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Frequency chirping of an energetic particle driven mode in the presence of kinetic thermal ions

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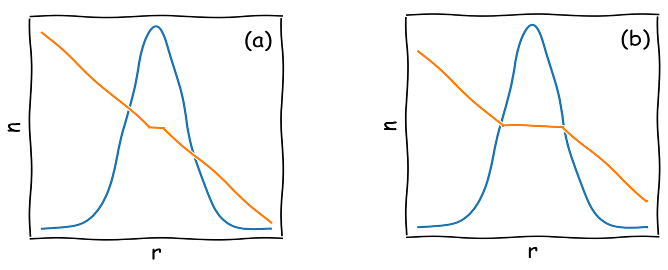
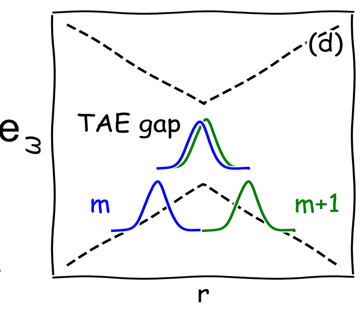
Motivation / Introduction

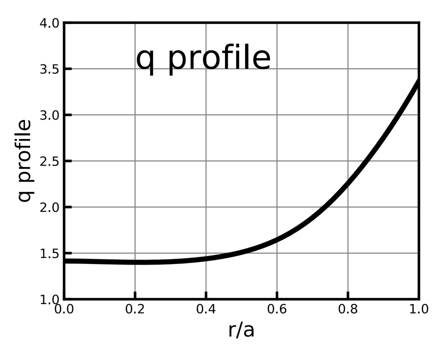
- **Nonperturbative effects**
  - Nonperturbative effects of energetic particles on Alfvén eigenmodes are important both in the linear property and in the nonlinear evolution [1].
  - Linear frequency and radial structure of the mode depend on the initial distribution of energetic particles.
  - During the nonlinear wave-particle interactions, a large redistribution of the energetic ions occurs, leading to mode frequency shift, an appreciable change in the mode radial structure, and breakdown of the perturbative approach.
- **A particle – MHD hybrid simulation code (X)HMGC [2, 3] is used to investigate the nonperturbative effects of EP.**
  - Both energetic particles and thermal ions are treated kinetically.
- **Review of saturation mechanism**
  - Resonance detuning vs. radial decoupling [4, 5]. For a constant mode structure and frequency mode, saturation amplitude scales as γ^2 for (a) resonance detuning, and scales as γ for (b) radial decoupling.

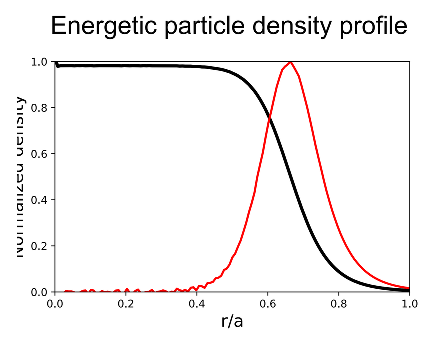


- **Expectations during the frequency chirping of a nonperturbative mode**
  - The above scaling rule for mode saturation will be broken by both frequency chirping and strong mode-structure modification. The saturation level is expected to reach higher level.
  - Each m harmonics will attach to their shear Alfvén continuum branches when the mode frequency chirps across the continuum.
  - Larger particle redistribution in phase space.



