Study of $q = 1$ Triple Tearing Modes

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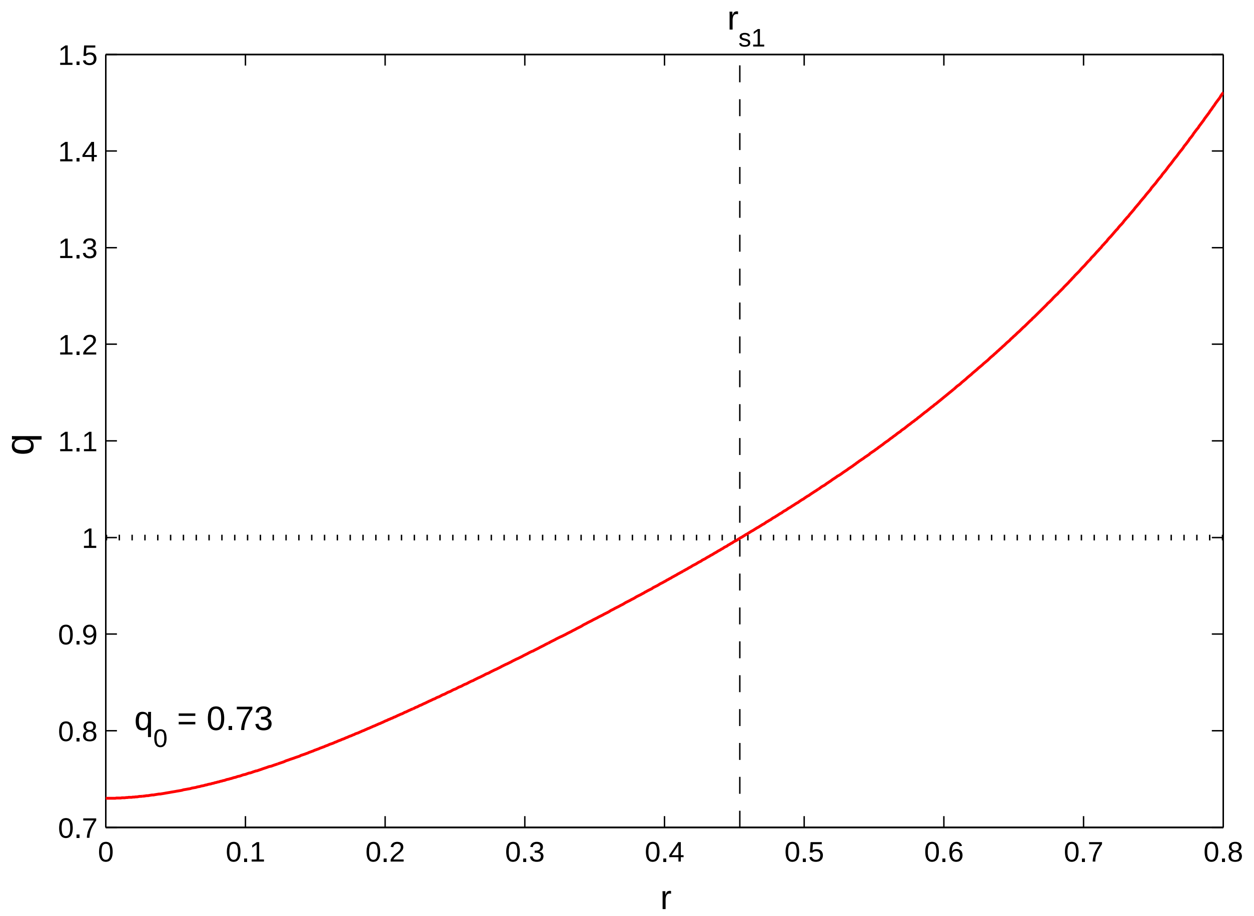
Introduction

- Sawtooth oscillations



Introduction

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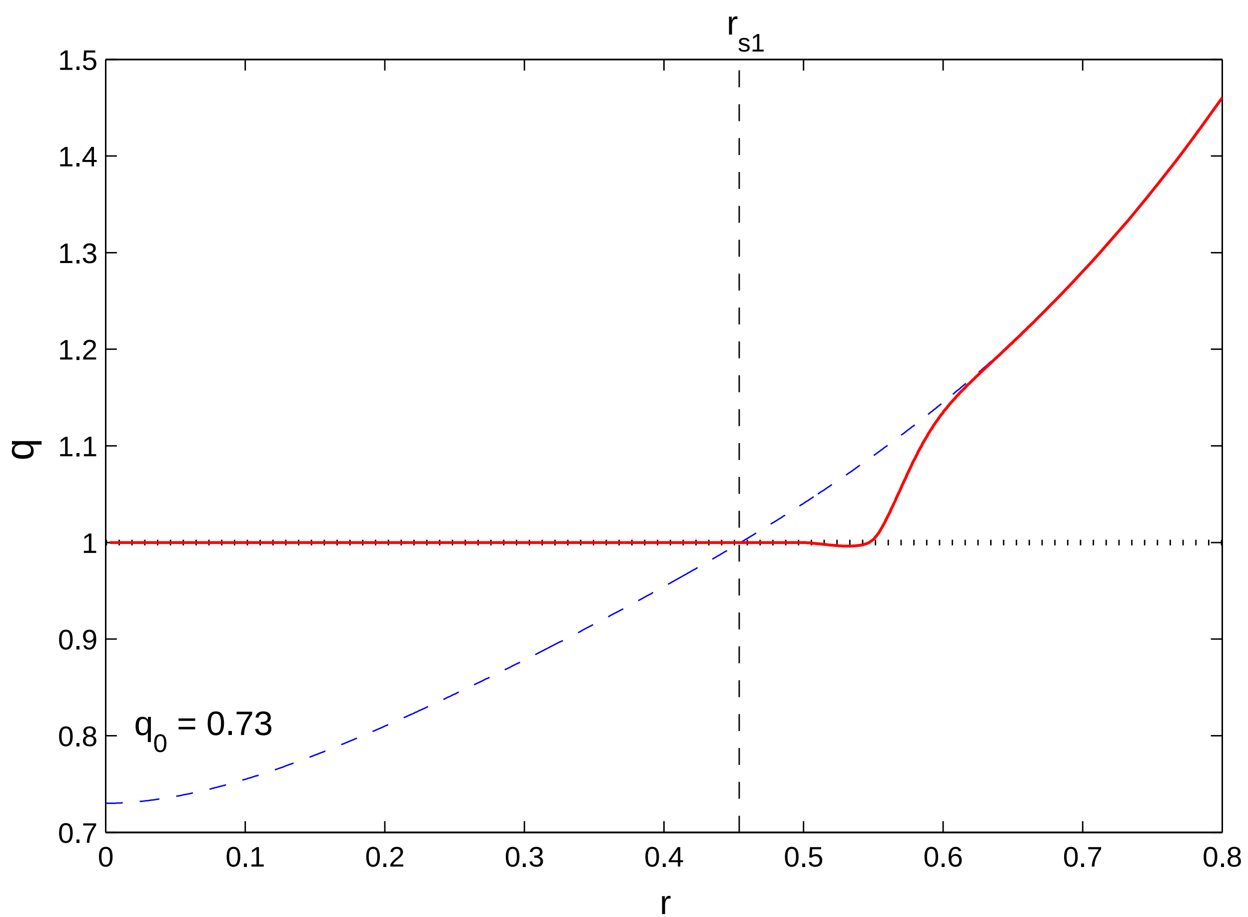
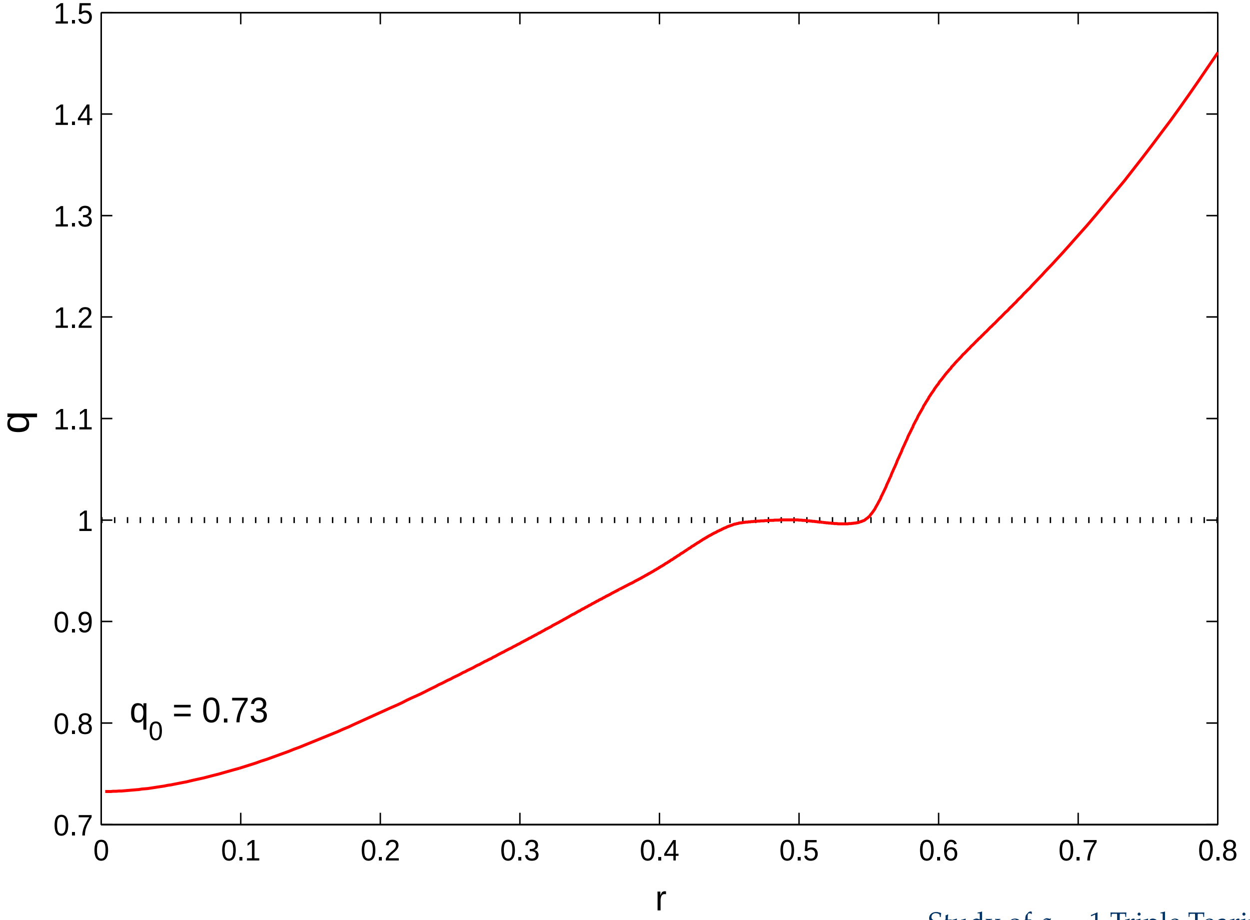


