MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Nonlinear dynamics of nonadiabatic chirping-frequency Alfvén modes in Tokamak plasmas

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EUROfusion

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Background: likelihood of frequency-chirping in Tokamak fusion plasmas

❑ Chirping is a major issue in connection with fast ion losses in tokamaks and there is currently little understanding of how to systematically avoid them.

- In the ref. [Duarte et al 2017], it is proposed that turbulence is a likely mediator of the chirping likelihood as shown in DIII-D experimental data.
- The conclusion of chirping based on turbulence holds for NSTX, for which dedicated gyrokinetic studies were performed [Duarte et al 2018].
- In DIII-D negative triangularity plasmas, more chirping of Alfvén modes are observed [Van Zeeland et al 2019], where turbulence is considerably lower than usual.
- More prevalent bursty behaviour has been observed in AUG experiments with impurity accumulation in the core. The strong radiation losses due to impurities likely made T_e and T_i flatter, which suppressed the drive for turbulence. [Lauber et al 2018]

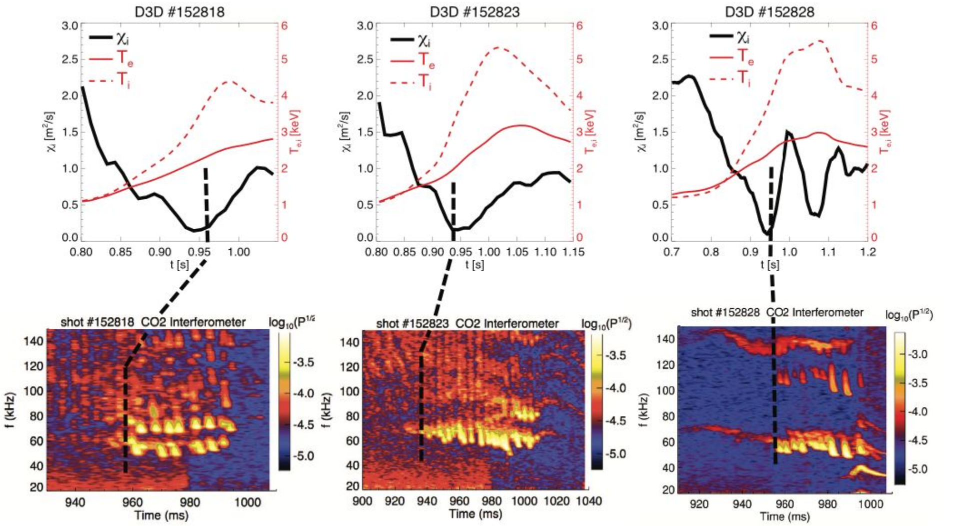


Figure 4. Correlation in DIII-D between the emergence of chirping and the development of low diffusivity, as calculated by TRANSP at the radius where the mode is peaked.

Duarte et al, NF 2017

Simulation setups

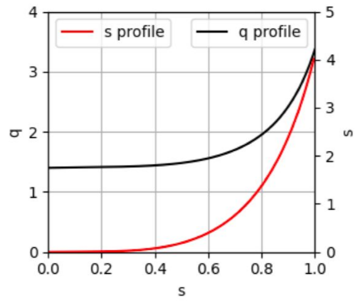
- Analytical magnetic equilibrium
  - Concentric circular flux surfaces
  - Large aspect ratio
  - Safety factor q profile as shown in the figure

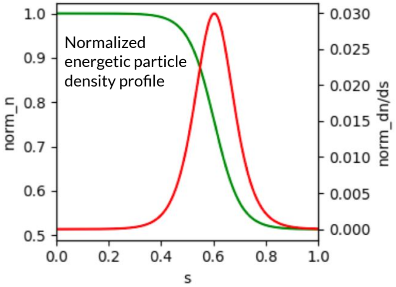
- Energetic particles
  - Deeply passing fast ions
  - Anisotropic slowing-down distribution function

- In the simulations, toroidal mode numbers n=1-40 with / without n=0 are performed respectively.

- For bulk plasmas, uniform density profiles are assumed for both thermal ion and electrons.

- The temperature gradient are assumed the same for both thermal ions and electrons. Three different temperature gradients are used, in order to have different intensity of the background ITG. (Two different temperature gradient cases will be shown here).





Roadmap: further studies on frequency chirping Alfvén modes

HMGC single-n simulations:
detailed dynamics are investigated by using Hamiltonian mapping tool

HMGC multi-n simulations: (by Sergio)
further development of Hamiltonian mapping tool in order to understand resonances overlapping etc.

- Full orbit data of test particles are stored.
- Hamiltonian mapping tool can be used for orb5 (partially, mainly missing power information)

To do

ORB5 single-n

- Different bulk plasma temperature scan
- From drift kinetic to gyrokinetic
- Different toroidal mode number scan
- Electron mass-ratio scan

ORB5 multi-n (low n)

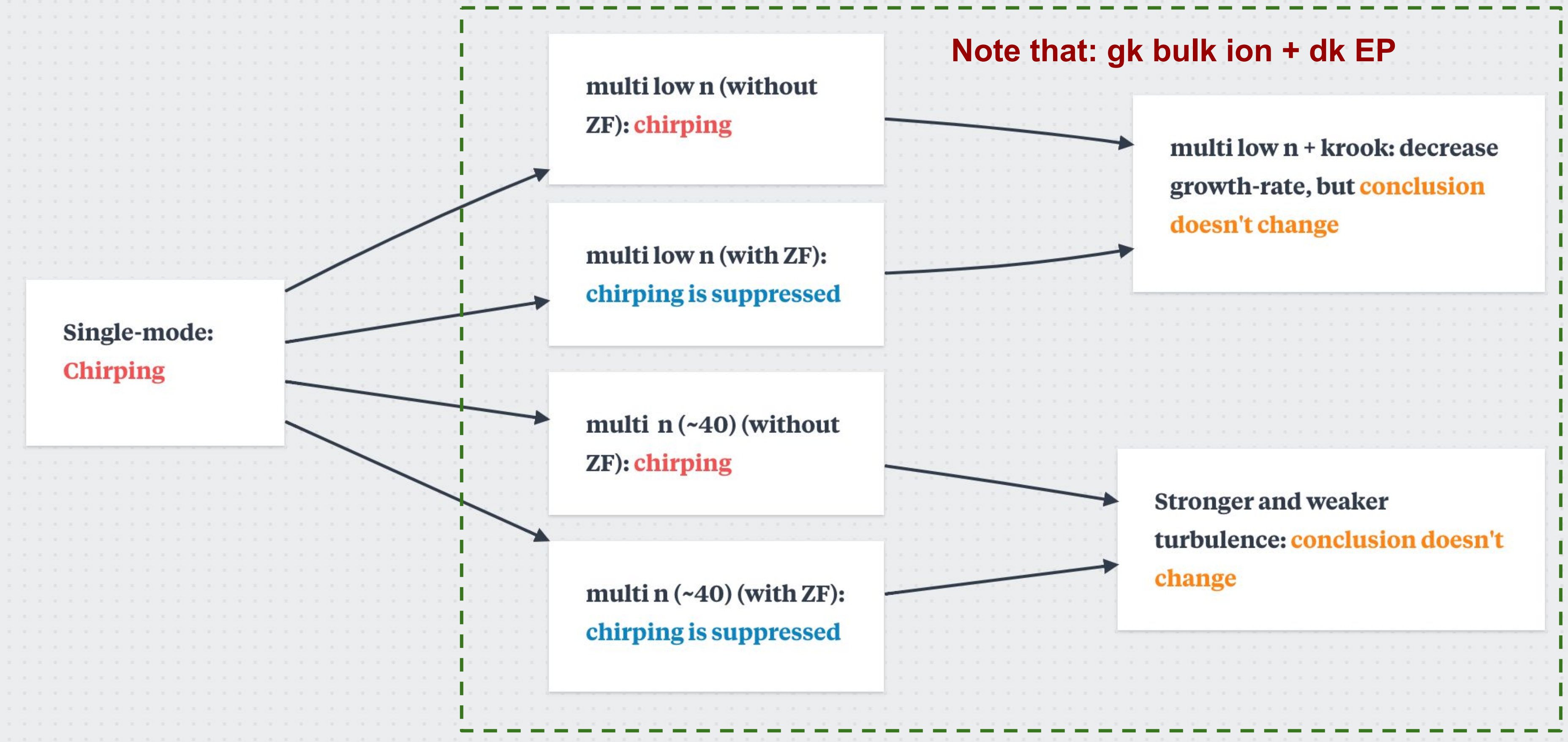
- Multi-n without zonal flow
- Multi-n with zonal flow
- Multi-n with zonal flow + krook
- Electron mass-ratio scan

ORB5 Turbulence + EP

- Without EP
  - ITG without zonal flow
  - ITG with zonal flow
- With EP
  - With zonal flow
  - Without zonal flow

- Larger temperature gradient
- Smaller temperature gradient
- Electron mass-ratio scan

