TSVV10 Meeting

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自然科学研究機構

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February 23, 2022

1. Tearing Mode Linear Simulations, Collisionless Limit
    - Benchmark with theory (no gradients)
    - Impact of gradients
2. Tearing Mode Non-Linear Simulations, Collisionless Limit
3. Tearing mode Linear Simulations, Collisional Limit
    - Investigations on the mode changing from (2,1) to (1,1)
4. Conclusions

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Initial profiles

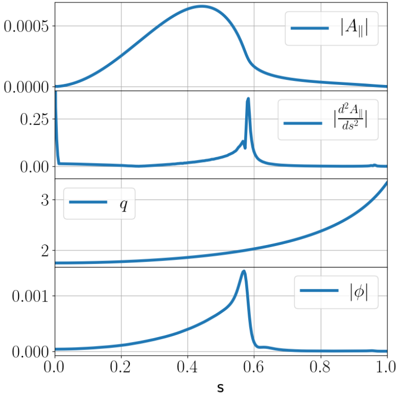
Plasma horizontal size $lx = 2/(\rho^*) = 200$ with $\rho^* = \rho/a$. Mass ratio $m_i/m_e = 200$. Initial current profile that generates a 2/1 island at $q = 2$.

- Current density profile

$$j = j_0 \left(1 - \left(\frac{r}{a}^2\right)\right)^\zeta$$

- Safety factor profile

$$q = q_a \frac{r^2/a^2}{1 - (1 - r^2/a^2)^{\zeta+1}}$$



Plasma–β_e and collisional skin-depth d_e

Plasma–β

- $\beta_e = 2\mu_0 N_0 T_0 / B_0^2$
- $N_0 = \langle n_e \rangle, \; T_0 = T_e \; (speak)$
- The plasma–β variation $\rightarrow$ variation of N_0 at $T_0 =$cst

Collisionless electron skin-depth d_e

- $d_e = c/\omega_{pe}$
- $\omega_{pe}^2 = 4\pi N_0 e^2 / m_e$
- Plasma-β change through $N_0 \rightarrow$ variation of $d_e = c/\omega_{pe}$

$$\beta_e = \left(\frac{\omega_{pe}}{c}\right)^2 \frac{m_e}{m_i} \rho_s^2$$

- $\rho_s = c_s/\Omega_i$ the ion sound Larmor radius, $c_s^2 = (T_i + T_e)/m_i$ and gyrofrequency $\Omega_i = Z_i e B_0/(m_i c)$

Tearing Mode Theoretical Linear Growth Rate

- Tokamak important regime for magnetic reconnection: $d_e < \rho_s$
- Tearing mode theoretical growth rate in collisionless regime in the limit of small Δ' Rogers et al.[1]

$$\gamma_{cl} = \frac{1}{\pi} k_y k_x \frac{c^2}{e^2} (T_i + T_e)^{1/2} m_e^{1/2} \Delta' \frac{B_{0,y}^{max}}{B_{0,z}} \frac{1}{4\pi N_0},$$

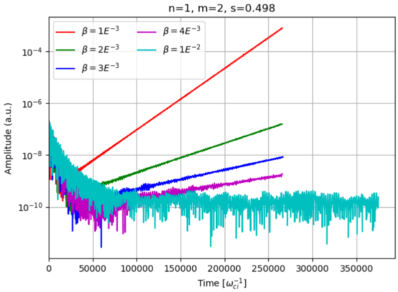
- Can be rewritten in terms of the plasma–β_e

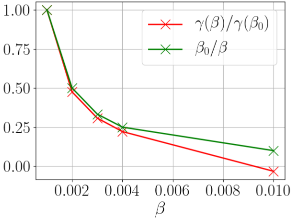
$$\gamma_{cl} = \frac{1}{\pi} k_y k_x \frac{c^2}{e^2} \Delta' \frac{B_{0,y}^{max}}{B_{0,z}^3} T_e^{3/2} m_e^{1/2} \left(1 + \frac{T_i}{T_e}\right)^{1/2} \frac{1}{\beta_e}.$$

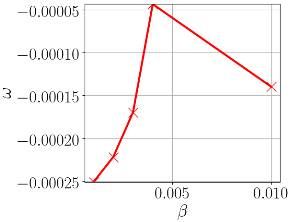
- Parameters tested with ORB5 in the linear regime: β_e, m_e, T_i and T_e

Plasma-β scan, 2/1 unstable mode at $s = 0.5$

- Plasma-$\beta_e = \frac{2\mu_0 N_0 T_0}{B_0^2}$. Linear estimations (Rogers et al.[1]): $\gamma_{i+1} \propto \gamma_i/\beta$