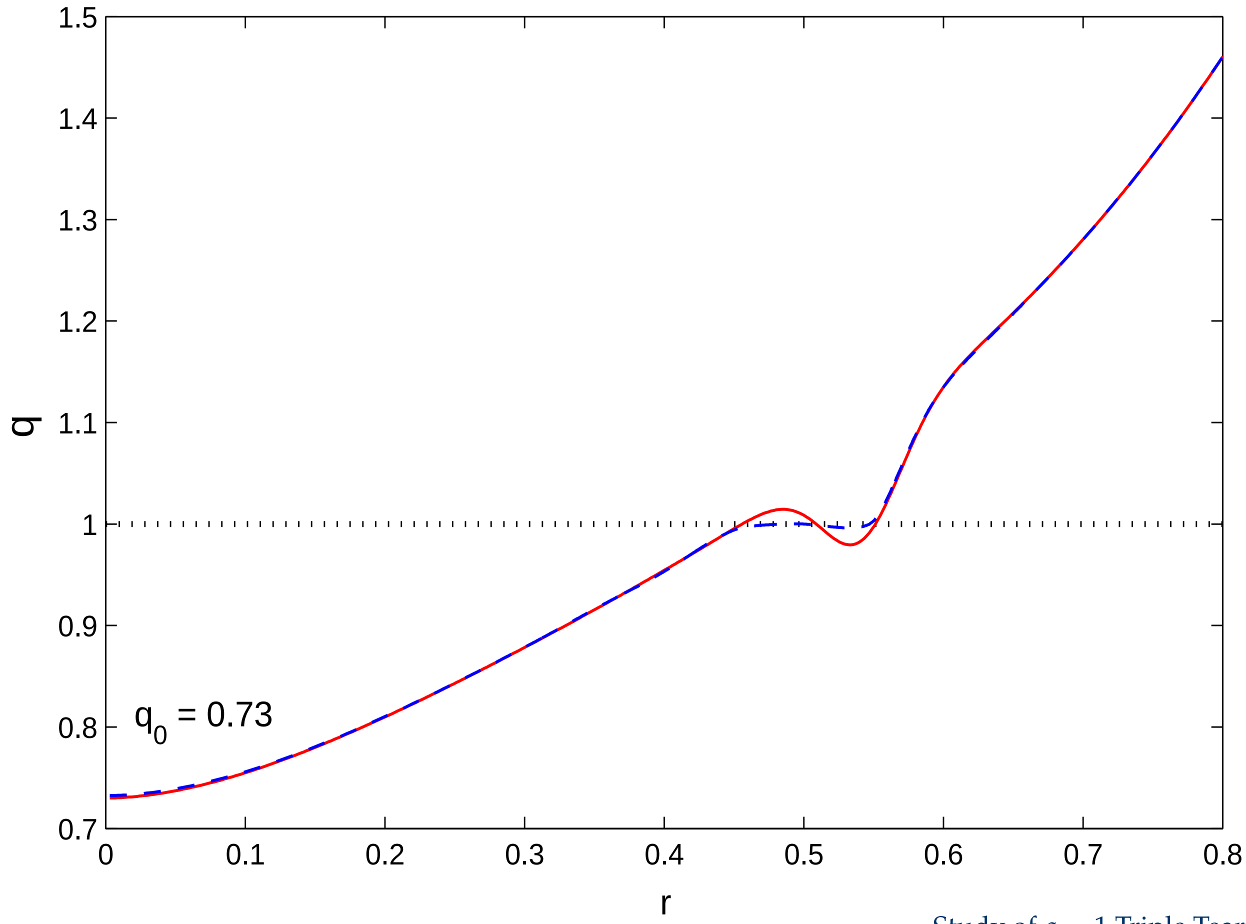
Introduction

- Partial collapse



Introduction

- Multiple $q = 1$ resonant surfaces may form



Motivations

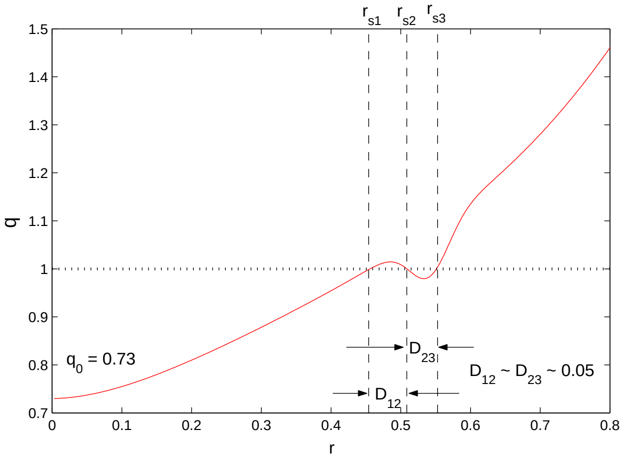
- Sawtooth oscillations
  - (-) degrade confinement
  - (+) impurity/ash removal
- Possibility of partial sawtooth collapse
  - no mixing of central core region
- Partial collapses may be preferable to full sawtooth crashes

$\Rightarrow$ detailed understanding of the partial collapse dynamics may open interesting possibilities for the control of tokamak discharges

Motivations (2)

- Multiple $q = 1$ resonant surfaces
  - may appear after preceeding partial crashes
- Simplest case with $q_0 < 1$:
  Three $q = 1$ resonant surfaces
  - give rise to triple tearing modes (TTMs)

$\Rightarrow$ study of linear instability characteristics and nonlinear evolution of TTMs



Outline

1. Model: Reduced MHD
2. Linear instability characteristics
   - *broad spectrum of unstable modes*
3. $m = 1$ mode in the early nonlinear regime
   - *“fast trigger” mechanism*
4. Random perturbation
   - *partial collapse without precursor*

Outline (2)

5. Overview: TTMs responding to various kinds of perturbations

6. Partial reconnection:
   - rebound, or “dynamic saturation”

7. Summary

8. Conclusion and perspectives

1. Model: Reduced MHD

$$\partial_t \psi = [\psi, \phi] - \partial_\zeta \phi - \frac{1}{S_{\mathrm{Hp}}} (\hat{\eta} j - E_0)$$