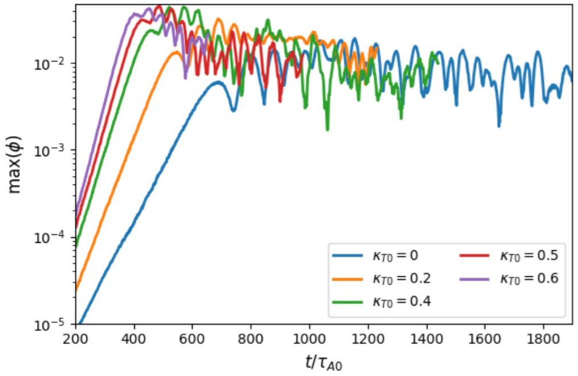
Preliminary results

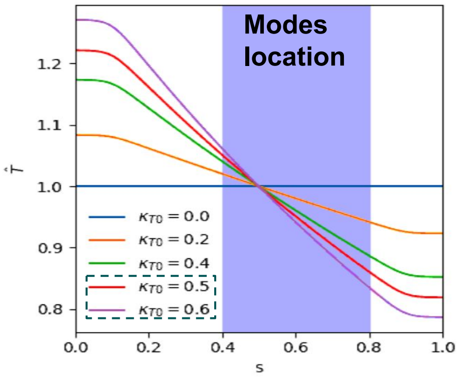


Temperature gradient scan for single

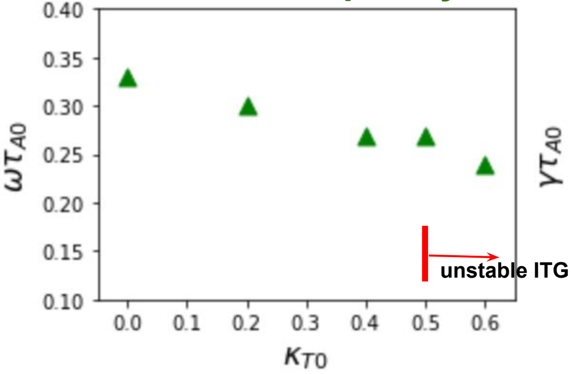
n=5

Dynamics of the Alfvén modes in single n=5 simulations:
background temperature gradient effects I

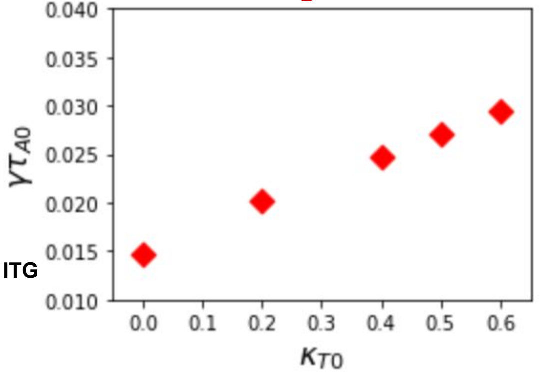




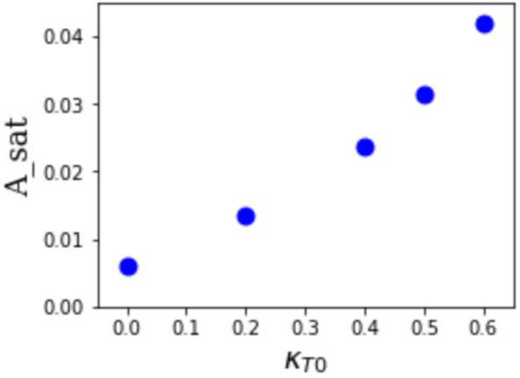
Linear frequency



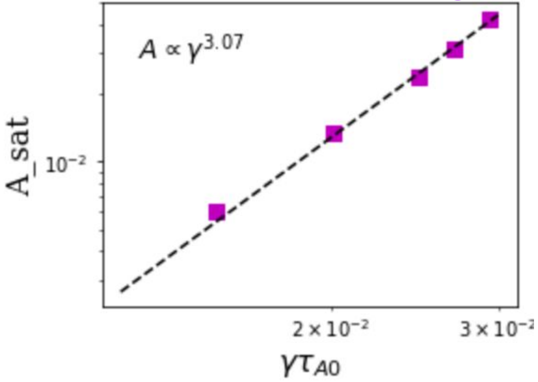
Linear growth-rate



Saturation level

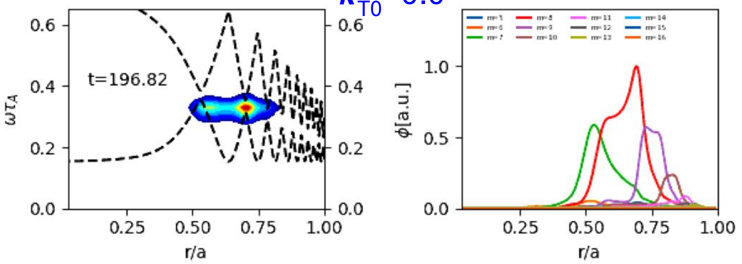


Saturation scaling

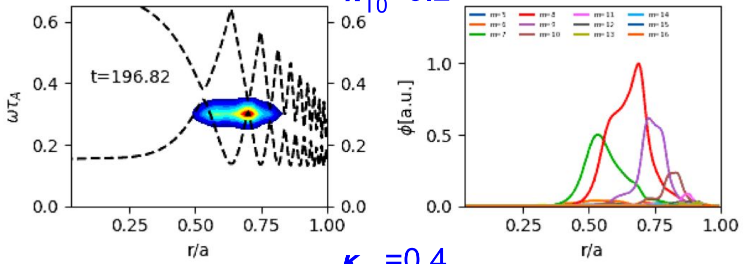


Dynamics of the Alfvén modes in single n=5 simulations:
background temperature gradient effects II

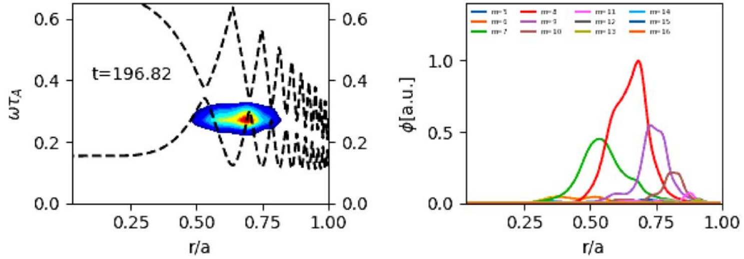
κ_{T0}=0.0



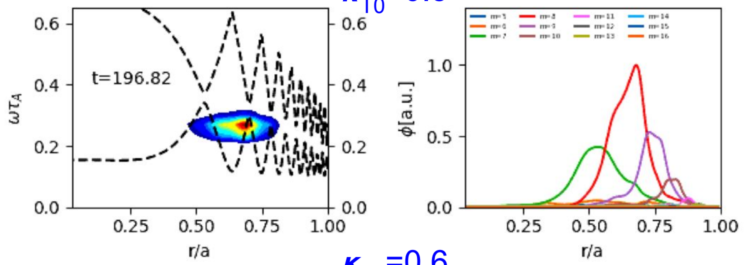
κ_{T0}=0.2



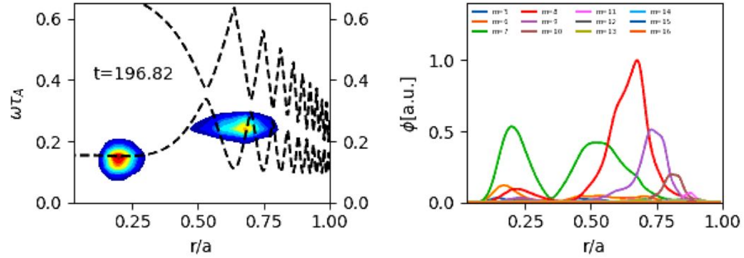
κ_{T0}=0.4



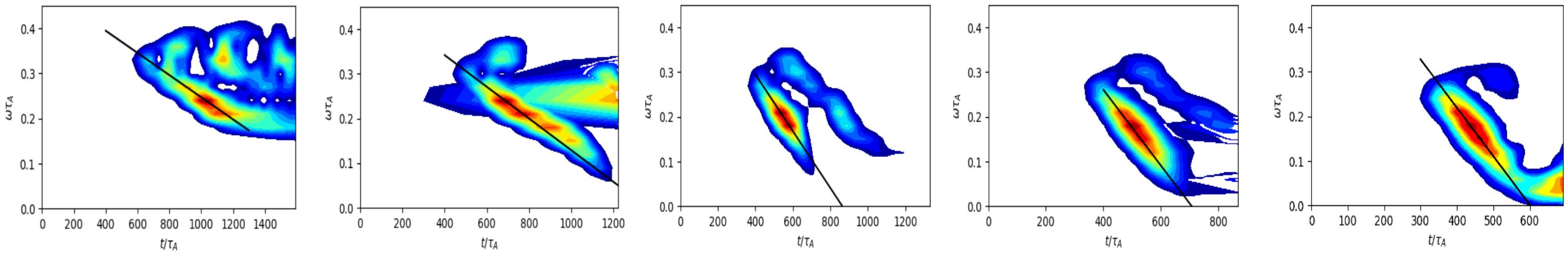
κ_{T0}=0.5

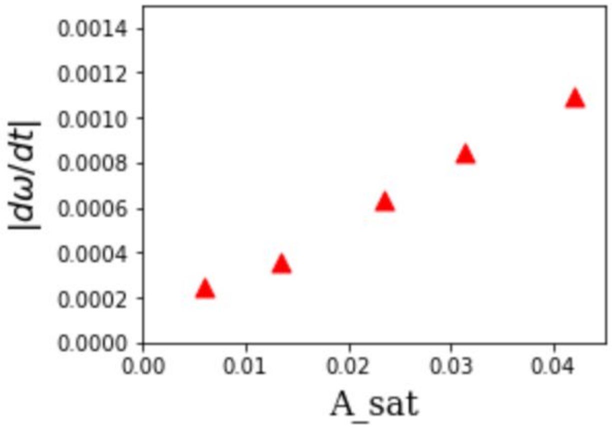


κ_{T0}=0.6



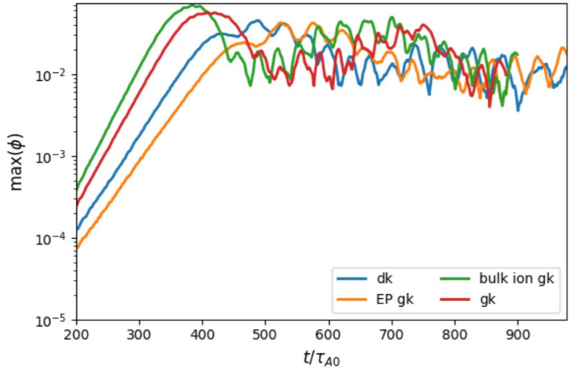
Dynamics of the Alfvén modes in single n=5 simulations:
background temperature gradient effects III