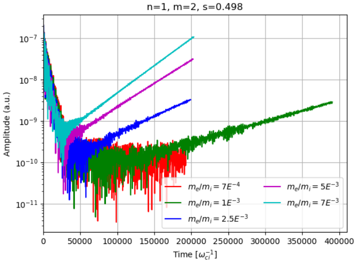


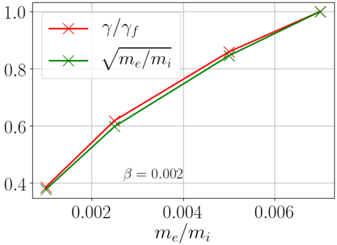


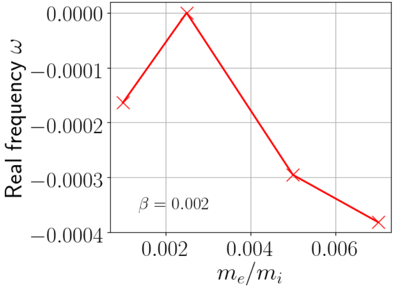


Mass ratio scan, 2/1 unstable mode at $s = 0.5$

- Linear estimations (Rogers et al. [1]): $\gamma_{i+1} \propto \gamma_i \sqrt{m_e/m_i}$







Temperature scans, 2/1 unstable mode at $s = 0.5$

- Linear estimations (Rogers et al.[1]): $\gamma_{i+1} \propto \gamma_i \sqrt{T_i + T_e}$

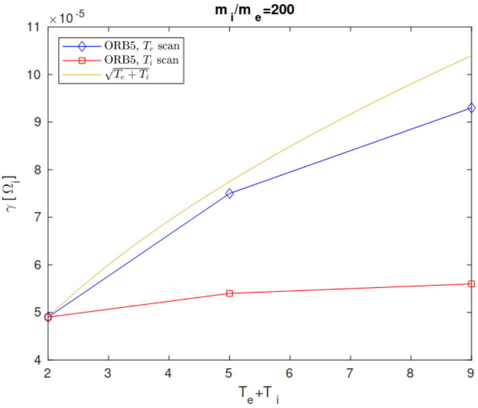
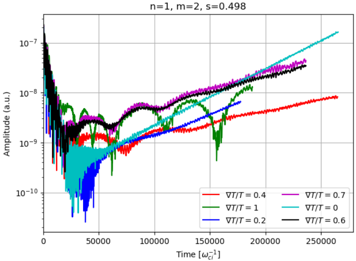
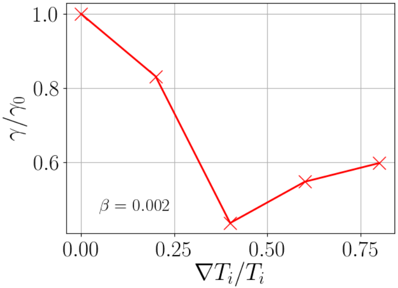
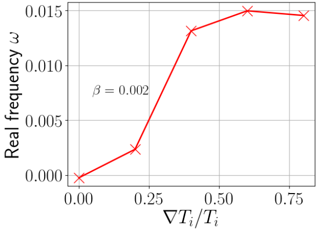


Figure – Courtesy: Emanuele Poli (IPP)

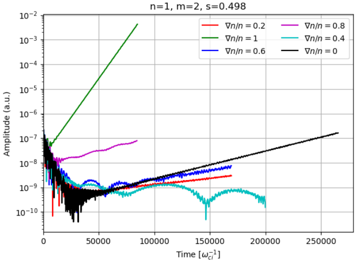
Scan $\nabla T/T$, $\nabla n/n = 0$, $\beta = 0.2\%$