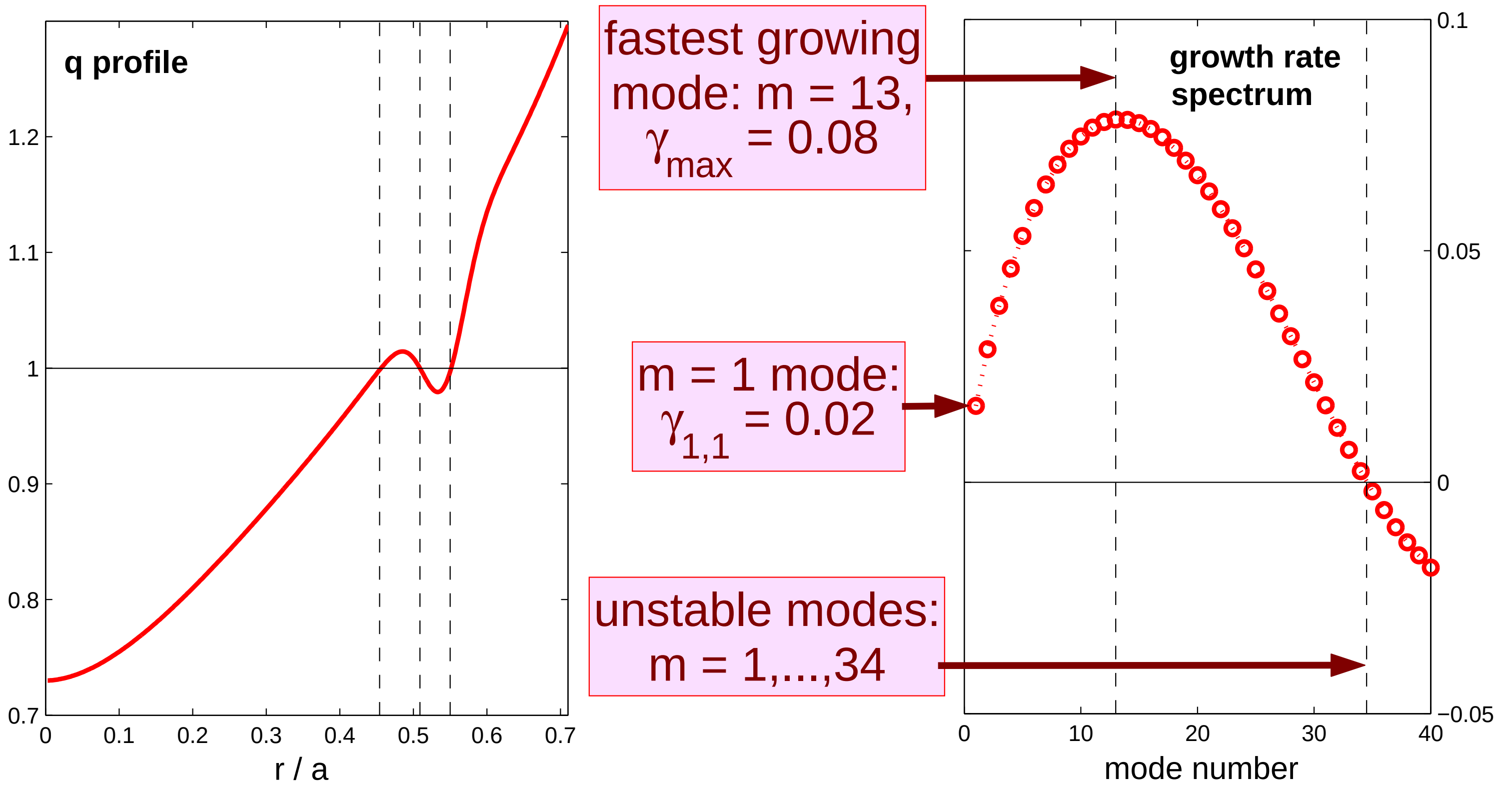
$$\partial_t u = [u, \phi] + [j, \psi] + \partial_\zeta j + \nu \nabla_\perp^2 u$$