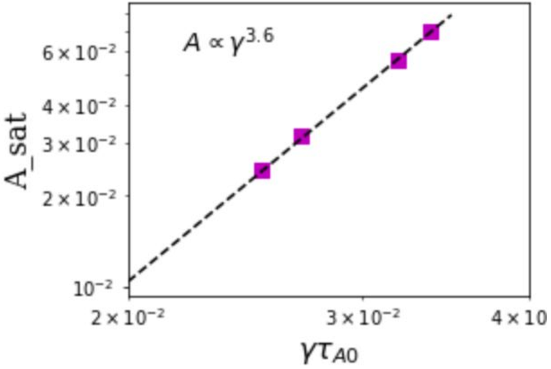


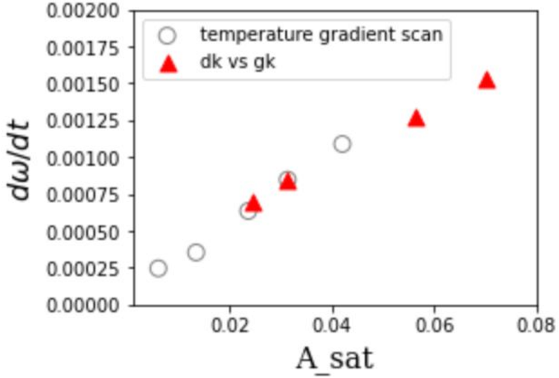


Drift kinetic vs Gyrokinetic for single n=5

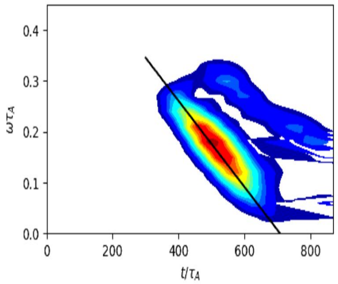
Dynamics of the Alfvén modes in single n=5 simulations: from drift kinetic to gyrokinetic I



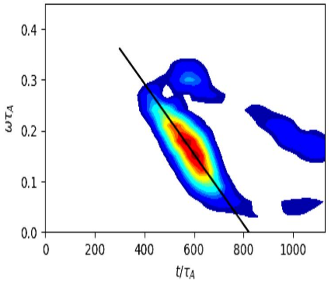




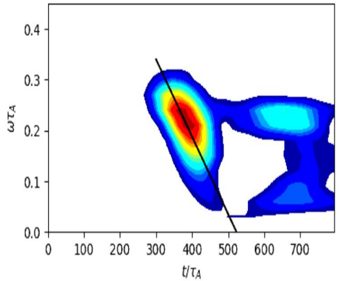
dk



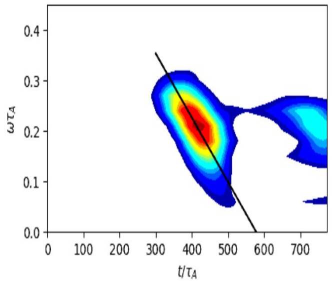
EP gk



Bulk ion gk



gk

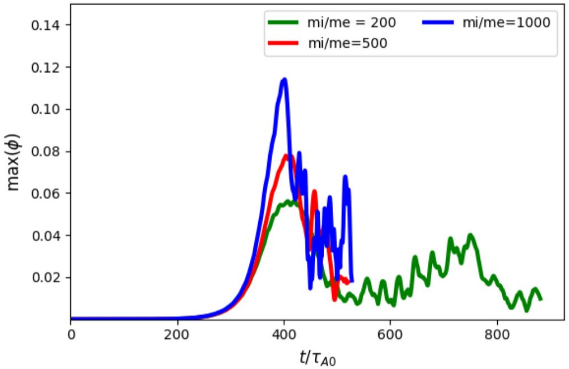


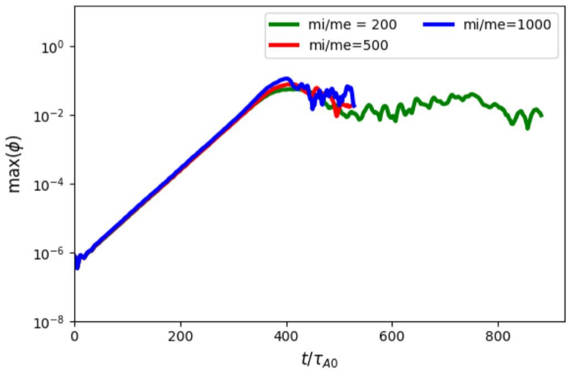
Preliminary results of mi/me=500

and mi/me=1000

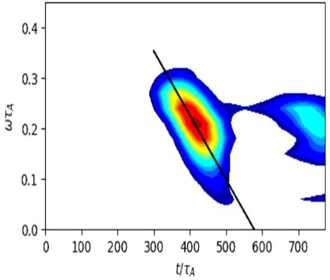
Electron mass scan for single-n simulation:

