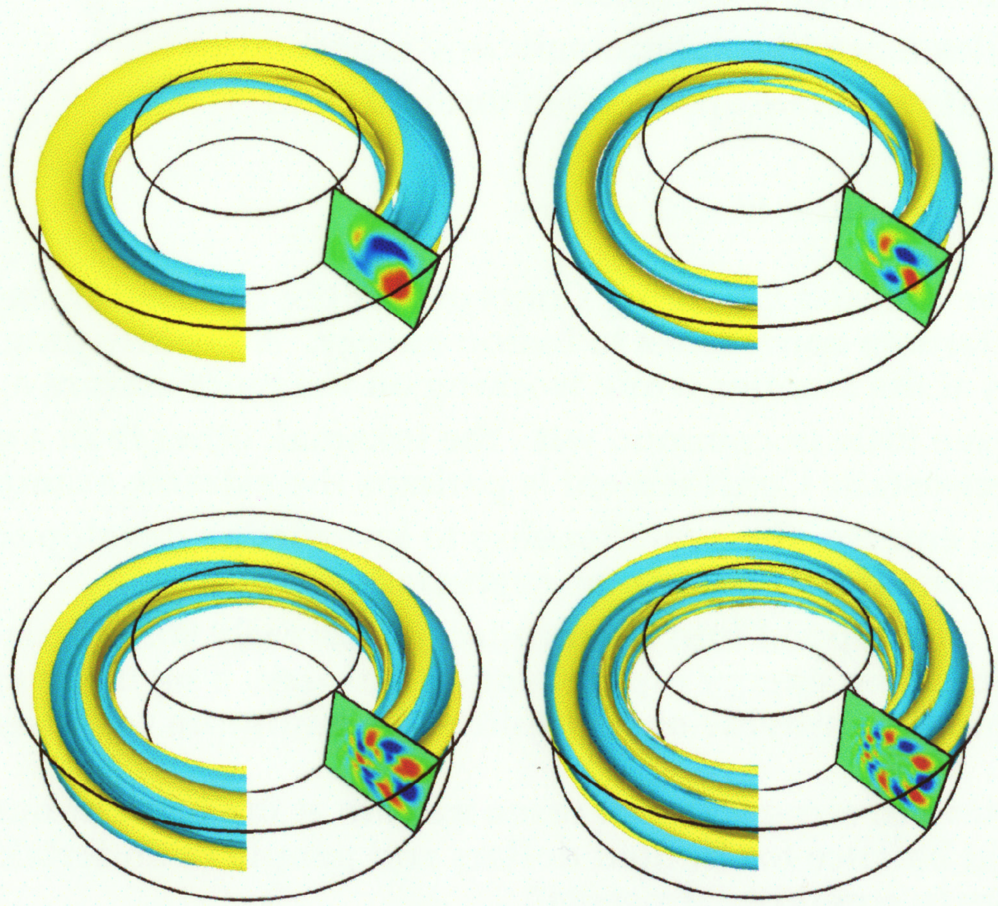


- Steady quasilinear diffusion cannot be maintained with a weak source (insufficient energy to overlap the resonances).

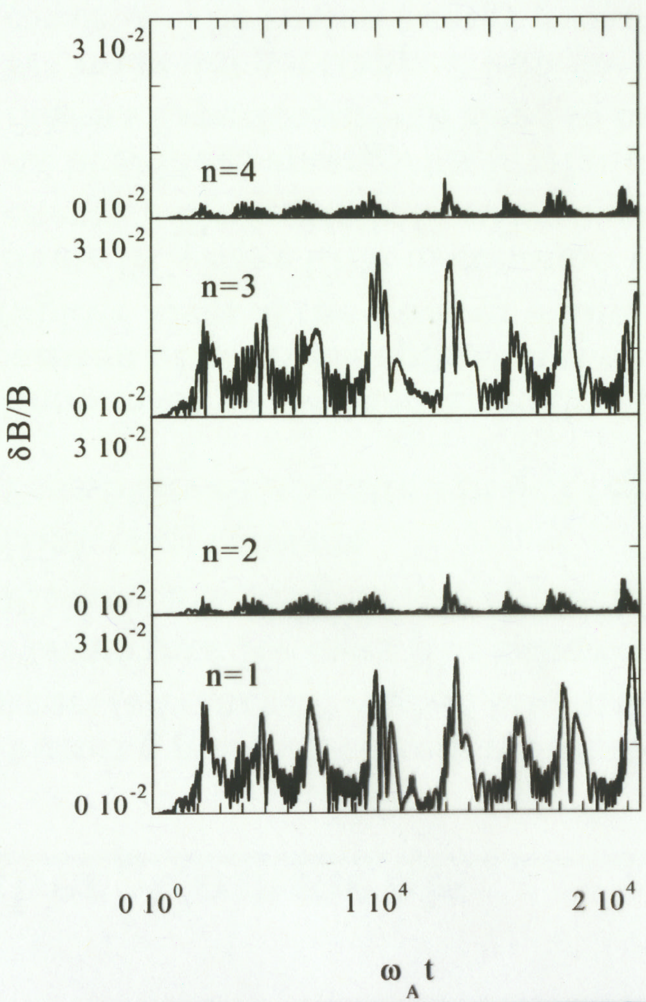
BURSTS NEAR THE MARGINALLY STABLE STATE



n=1-4 TAE



Time Evolutions of Mode Amplitudes and Stored Beam Energy



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