with $j = -\nabla_\perp^2 \psi$ and $u = \nabla_\perp^2 \phi$

single helicity: $h = m/n = 1$ $(m = n = 0, ..., 127)$

dissipation parameters: $S_{\mathrm{Hp}} = 10^6, \nu = 10^{-6}$

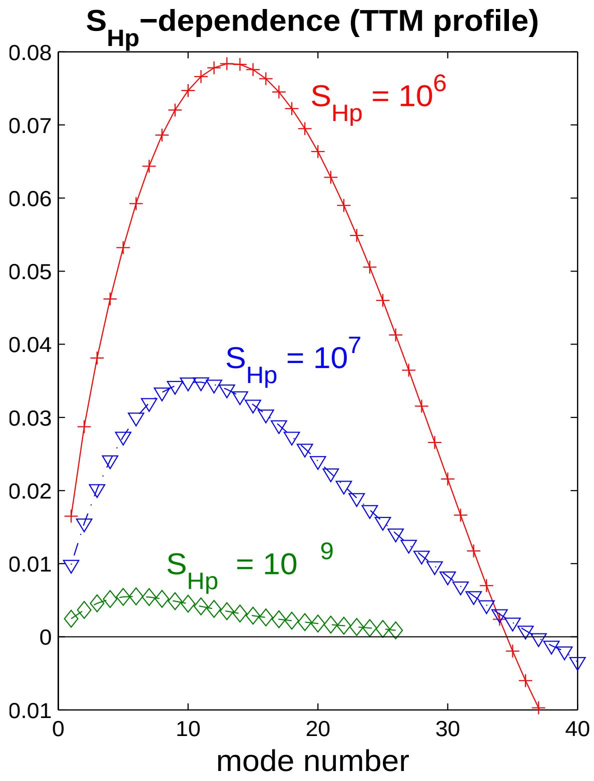
2. Linear instability

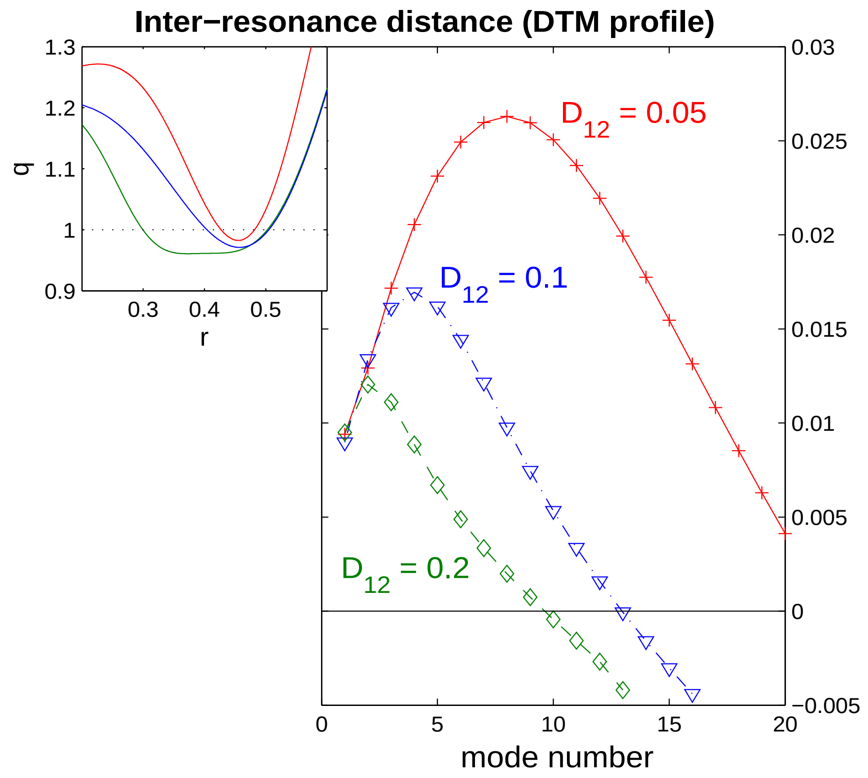


- Broad spectrum of unstable modes
- Peaking at large *m*

2. Linear instability (2)

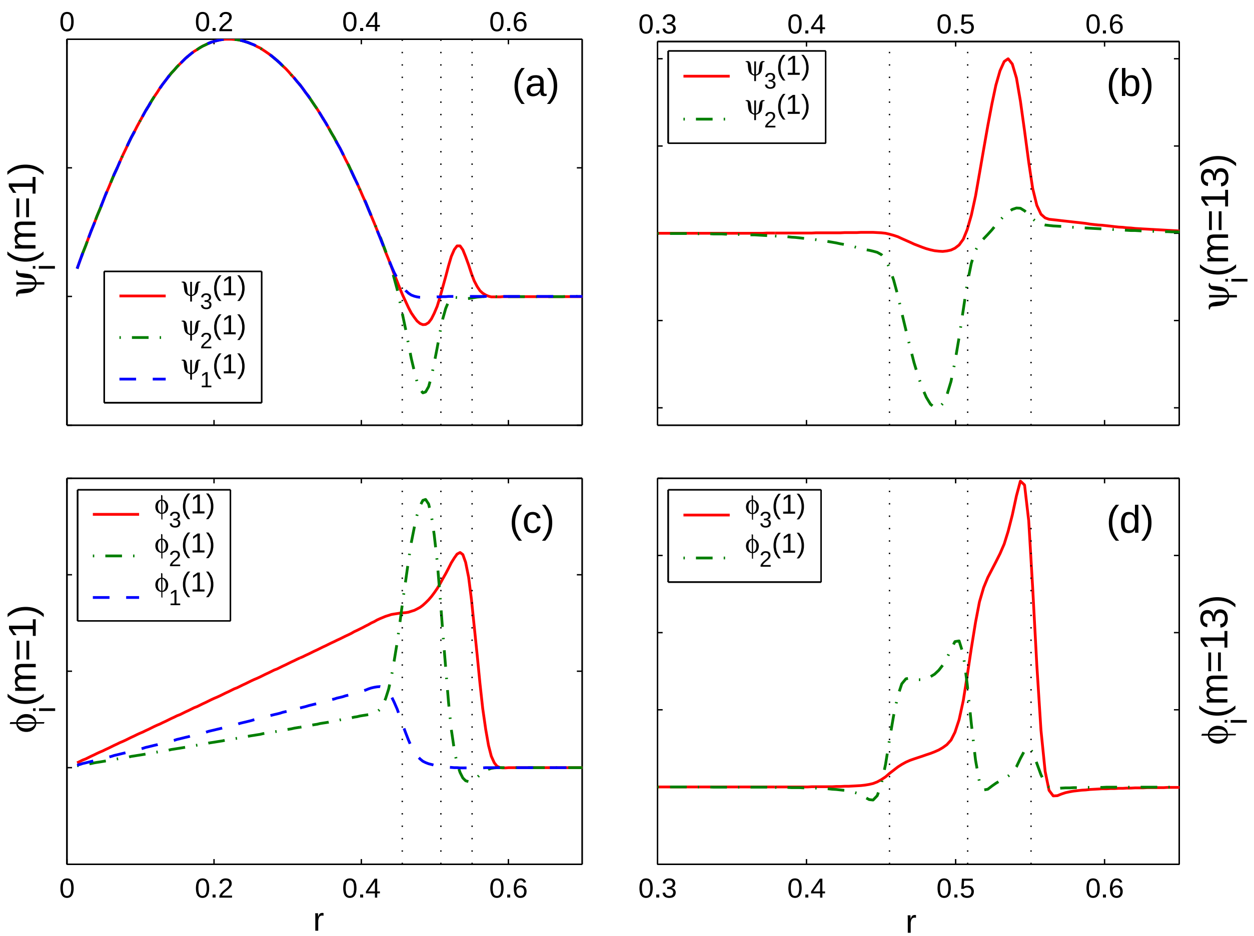
- Two important parameters: S_{Hp} and $D_{ij} = r_{sj} - r_{si}$





2. Linear instability (3)

Eigenmode structures



Parameters determining relative stength of the modes:

- local magnetic shears $s_i = s(r_{si})$
- distance D_{ij}

3. Early nonlinear evolution of the $m = 1$ mode

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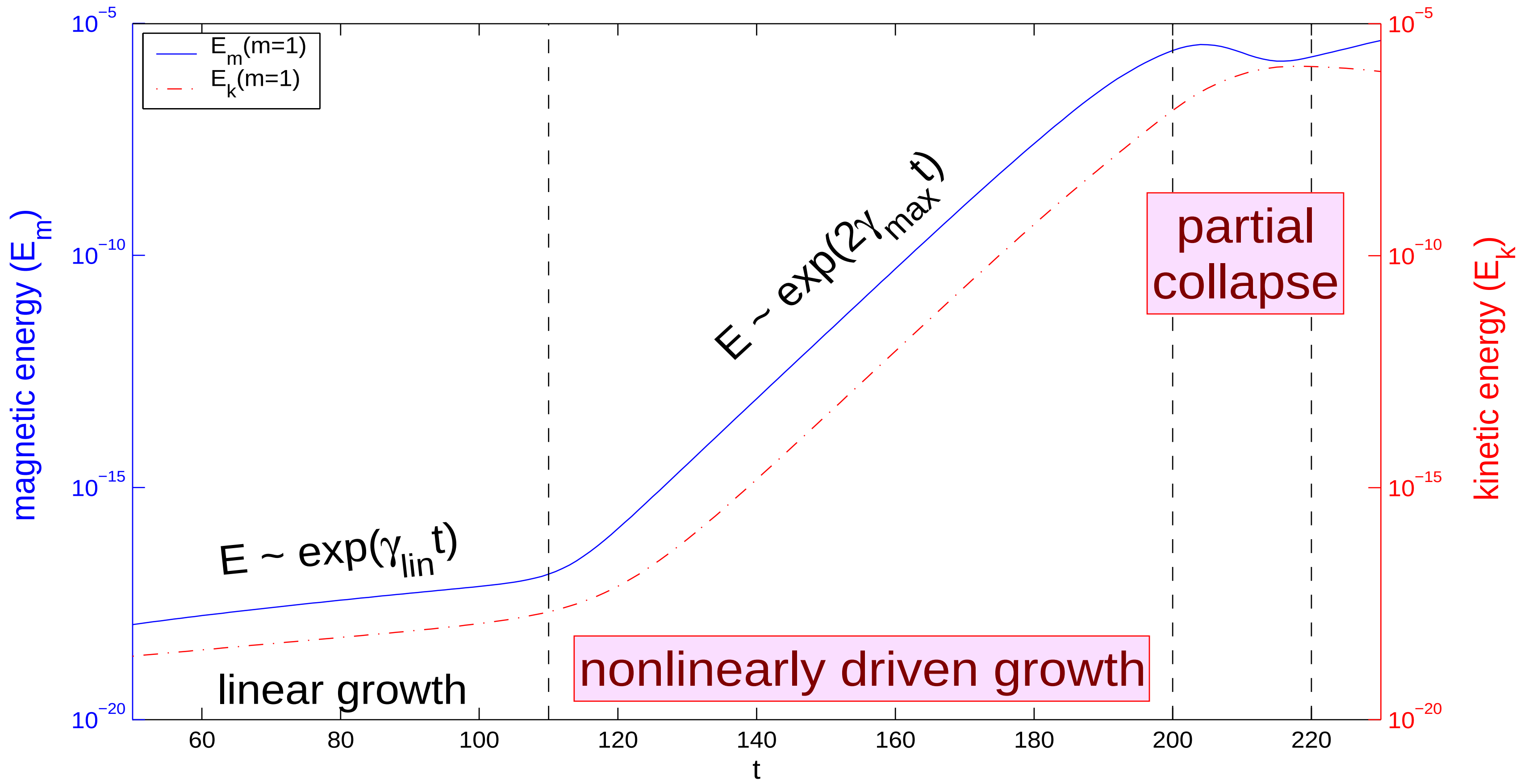
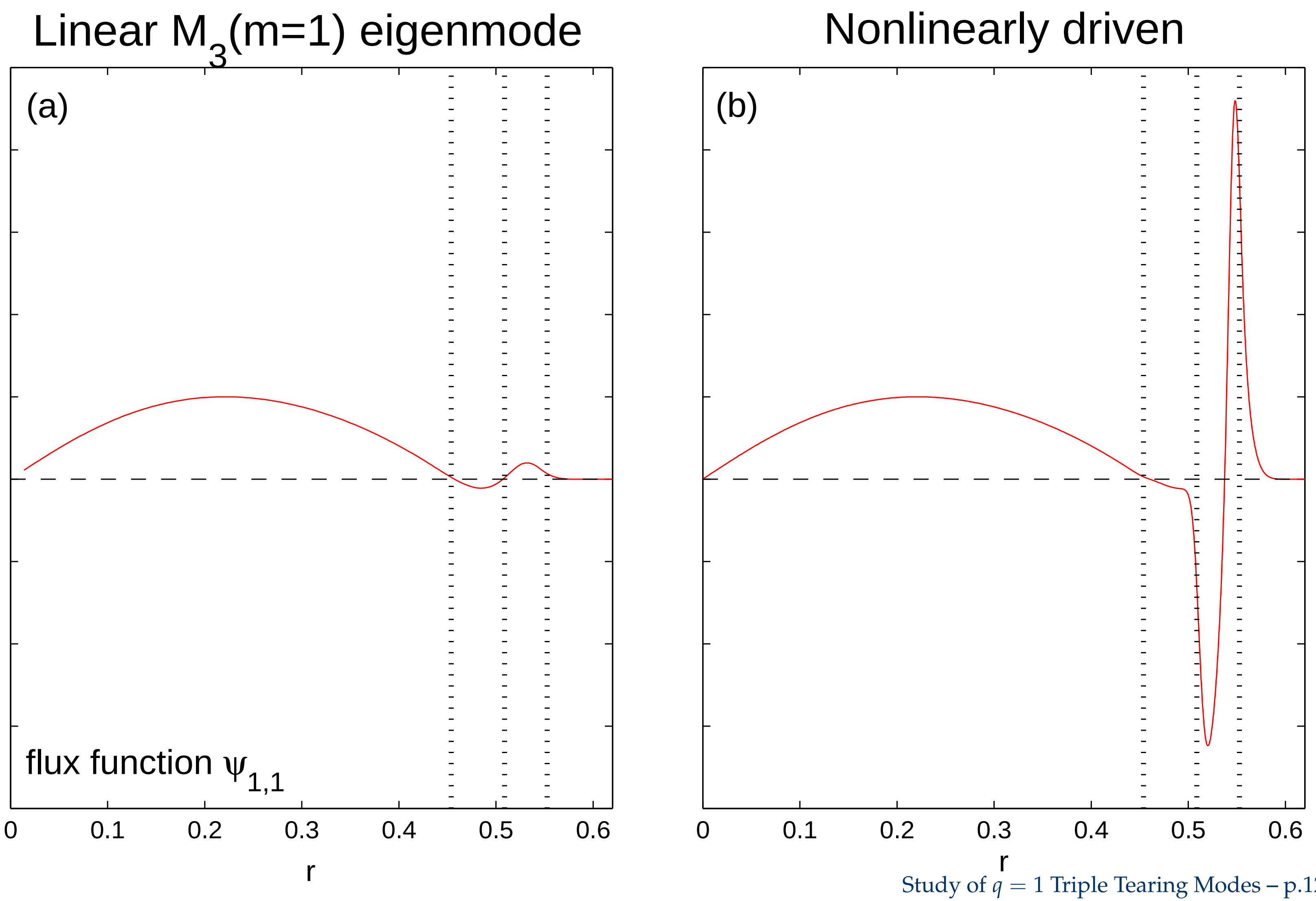
Energy evolution