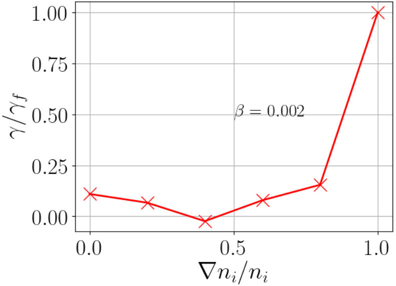


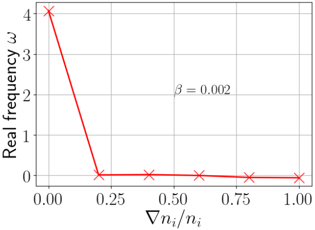




Scan $\nabla n/n$, $\nabla T/T = 0$, $\beta = 0.2\%$

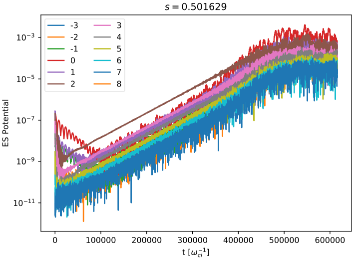




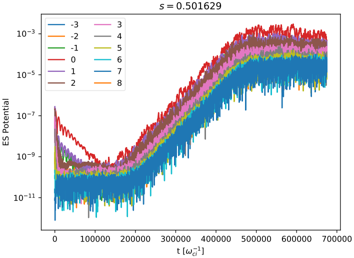


ES potential time amplitude, $\nabla T/T = 0.5$, $\nabla n/n = 0.1$

- Tearing driven simulations $\boldsymbol{J} \neq 0$
- m modes for n=1, drive: m/n=2/1



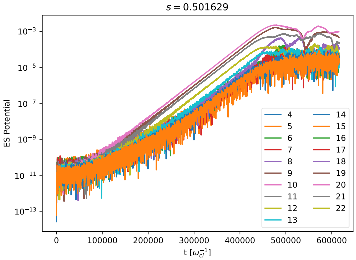
- Tearing driven simulations $\boldsymbol{J} \neq 0$
- m modes for n=1, m/n=2/1 driven by turbulence.



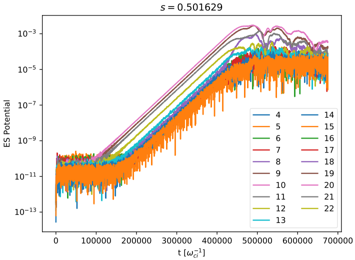
Probably marginal for ITG.

ES potential time amplitude, $\nabla T/T = 0.5$, $\nabla n/n = 0.1$

- Tearing driven simulations $\boldsymbol{J} \neq 0$
- m modes for n=5. Driven by m/n=2/1: m=[9-12].

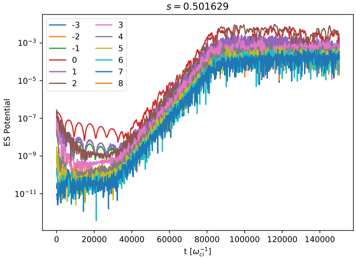


- Not tearing driven simulations $\boldsymbol{J} = 0$
- m modes for n=5. Drive m=[9-12].

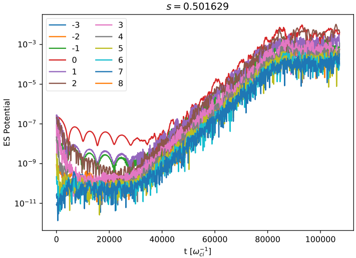


ES potential time amplitude, $\nabla T/T = 0.8$, $\nabla n/n = 0.2$

- Tearing driven simulations $\boldsymbol{J} \neq 0$
- m modes for n=1, m/n=2/1 driven by turbulence.

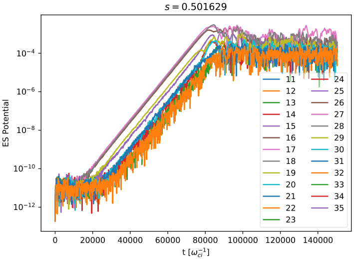


- Not tearing driven simulations $\boldsymbol{J} = 0$
- m modes for n=1, m/n=2/1 driven by turbulence.



ES potential time amplitude, $\nabla T/T = 0.8$, $\nabla n/n = 0.2$

- Tearing driven simulations $\boldsymbol{J} \neq 0$
- m modes for n=9. Drive m=[16-18].



- Not tearing driven simulations $\boldsymbol{J} = 0$
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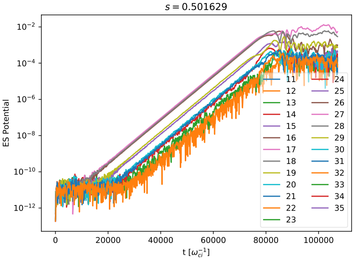

Large wave number drive the growth. Possibly an ITG.

