Ballooning Instability of a Divertor Tokamak [1]

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To understand the roles of divertor in ELM dynamics

- The X-point of a divertor tokamak was believed to introduce new regimes of edge instabilities (RX mode) [1].
- During the late nonlinear stage of ELMs, field line stochasticity induced by the divertor configuration may play significant roles in ELM dynamics [2].
- In general, it is not clear if the presence of divertor separatrix is a prerequisite for the onset of ELMs.
- Recent NIMROD simulations have observed an edge ballooning instability with distinctively different mode structures and active regimes in a divertor tokamak.

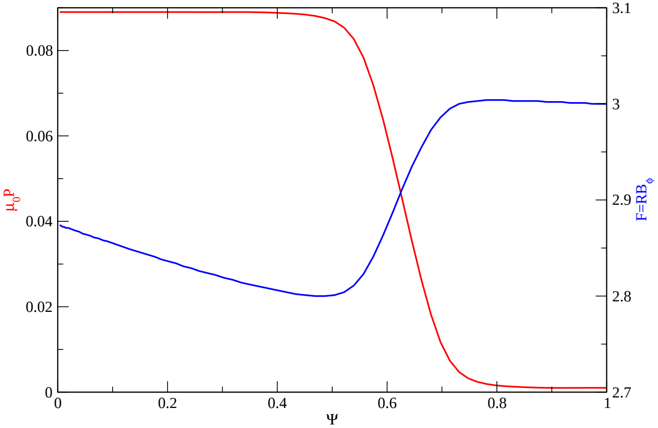
[1] J. R. Myra and D. A. D'Ippolito, *Phys. Plasmas* **12**, 092511 (2005).

[2] L. Sugiyama and H. Strauss, ELMs: A new type of plasma instability, CEMM Workshops, 2009; L. Sugiyama, APS-DPP talk, 2009.

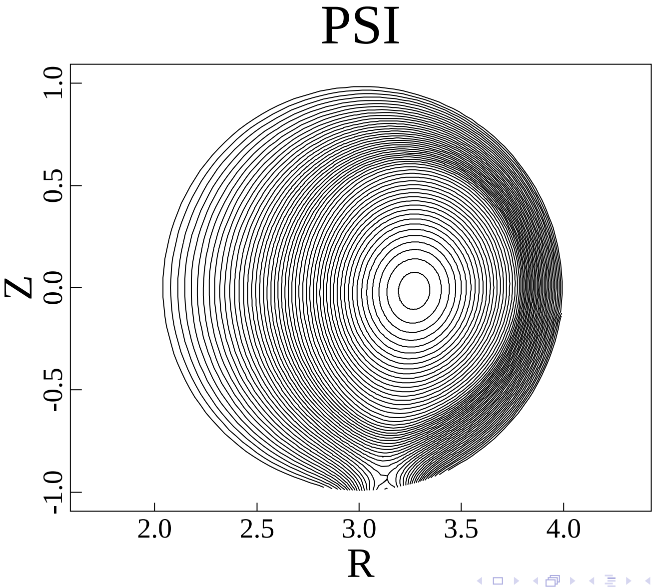
NIMEQ generates tokamak equilibria with a single null divertor for this study

- NIMEQ is a direct Grad-Shafranov equilibrium solver developed within NIMROD framework [Howell and Sovinec 2008].
- NIMEQ has been applied to construct toroidal equilibria with a wide range of complexities.
- A circular-shaped tokamak equilibrium with a single null divertor is generated using NIMEQ:
  - Pressure $P(\Psi)$ and current $F(\Psi)$ profiles are prescribed for both closed and open flux regions.
  - Boundary $\mathbf{B} \cdot \mathbf{n}$ is prescribed to model effects of external coils.
  - Double null divertor equilibrium can be similarly obtained.

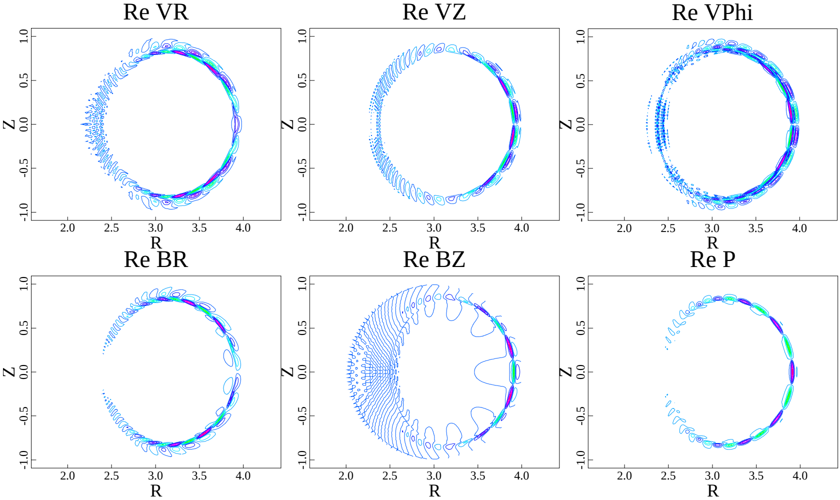
Core plasma is defined by the pressure and current profiles inside edge pedestal foot