3. Early nonlinear evolution of the $m = 1$ mode (2): NL driving



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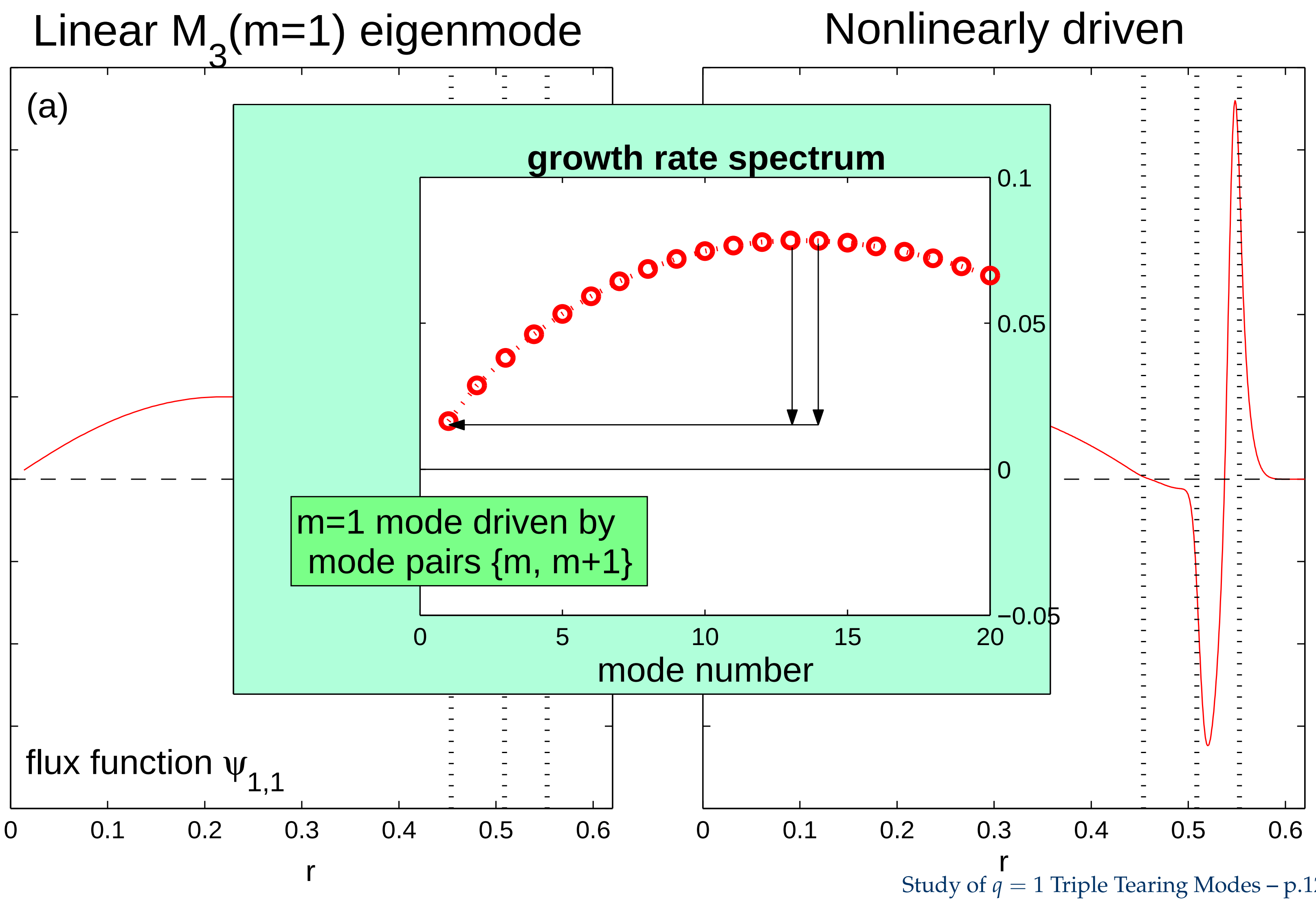

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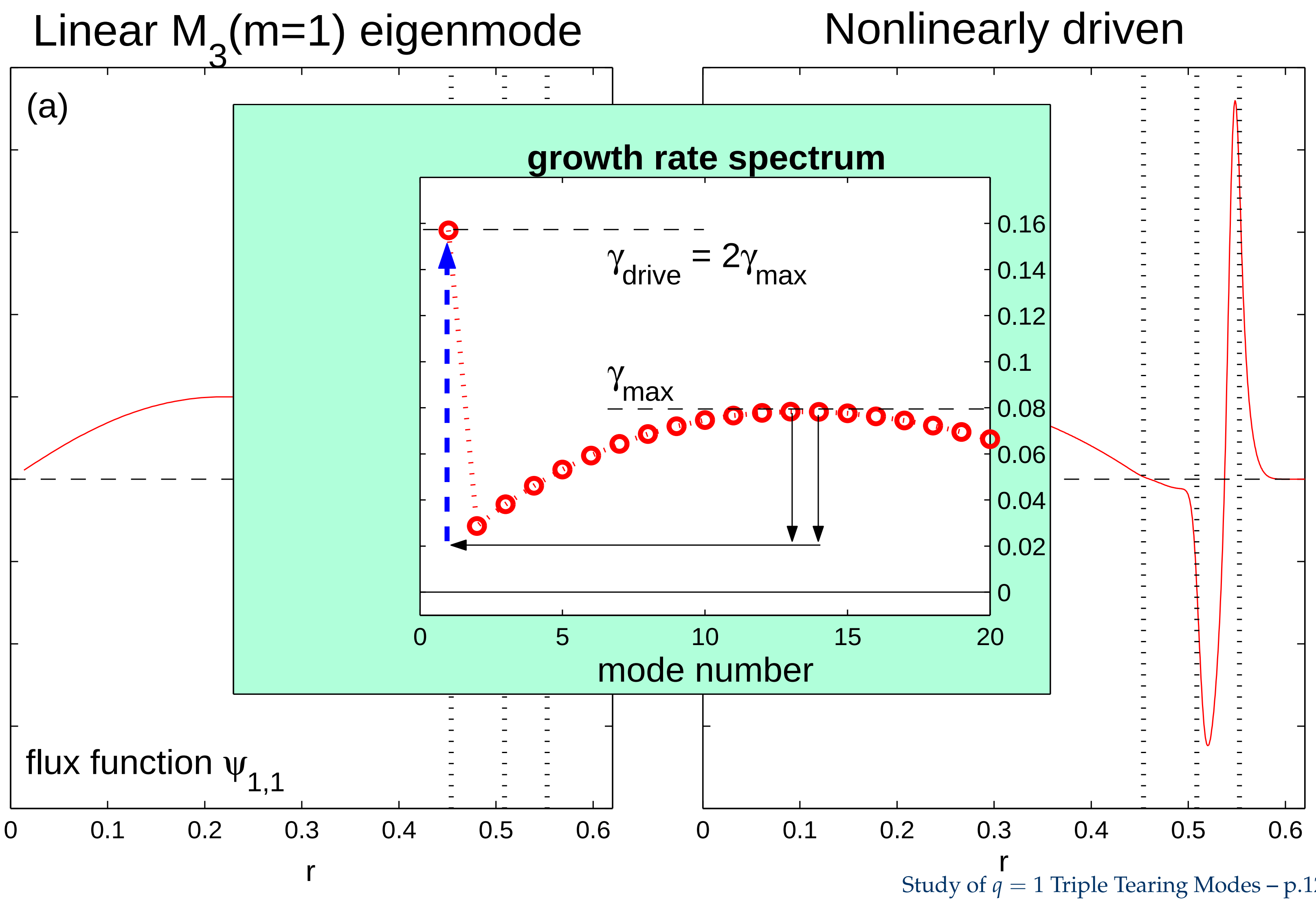
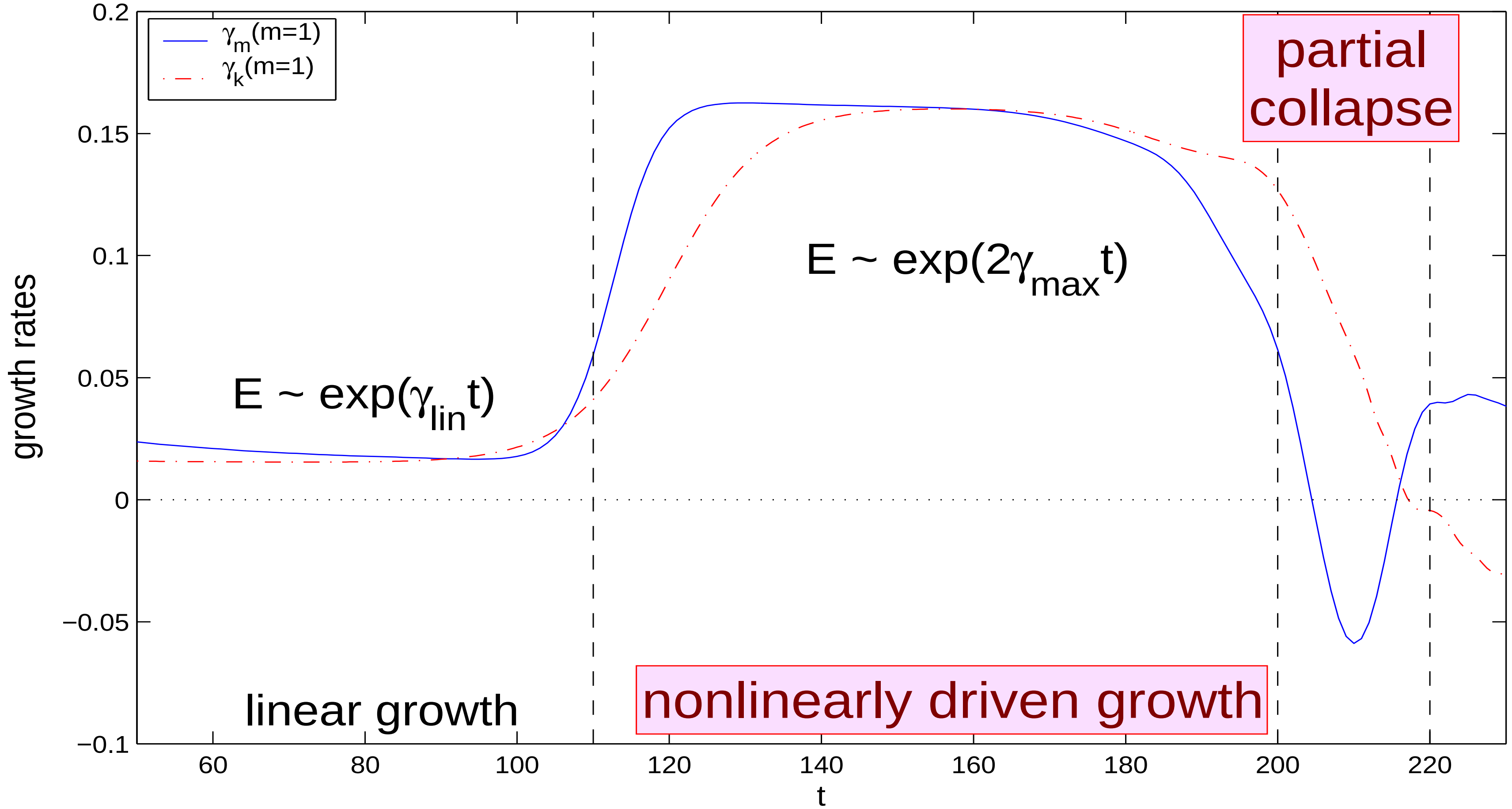