mi/me=200,500,1000

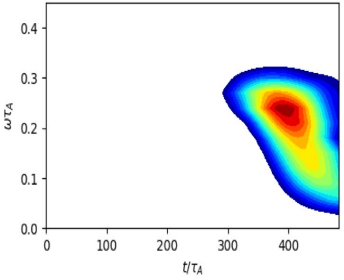




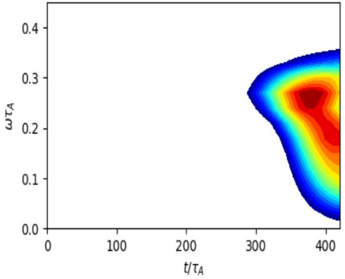
mi/me=200



mi/me=500



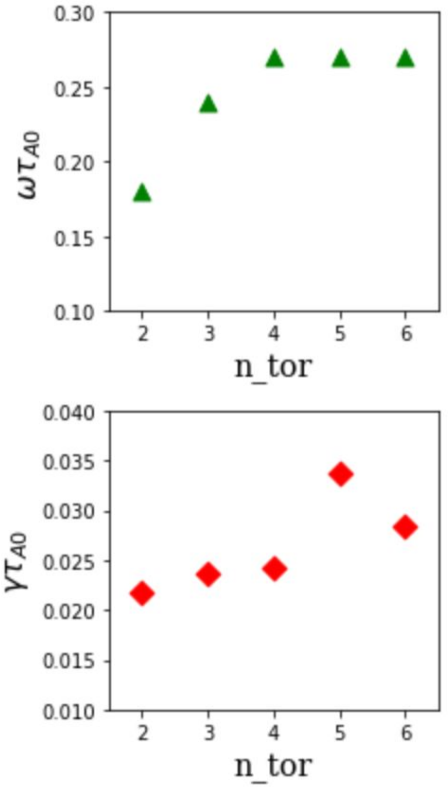
mi/me=1000

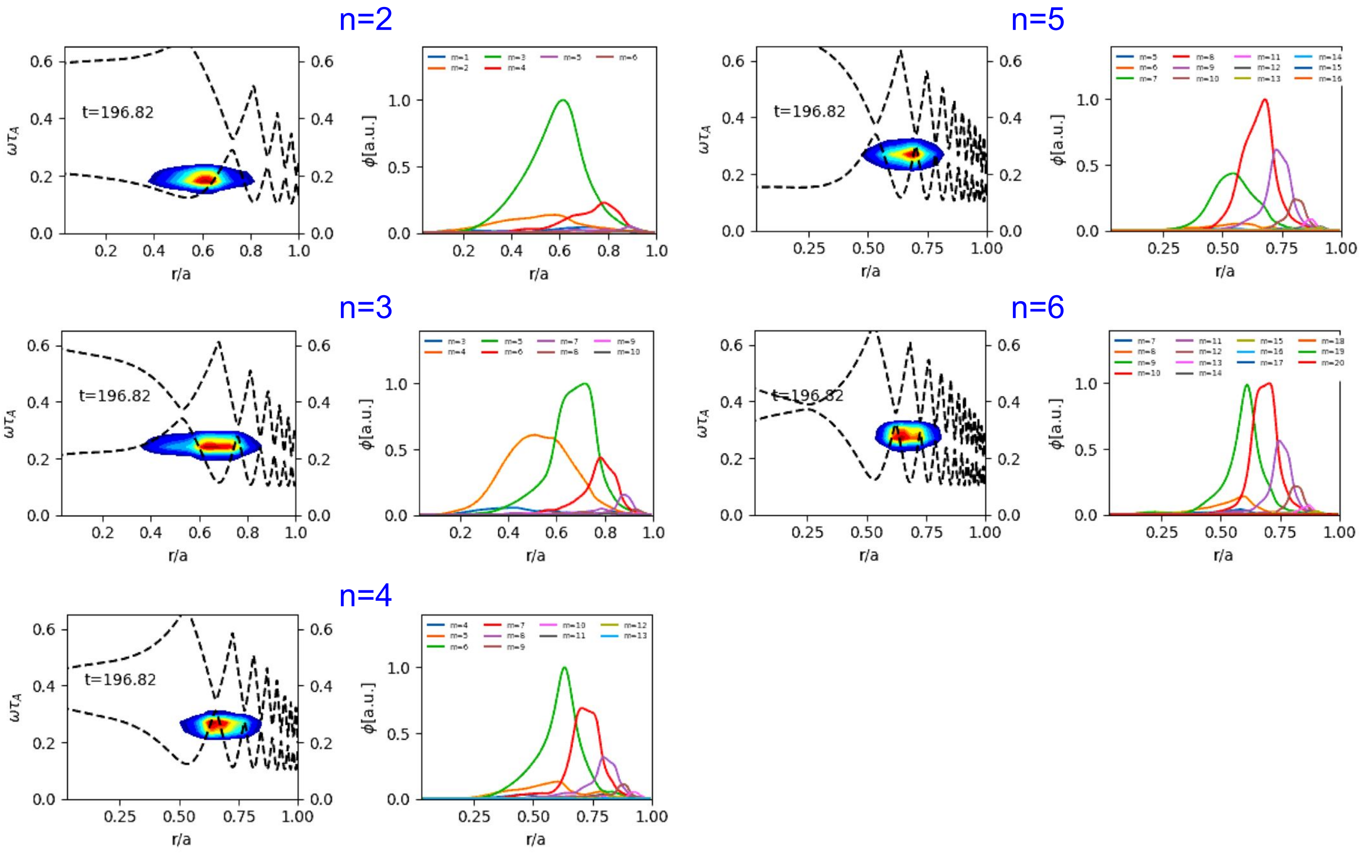


Toroidal mode number scan for

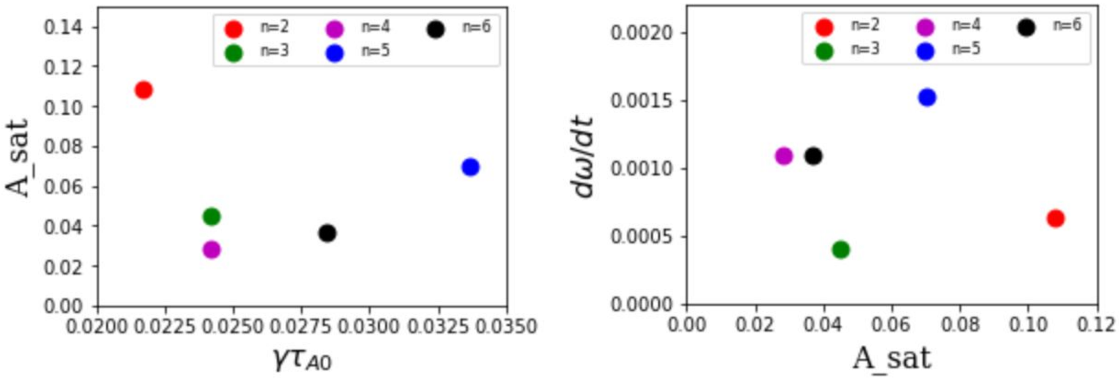
n= 2 ~ 6

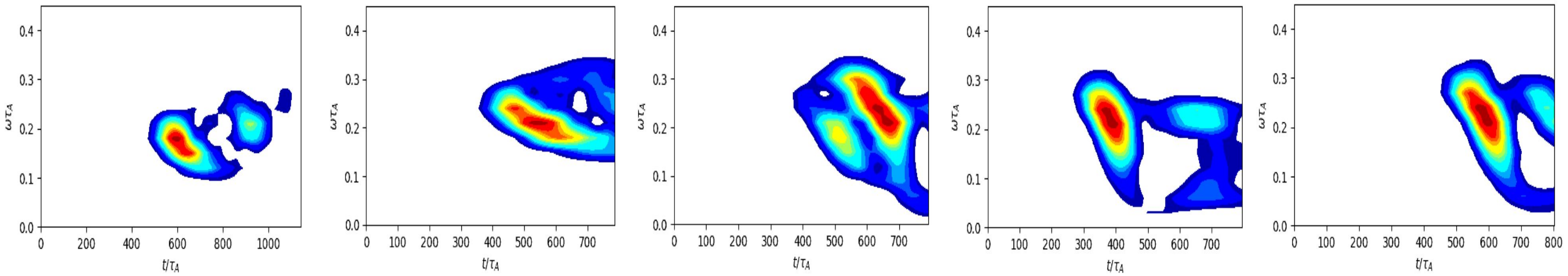
Dynamics of the Alfvén modes for different toroidal numbers (n = 2 to 6): linear dynamics





Dynamics of the Alfvén modes for different toroidal numbers (n = 2 to 6): nonlinear dynamics

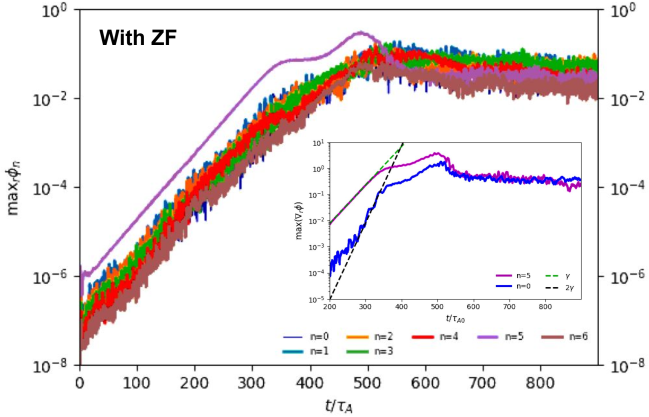




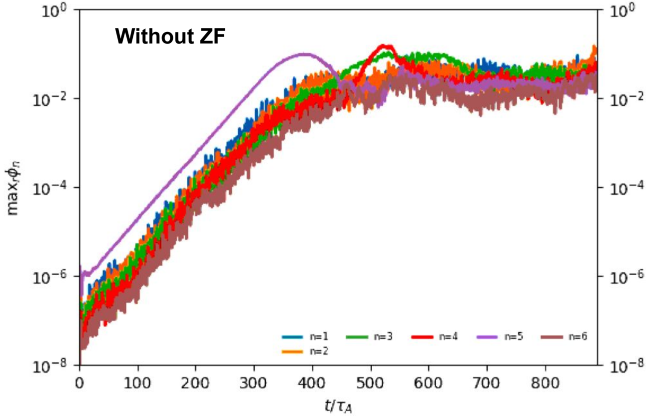
Multi-low-n simulations without / with zonal flow