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Collision frequency

The collisionality of ion with ion is defined as:

$$\nu_* = \nu_{ii} qR/(v_{th,i}\epsilon^{3/2}) \quad (1)$$

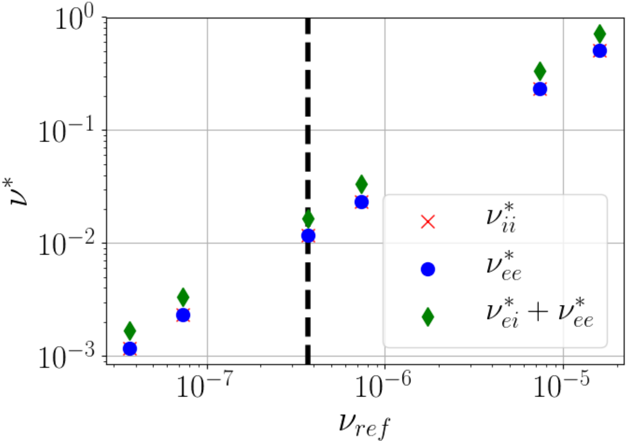
$$\nu_{ii} = \frac{1}{3\sqrt{\pi}} \frac{N_i}{N_0} \left(\frac{v_{T,0}}{v_{T,i}}\right)^3 \left(\frac{m_0}{m_i}\right)^2 Z_i^4 \nu_{ref}, \quad (2)$$

$$\nu_* = \frac{qR_0}{\epsilon^{3/2} v_{T,0}} \frac{1}{3\sqrt{\pi}} \frac{N_i}{N_0} \left(\frac{v_{T,0}}{v_{T,i}}\right)^4 \left(\frac{m_0}{m_i}\right)^2 Z_i^4 \nu_{ref}. \quad (3)$$

$$\nu_{ref} = \frac{N_0 e^4 \ln \Lambda}{4\pi\epsilon_0^2 \sqrt{m_0}\, T_0^{3/2}}, \quad (4)$$

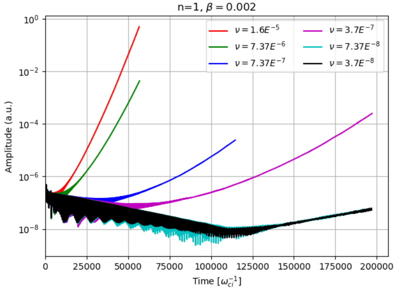
with N_0, m_0, T_0 and $v_{T,0}$ the reference density, mass, temperature and thermal velocity at the radius of reference.

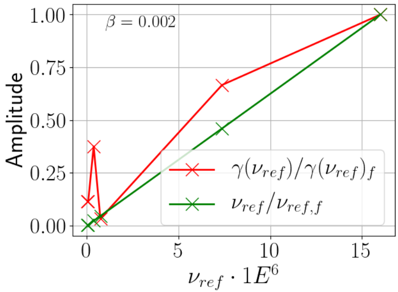
Collisionality frequency values



Scan in collisionality, ORB5 linear results

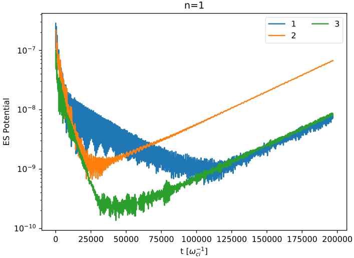
- $\beta \propto N_0$ and $\nu_{ref} \propto N_0$
- Scans in ν_{ref} with β fixed $(2 * 10^{-3})$
- Growth rate increase with ν_{ref}