3. Early nonlinear evolution of the $m = 1$ mode (3): Fast trigger



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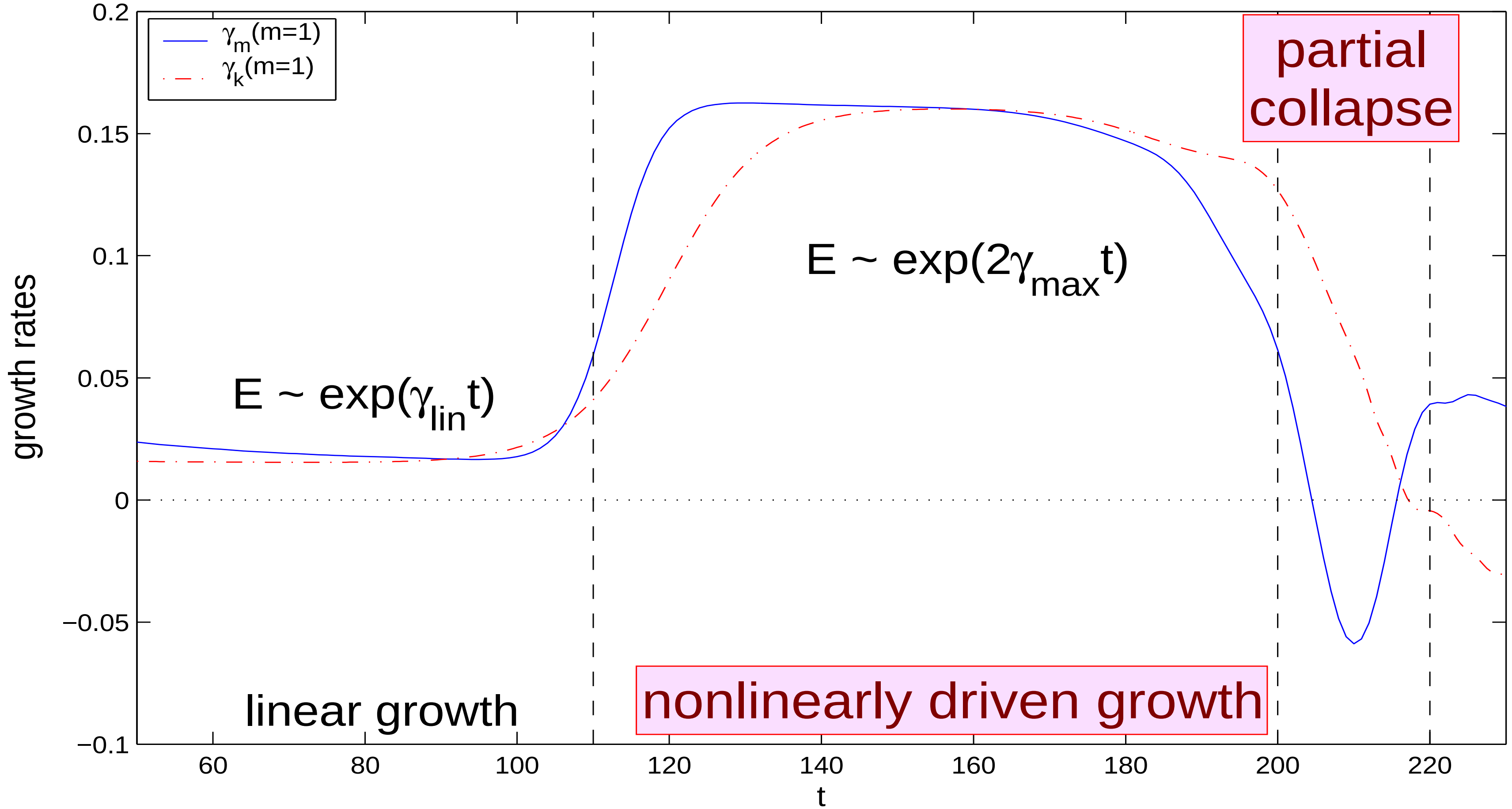
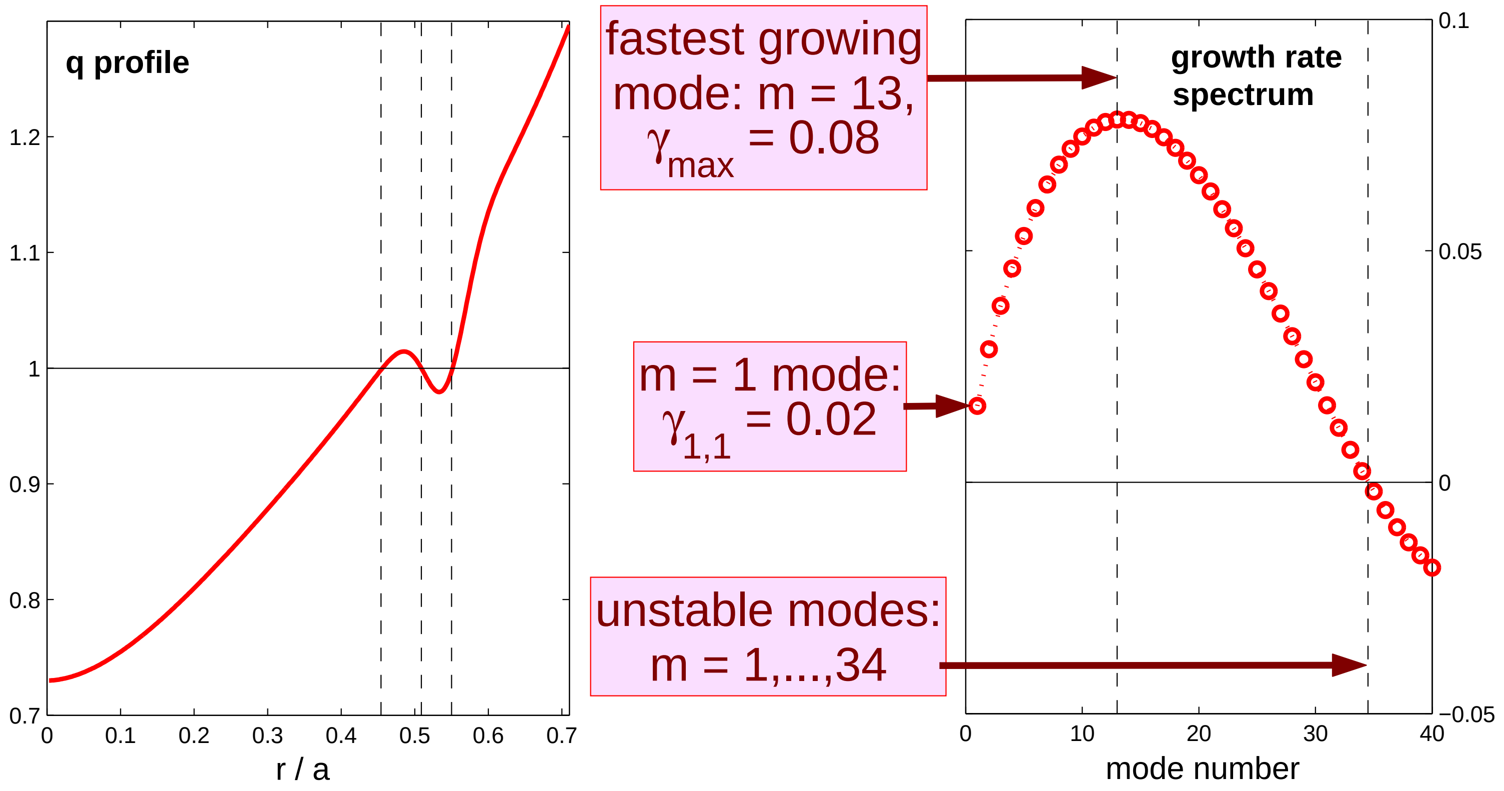