Dynamics of the Alfvén modes and zonal flow in n=0~6 simulations I

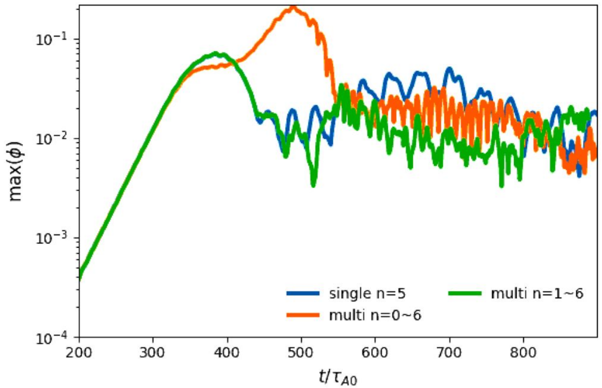
Multi n simulations with n=0~6



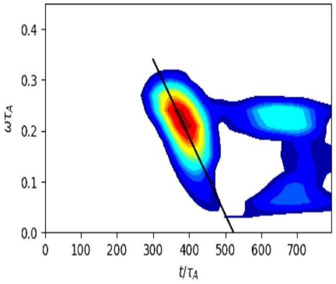
Multi n simulations with n=1~6



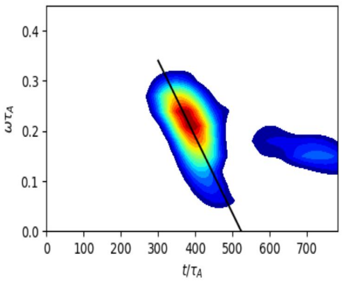
n=5 mode evolution in different cases



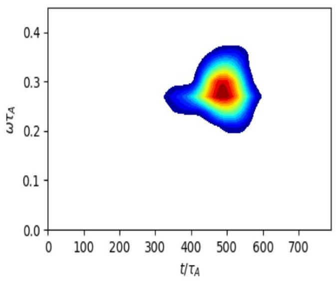
Single n=5 case



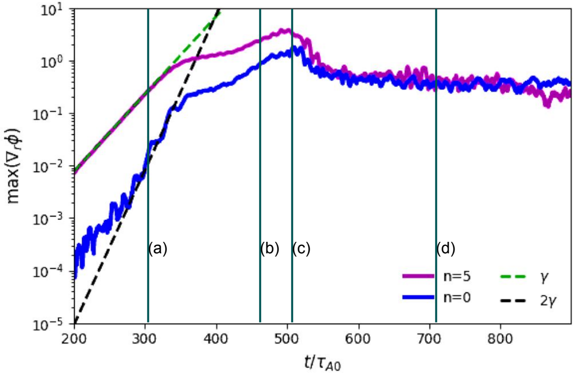
Multi n=1~6 case

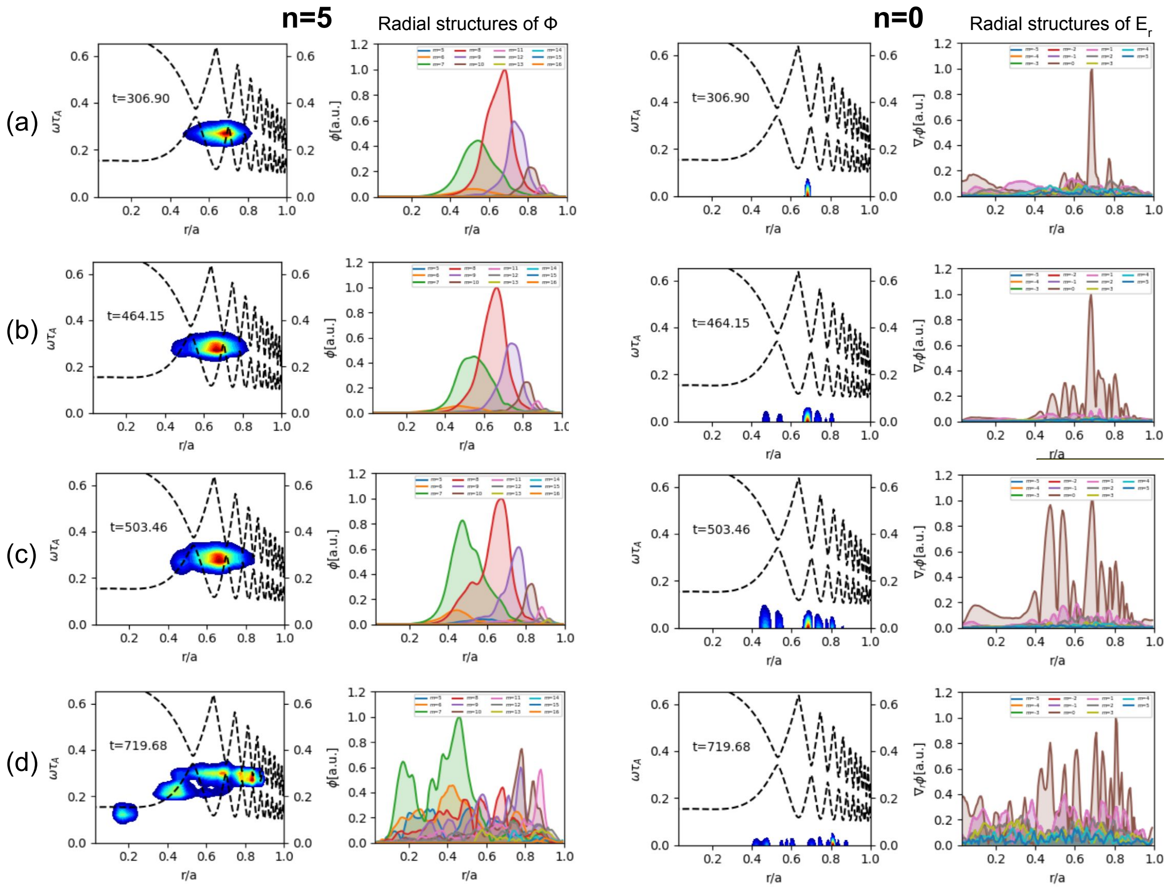


Multi n=0~6 case



Dynamics of the Alfvén modes and zonal flow in multi n (n=0~6) simulations II



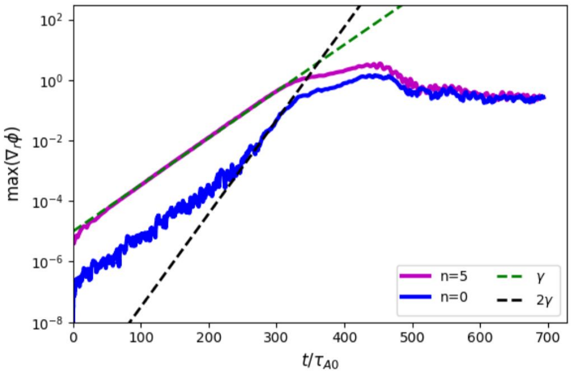


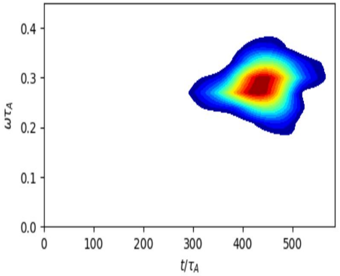
Preliminary result of mi/me = 1000

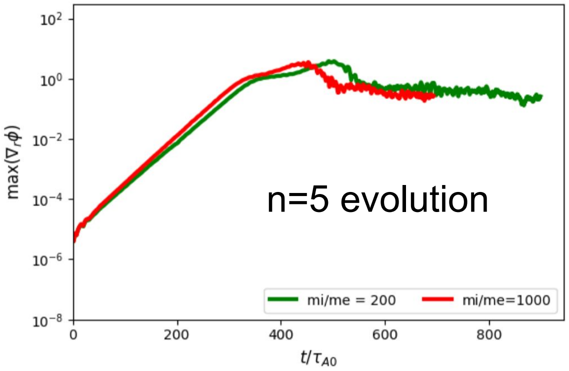
n=0~6 simulation

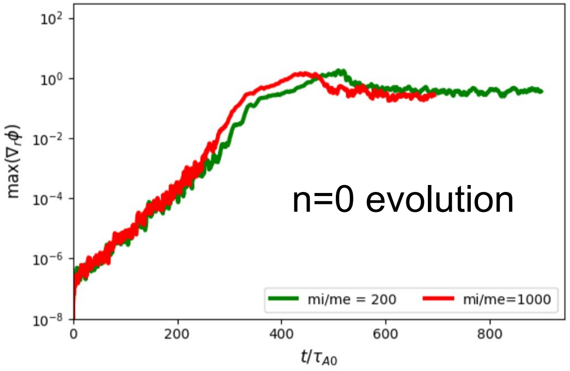
mi/me = 1000 vs. mi/me=200 for n=0~6 simulation

mi/me=1000



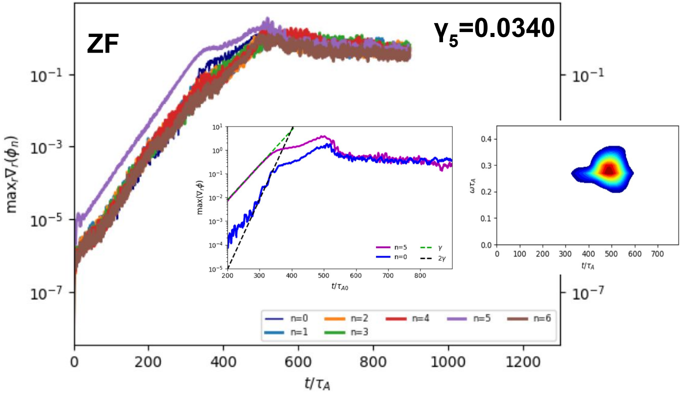




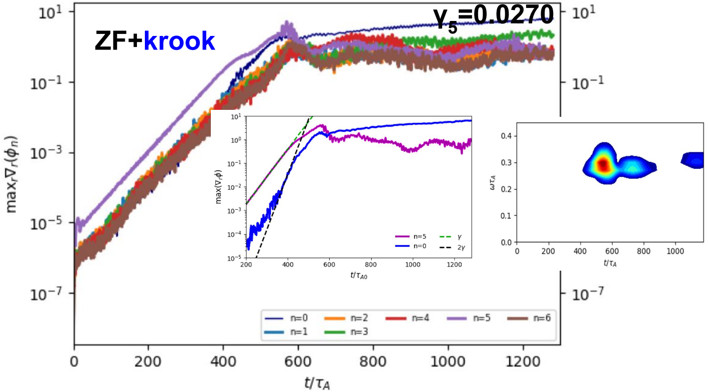


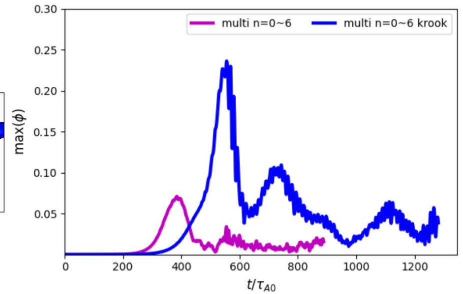
Multi-low-n simulations without / with zonal flow + krook