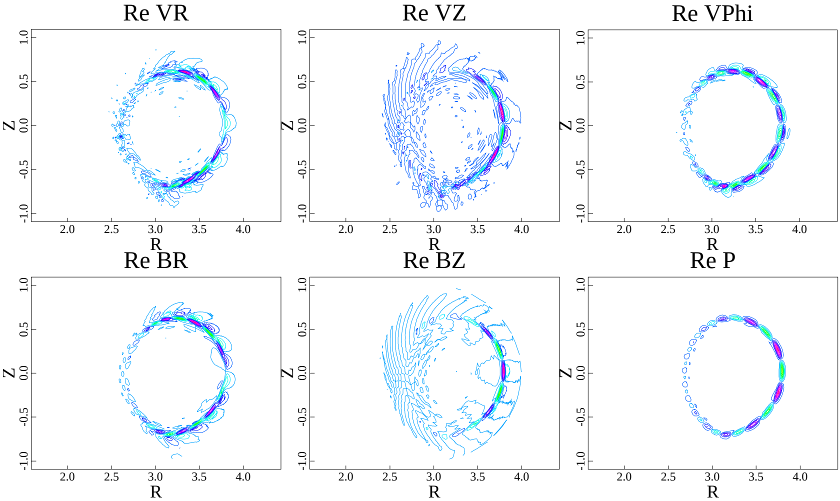
Edge plasma outside pedestal features a single null separatrix



In a limiter tokamak (no separatrix), ballooning mode structures are localized near outboard midplane with up-down symmetry ($n = 15$)

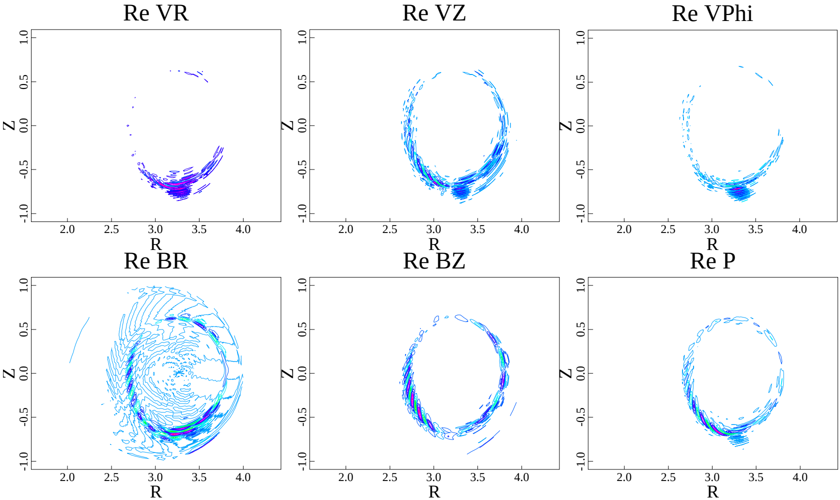


Mode structures remain similar in presence of separatrix in dissipative regime ($\theta_x = -82.5, n = 15$)



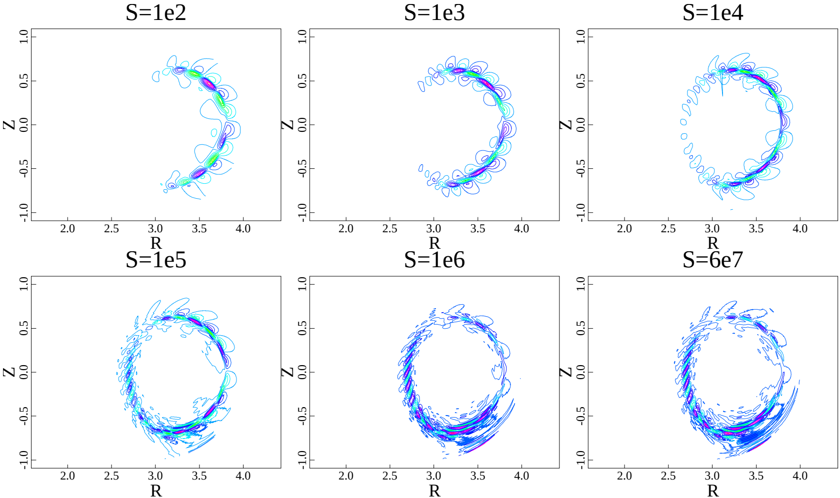
- Mode amplitudes remain peaked in outboard middle plane and up-down symmetry.