onset much faster than expected from linear growth rate

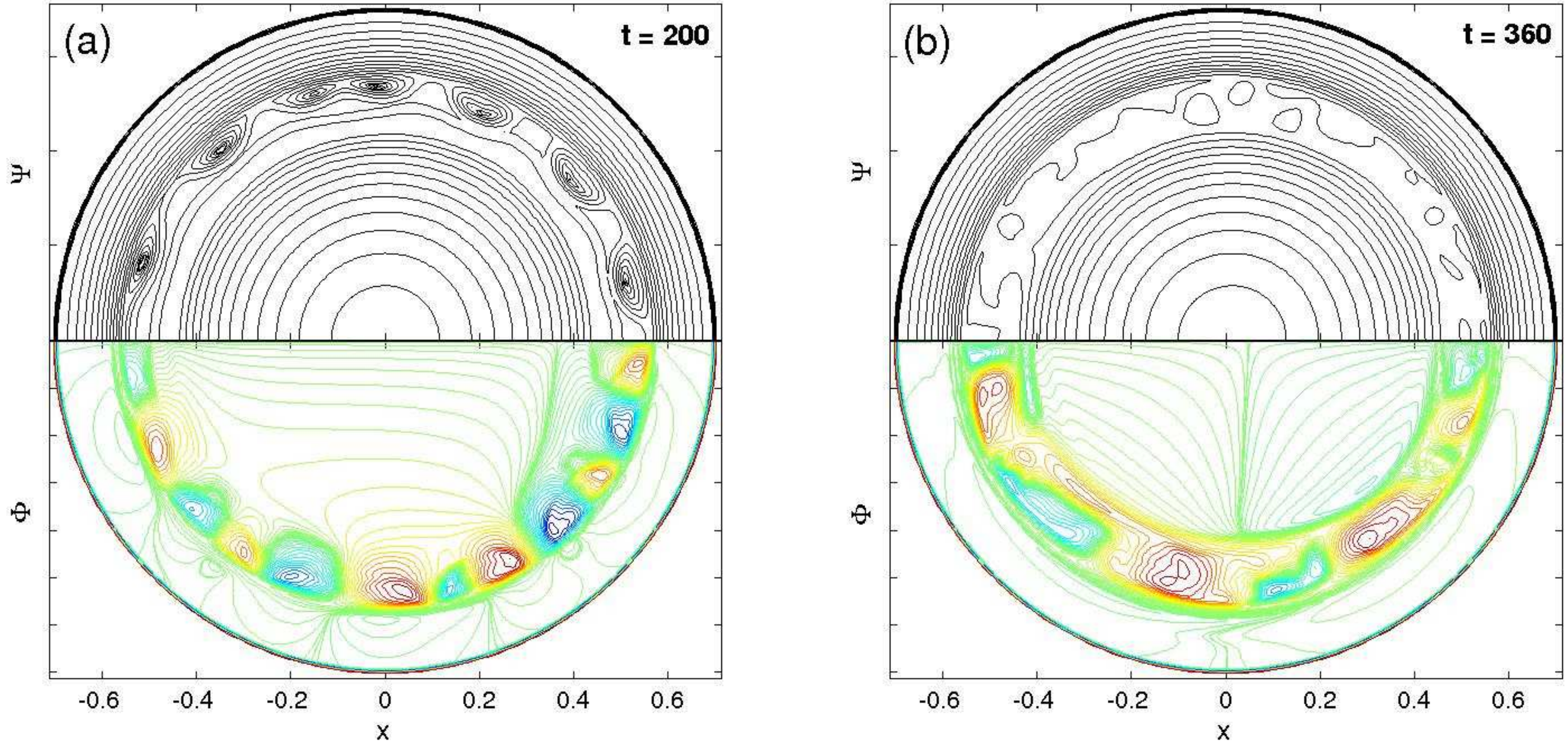
4. Random perturbation



[MOVIE]

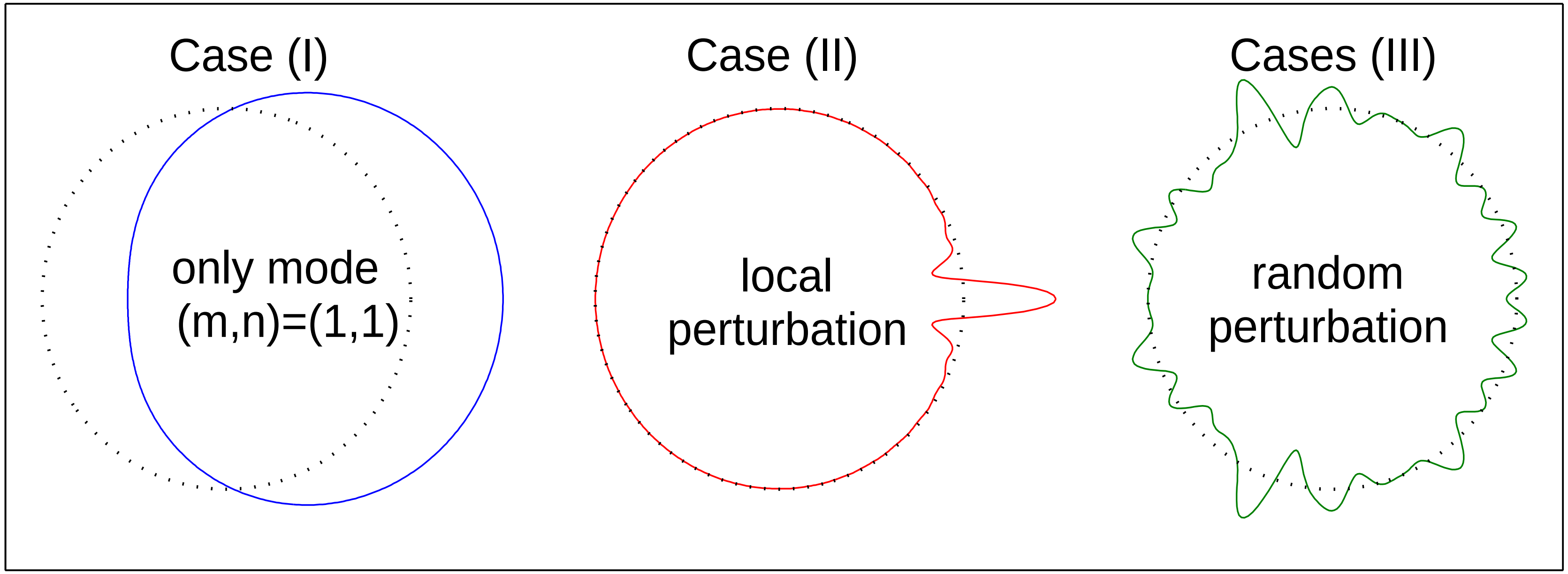
4. Random perturbation (2)