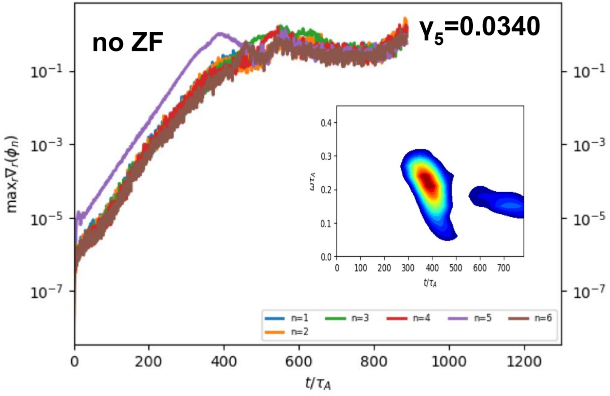
Comparison between no krook vs. krook



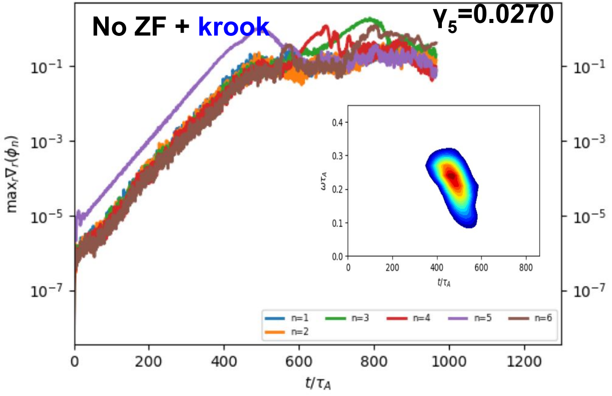
Multi n simulations with n=0~6

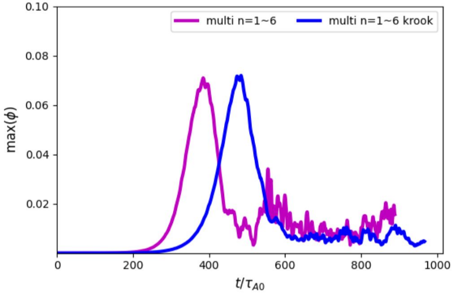






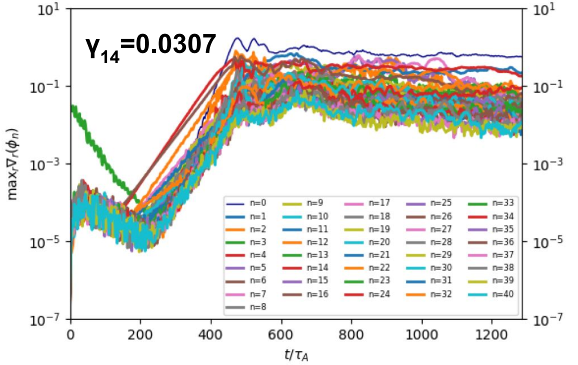
Multi n simulations with n=1~6

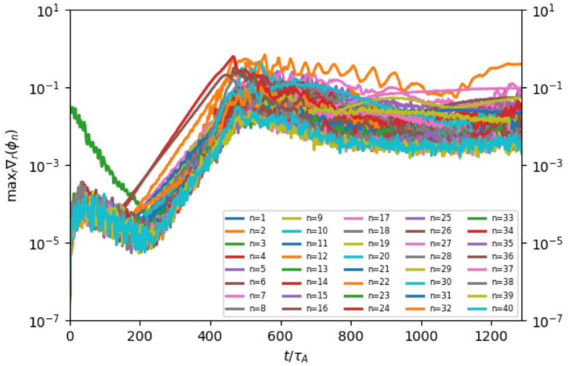




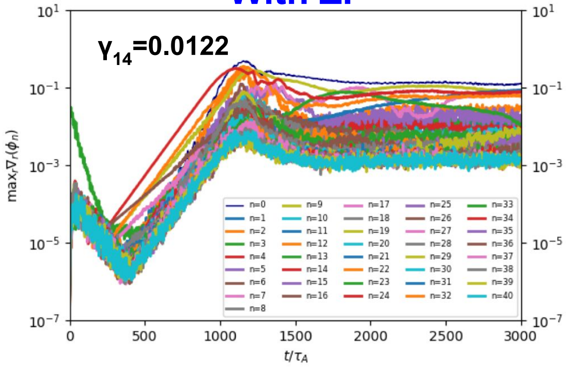
Turbulence and EP simulations without / with zonal flow n=0-40