Mode structures are very different in presence of separatrix in ideal regime ($\theta_x = -82.5, n = 15$)



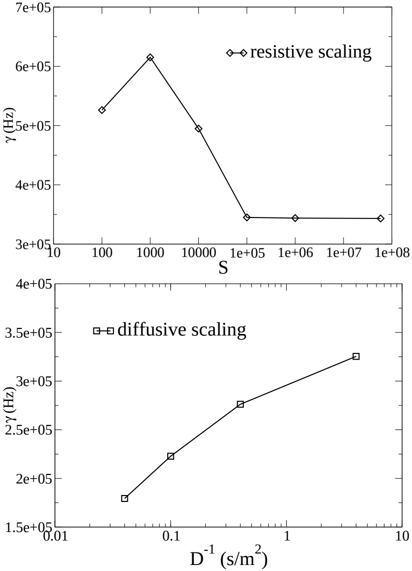
- Mode structures seem peaked near X-point of separatrix.

Transition of mode structure from limiter-like to divertor-like can be also modulated by resistivity ($\theta_x = -82.5, n = 15$)

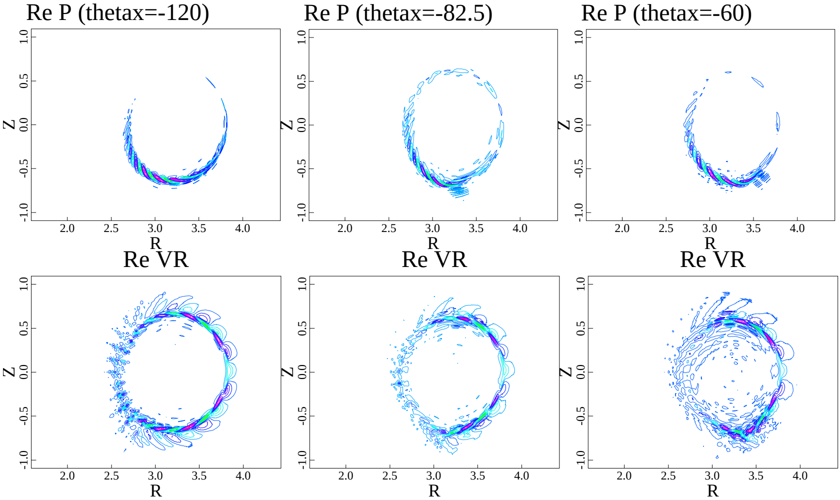


- “X-point mode” seems to mostly exist in $S \to \infty$ regime.

Growth rates of resistive and diffusive ballooning approach the ideal X-point mode from opposite ends

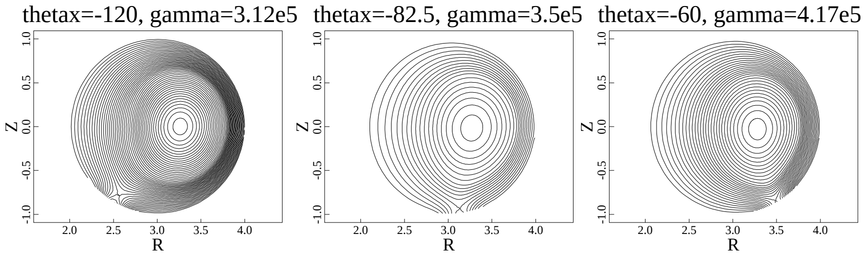


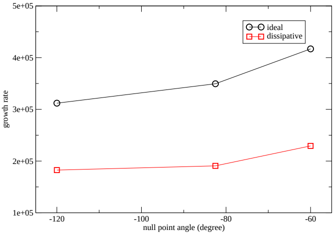
Linear mode structures are also regulated by X-point location



- Upper row: ideal mode; Lower row: diffusive mode

Linear growth increases as X-point moves to outboard





- Ideal regime:
  $D = \mu = \chi = 0$,
  $D_{\text{hyper}} = 1$, $\eta = 0$
- Diffusive regime:
  $D = \mu = \chi = 25$,
  $D_{\text{hyper}} = 0$, $\eta = 0$

Summary

- NIMROD calculations have identified two types of ballooning instabilities of a divertor tokamak in two opposite collisionality regimes.
- In collisional regime, ballooning mode has a similar structure as in a limiter tokamak;
- In ideal regime, ballooning mode structure is localized near X-point instead of outboard midplane.

Future work on ballooning instability physics

- CEMM relevant topics
  - Mostly in context of ELMs
  - 2D shaping (non-circular shape, divertor separatrix/X-point)
  - 3D shaping effects (RMP)
  - Edge shear flow effects
  - Peeling-ballooning coupling
  - Nonlinearity
    - Marginal state crossing and detonation regime
    - Late nonlinear regimes: saturation, filament and blob
  - Nonideal effects (resistive,2-fluid, kinetic, hot-particle)
    - Determine edge stability boundary.
- Supporting topics
  - Mostly in context of substorms (NSF, CMSO)
  - Interchange and ballooning instabilities of plasma sheet.
  - Coupling to tearing instability and reconnection process.
- Verification and validation efforts