- Partial collapse without precursor
- Generation of electromagnetic turbulence

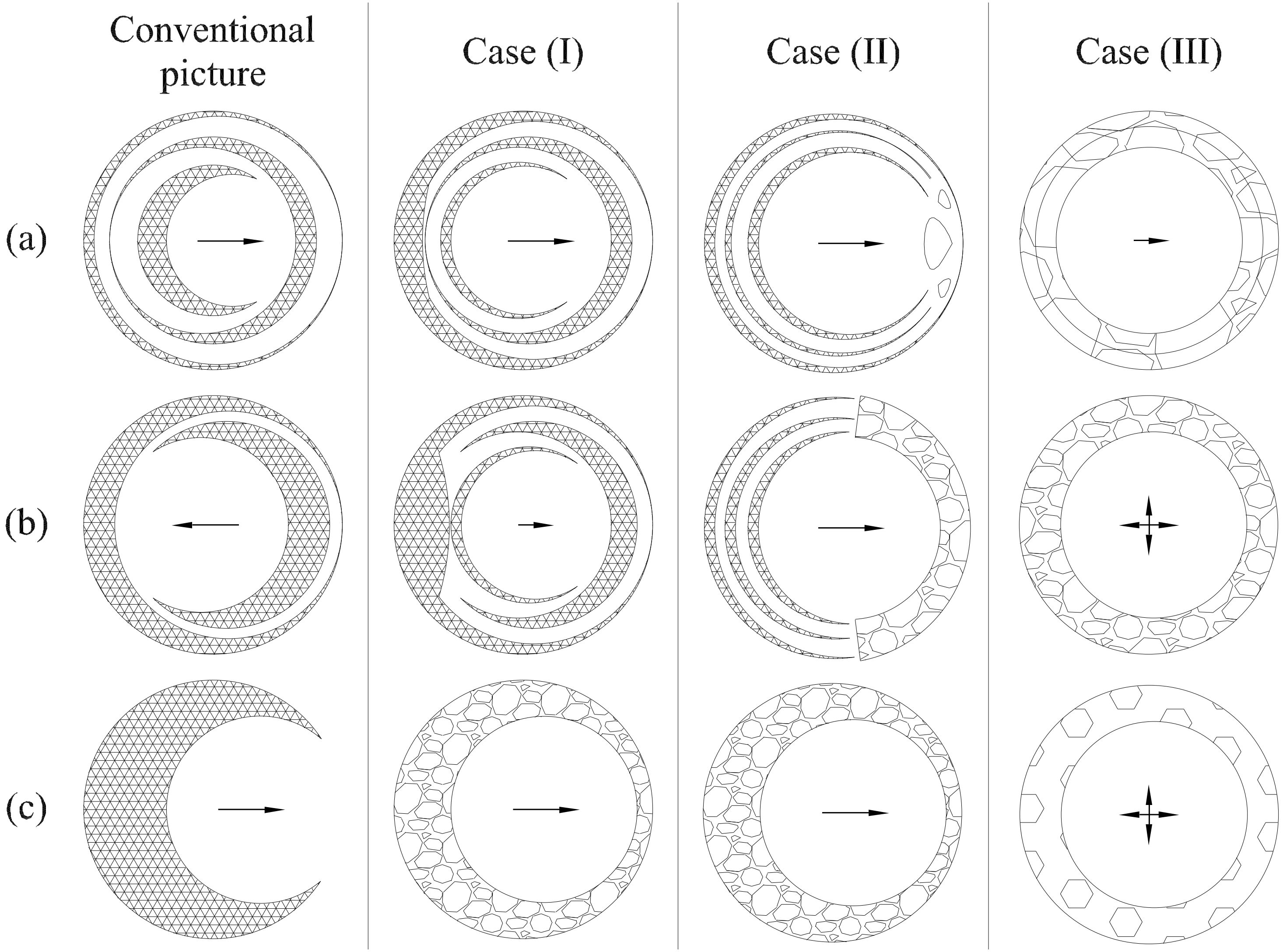


5. Overview

Study response to different kinds of perturbations



5. Overview (2)



6. Partial reconnection

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Scenarios for partial reconnection

- Scenario 1: saturation due to reduced drive
  - *observed after random perturbation of configurations with* $\gamma_{\max}$ *at* $m \sim \mathcal{O}(10)$

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- Scenario 1: saturation due to reduced drive
  - *observed after random perturbation of configurations with* $\gamma_{\max}$ *at* $m \sim \mathcal{O}(10)$
- Scenario 2: “dynamic saturation”
  - *in cases where kink continues to grow* $\longrightarrow$ *experiences “rebound” and decays* $\longrightarrow$ *axisymmetry restored,* $q_0 < 1$

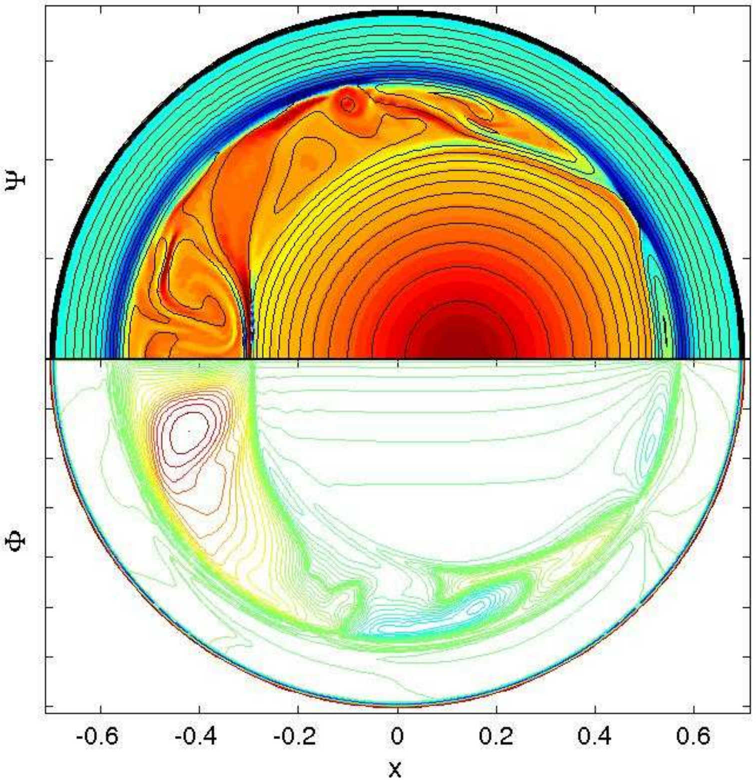
6. Partial reconnection (2)

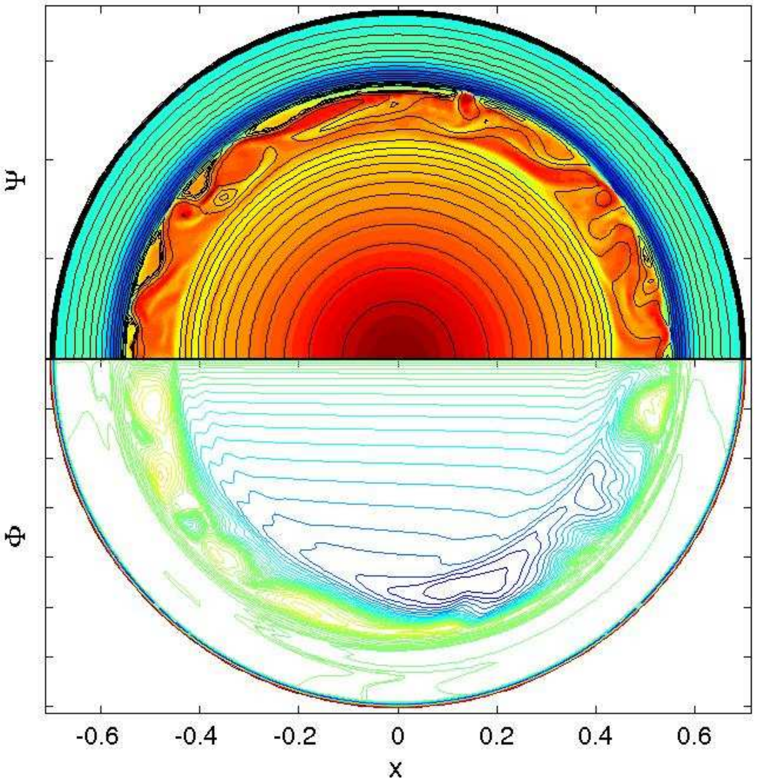
Partial collapse due to “dynamic saturation”

[MOVIE: TTM, γ_{lin} peaks at $m = 13$]

6. Partial reconnection (3)

Partial collapse due to "dynamic saturation"





7. Summary

- Three $q = 1$ resonant surfaces
  - broad spectrum of unstable TTMs peaking at high m
  - fast trigger for $m = 1$ mode due to nonlinear driving
  - possibility of annular collapse without precursor
  - generation of electromagnetic turbulence
  - partial reconnection

8. Conclusions and Perspectives

- May give valuable insights into dynamics of sawtooth collapses, e.g., partial collapses during compound sawteeth
- Paradigm to study the interaction between the internal kink and electromagnetic turbulence

large-scale instability ($m \sim \mathcal{O}(1)$)	$\leftrightarrow$	meso-scale fluctuations ($m \sim \mathcal{O}(10)$)

Acknowledgements

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