Dynamics of n=0~40 simulations without EP drive

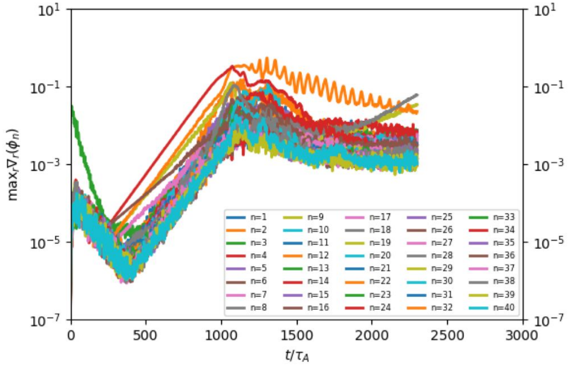


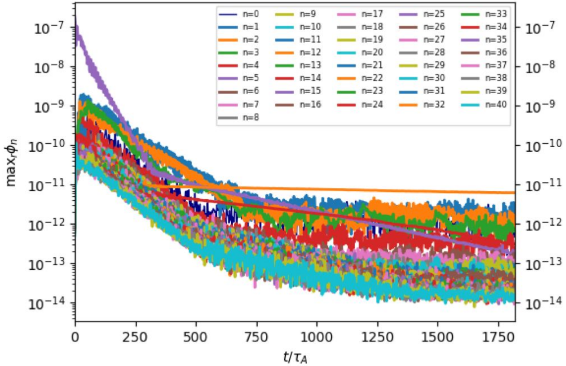


With ZF



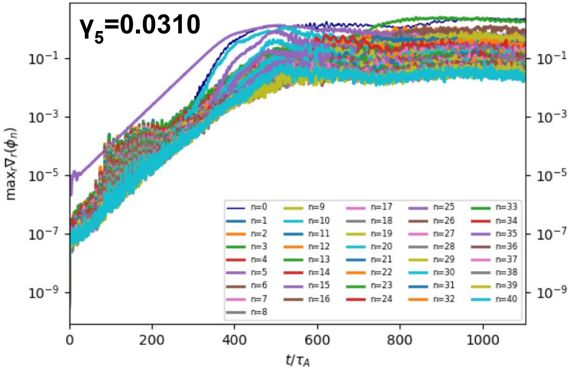
Without ZF

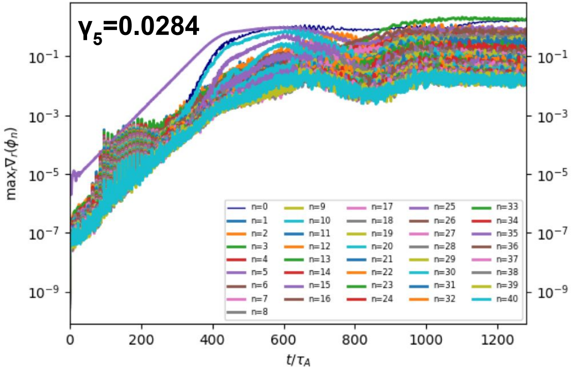


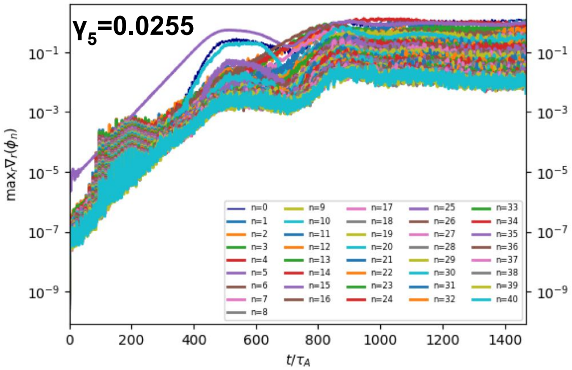


Dynamics of n=0~40 simulations with EP drive

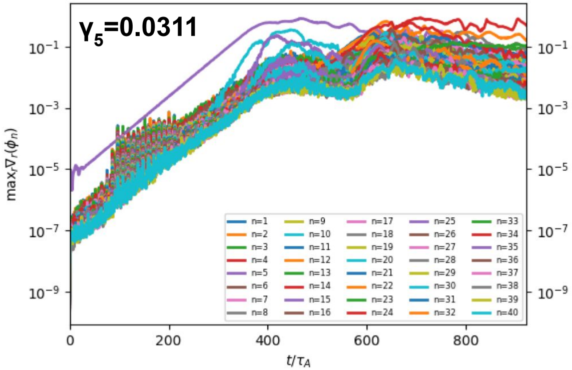
With ZF

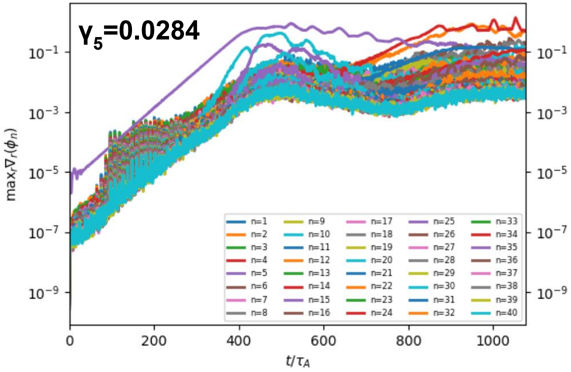


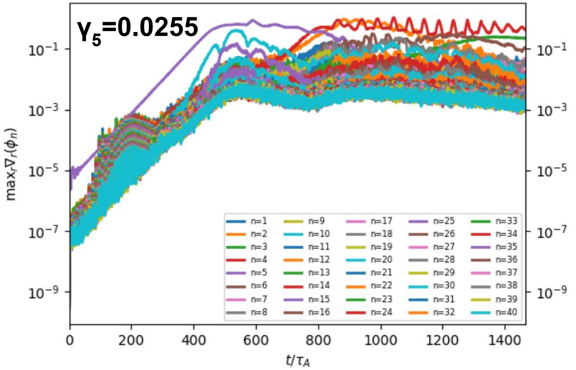




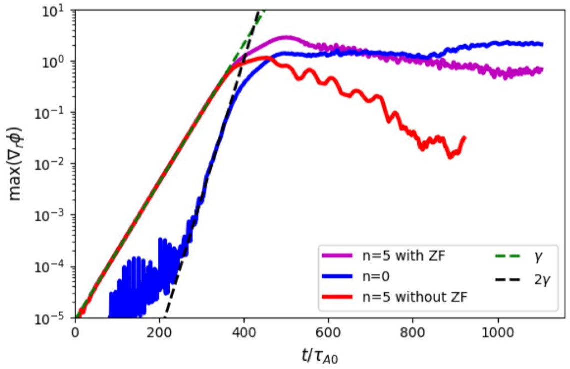
Without ZF

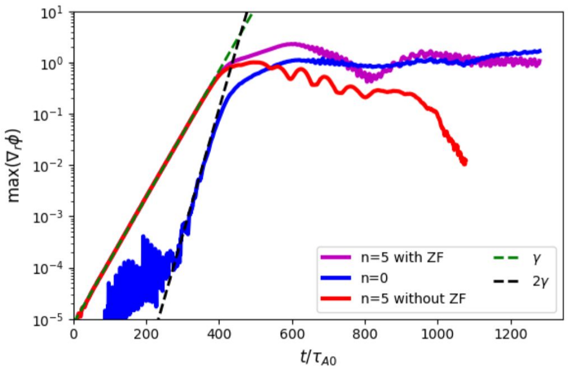


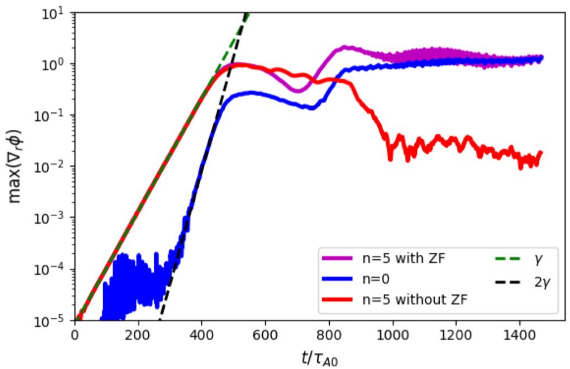




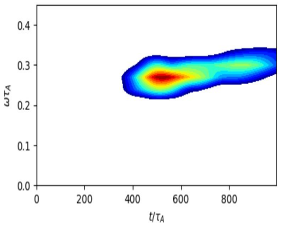
Dynamics of n=5 mode evolutions in n = 0~40 simulations I







With ZF



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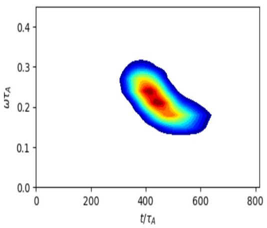

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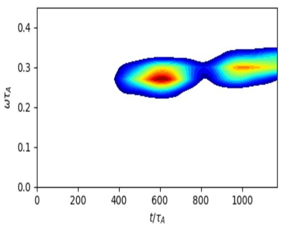

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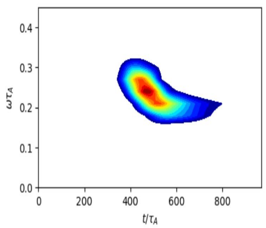

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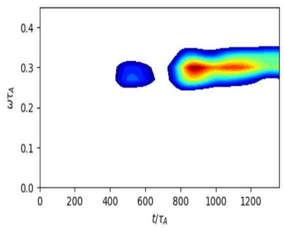

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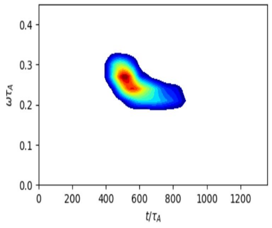
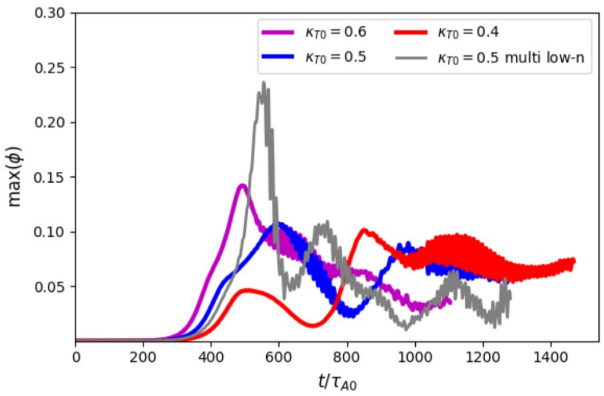
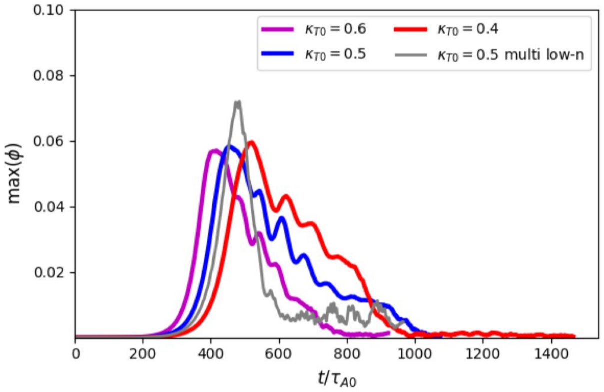