- **Simulation setups**



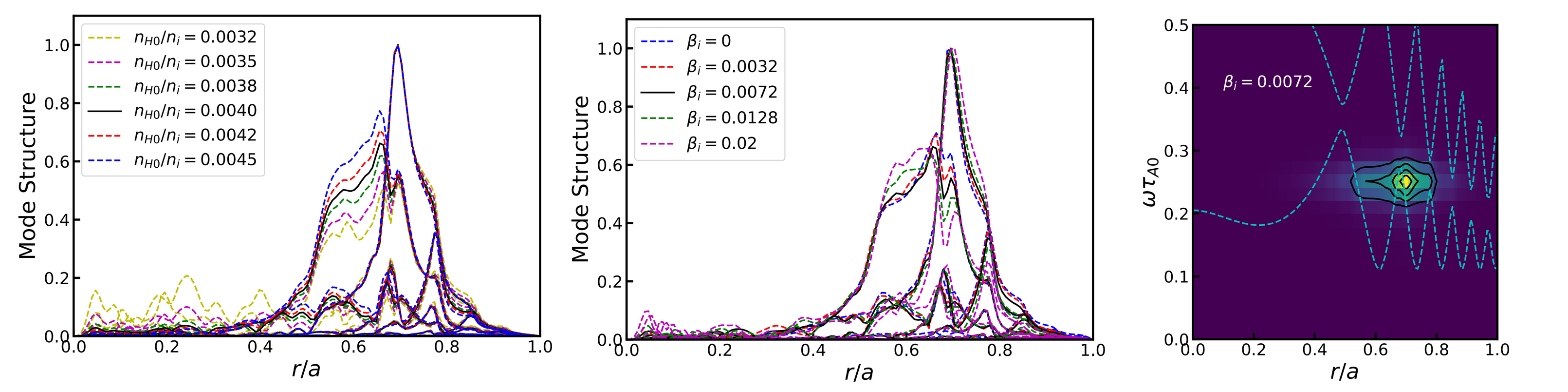


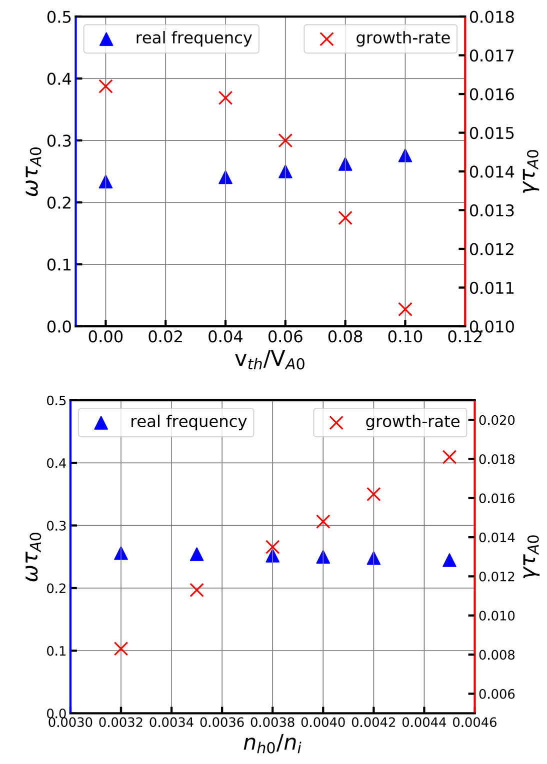
- n=3
- Kinetic bulk ion
- Flat density and temperature profiles are assumed for bulk ion

Co-passing EP : anisotropic slowing down distribution function with single pitch angle
– Bulk ion beta scan
– EP density scan for fixed bulk ion beta
different EP distribution functions:
– counter-passing EP with single pitch angle slowing-down distribution
– Isotropic Maxwellian EP