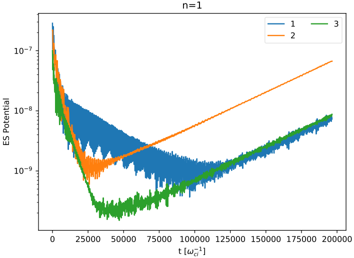


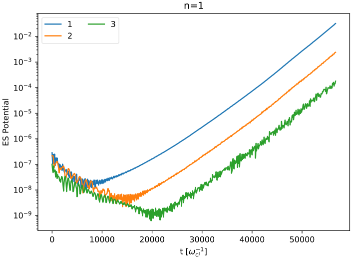


Collisionality changes the modes I

- (n,m)=(1,1) dominates for $\nu_{ref} > 7.37E^{-8}$ but $q_{min} = 1.75$

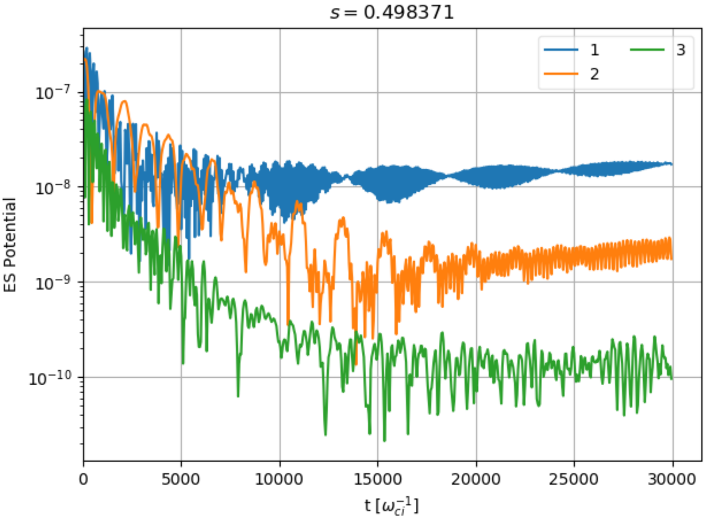






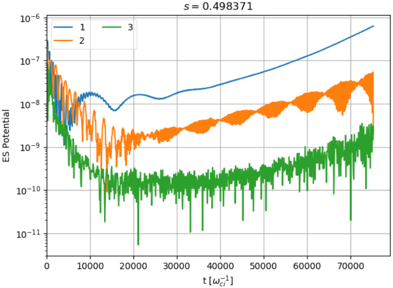
Halving the time step

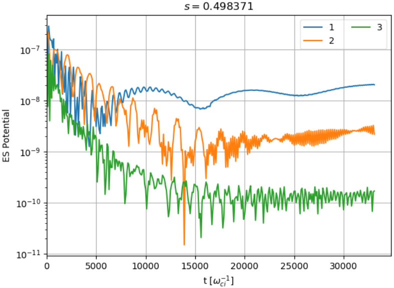
- Not a matter of time step



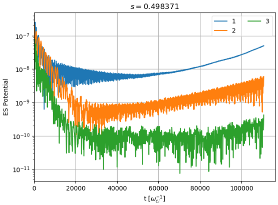
Increasing number of markers: $2E8$ and $1E9$

- Not a resolution matter

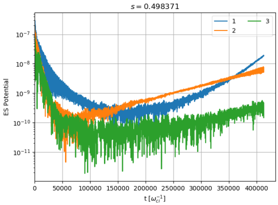




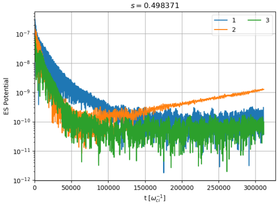
Increasing plasma–β, $\nu_{ref} = 3.7E^{-7}$



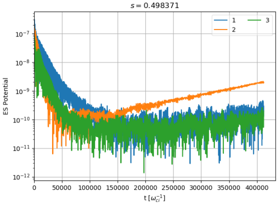
(a) Plasma–$\beta = 0.2\%$



(b) Plasma–$\beta = 0.45\%$



(c) Plasma–$\beta = 0.5\%$



(d) Plasma–$\beta = 0.55\%$

Tearing mode in collisionless limit

- Linear scans in plasma-β and mass ratio validated by linear theory: $(\gamma \propto 1/\beta)$, $(\gamma \propto \sqrt{m_e/m_i})$
- NL simulations $\nabla T/T = 0.5$, $\nabla n/n = 0.1$:
  - $\boldsymbol{J} \neq 0$: Tearing $(m, n) = (2, 1)$ is the driving
  - $\boldsymbol{J} = 0$: $(m, n) = (9 - 12, 1)$ are the driving
  - $\boldsymbol{J} = 0$: retarted including $\boldsymbol{J}$
- NL simulations $\nabla T/T = 0.8$, $\nabla n/n = 0.2$:
  - $\boldsymbol{J} \neq 0$: Turbulence drives the tearing (linearly $\nabla T/T$ reduces γ_{tear})
- Next Steps:
  1. Determine what kind of turbulence is present (local GKW linear simulations)
  2. Turbulence bath without tearing $\boldsymbol{J} = 0$ from $t = 0$
  3. Bi–coherence analysis tool
  4. Improve diagnostic for mode frequency

Tearing mode in collisional limit

- Collisions enhance the linear growth rate at fixed plasma-β
- The collisionality modifies the mode responsible for the growth (linearly and non-linearly)
- The issue seems to be related to the a fixed value of the plasma-β
- In current discussions with Peter Donnel (CEA). Devellopped collisions for ES, not fully tested in EM.

[1] B. N. Rogers, S. Kobayashi, P. Ricci, W. Dorland, J. Drake, and T. Tatsuno. Gyrokinetic simulations of collisionless magnetic reconnection. *Physics of Plasmas*, 14(9), 2007. ISSN 1070664X. doi: 10.1063/1.2774003.