Dynamics of n=5 mode evolutions in n = 0~40 simulations II

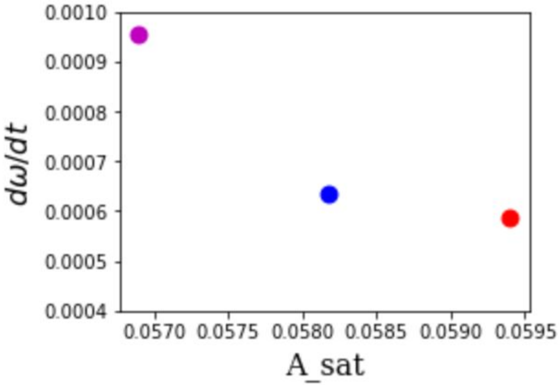
With ZF



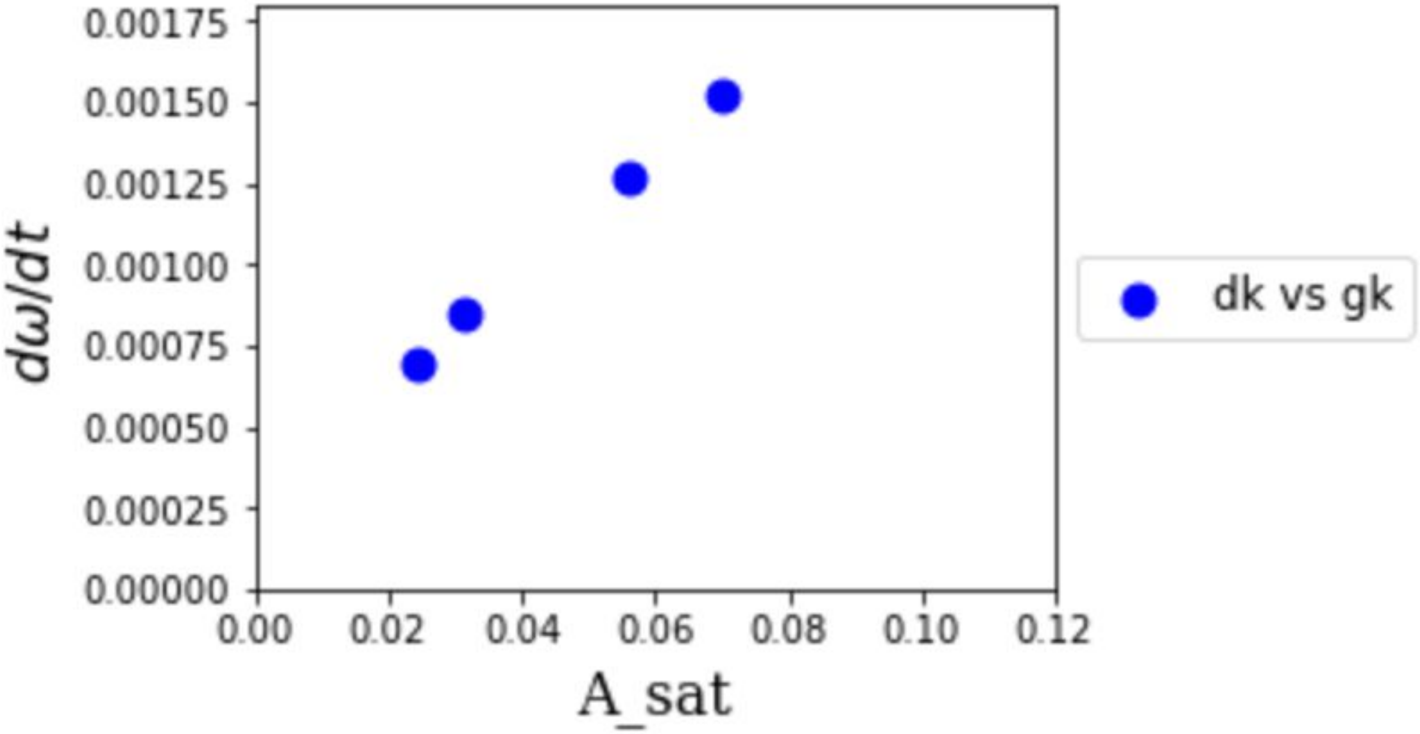
Without ZF



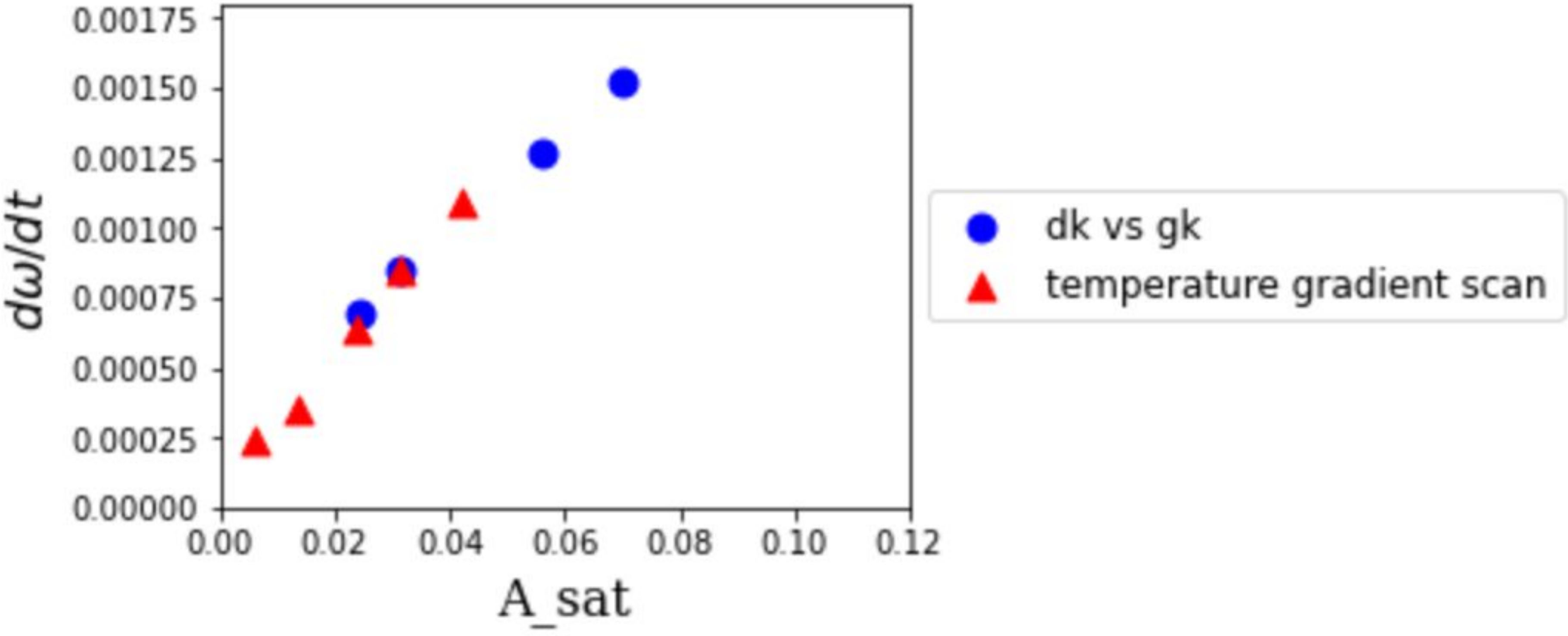
- Comparing with multi low-n simulations with krook operator, the linear growth-rate is larger in n~40 simulations.
- The saturation level is smaller comparing to the multi low-n simulations.
- In the n=1~40 simulations, the saturation level relatively increases as the grow-rates decreases, and the chirping-rate is inversely proportional to the saturation level.



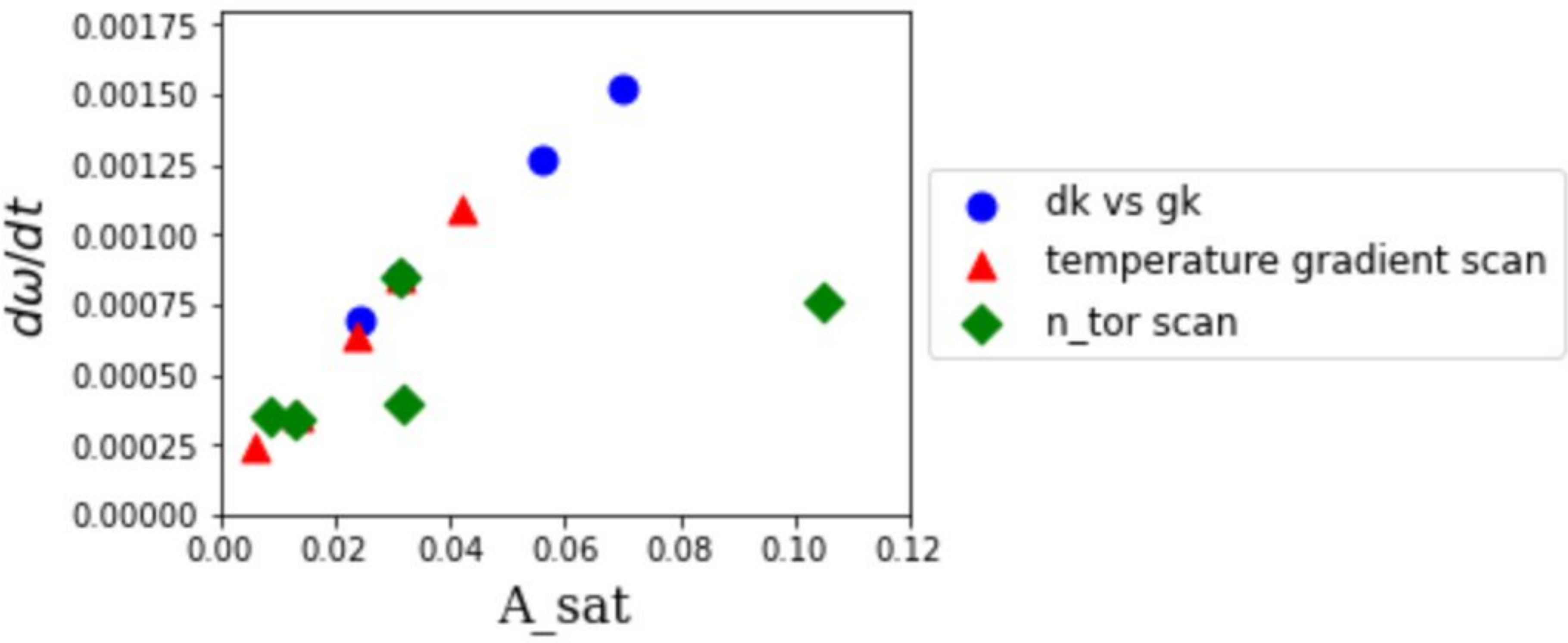
Frequency chirping rate vs. Saturation amplitude



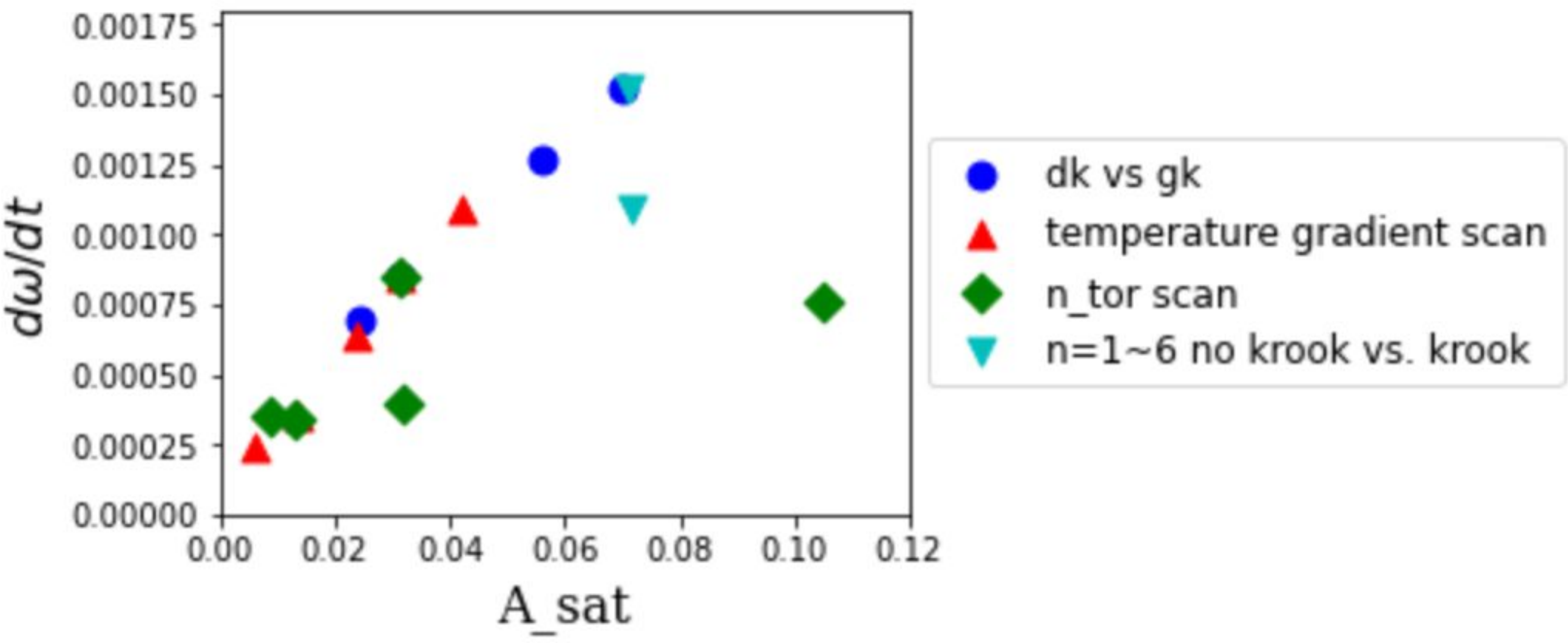
Frequency chirping rate vs. Saturation amplitude



Frequency chirping rate vs. Saturation amplitude



Frequency chirping rate vs. Saturation amplitude



Frequency chirping rate vs. Saturation amplitude