Frequency chirping behaviours for co-passing cases

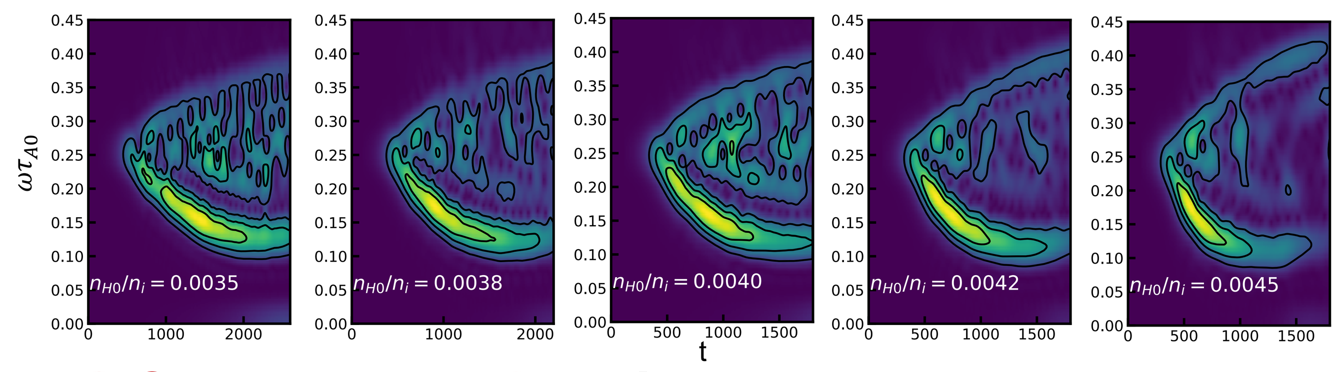
1 Linear properties





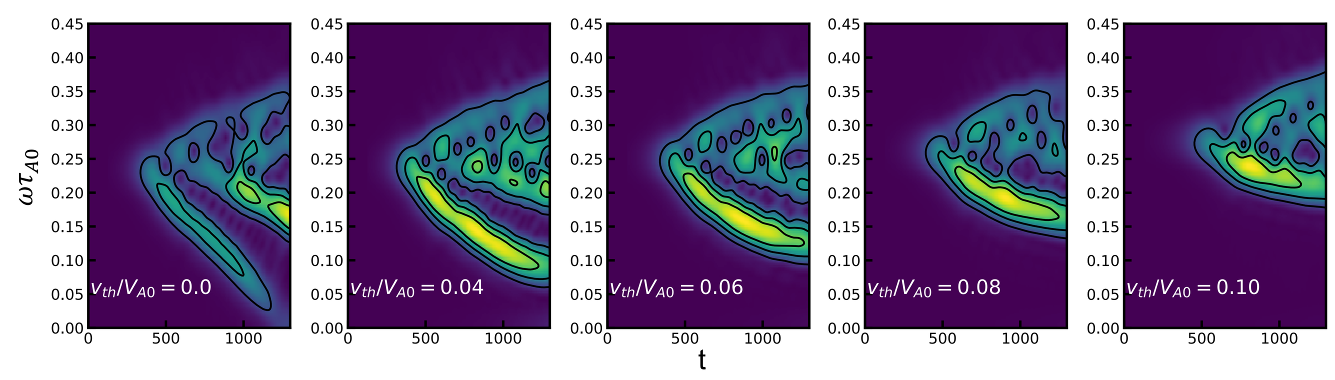
- Bulk ion beta is fixed for the EP density scan. Energetic particle profile is fixed for the bulk ion beta scan.
- The modes are initially located near TAE gap, with frequencies lower than the TAE eigenfrequency.
- The mode structures are dominated by m=5 and m=6 harmonics and and located around the n=3 TAE gap.

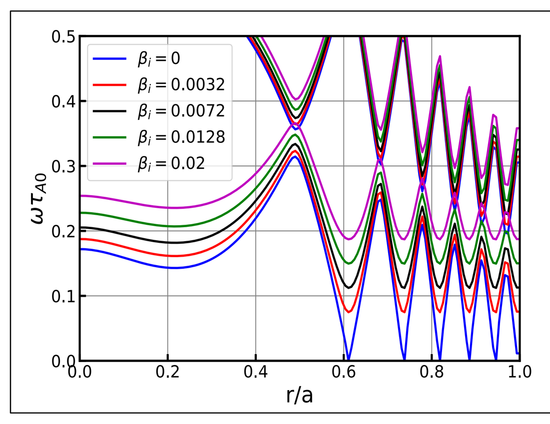
1 Co-passing EP: EP density scan



- For all the cases, the frequency chirps down to the same BAE frequency.
- The frequency chirping rates becomes larger by increasing EP density.

2 Co-passing EP: bulk ion beta scan

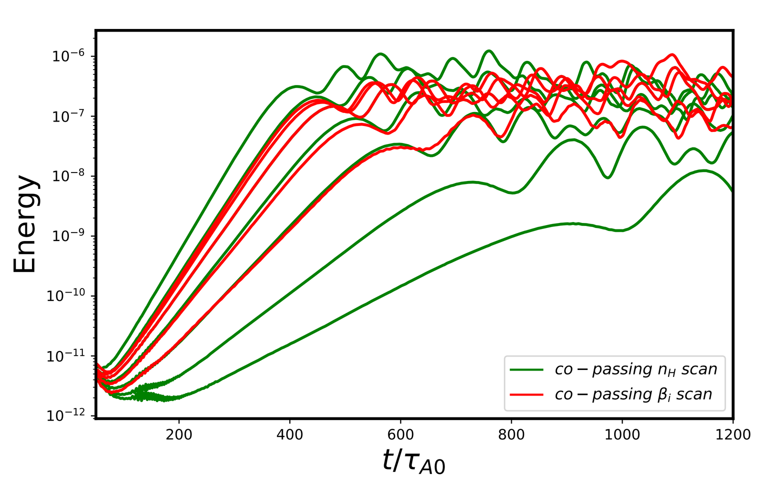


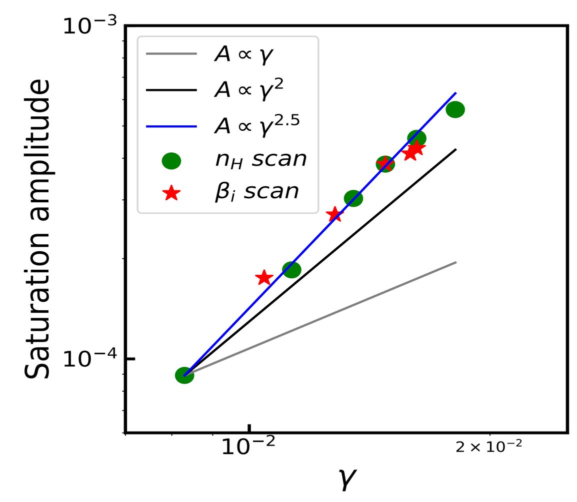


Changing bulk ion beta modifies the shear Alfvén continuum, by opening the kinetic thermal ion gap.

- All cases show both up and down chirping, but down-chirping is always dominant.
- For cold bulk ion case, the frequency chirping rate is approximately constant.
- Frequency chirping rate reduced to zero when approaching BAE accumulation point.

Mode saturation level scaling

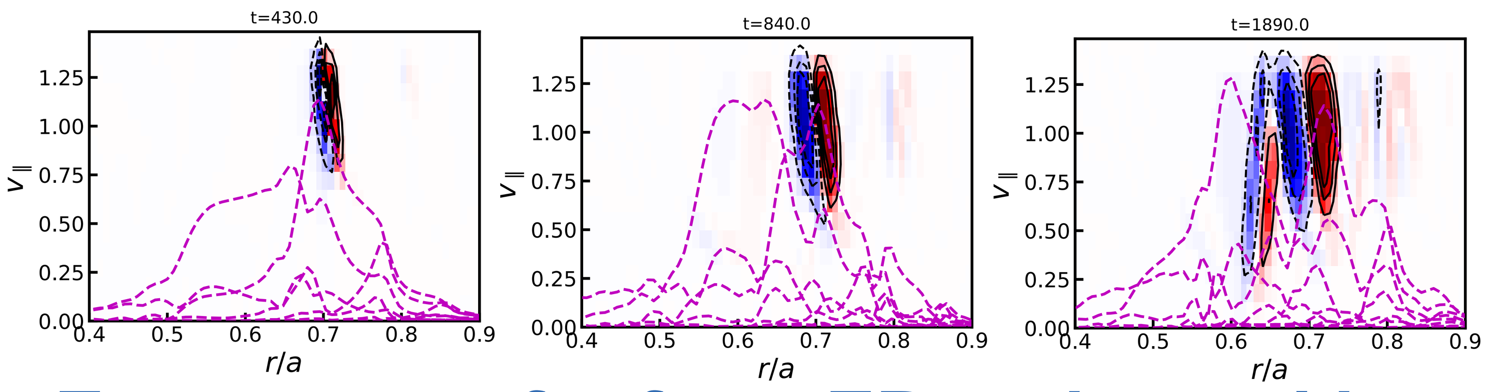




- The saturation amplitude is defined at the first maximum position, as in [Briguglio et al. 2014, Wang & Briguglio 2016, etc.].
- The saturation level scales approximately as $\propto \gamma^{2.5}$, which is higher than both resonance detuning and radial decoupling scaling for fixed mode structure and mode frequency cases.

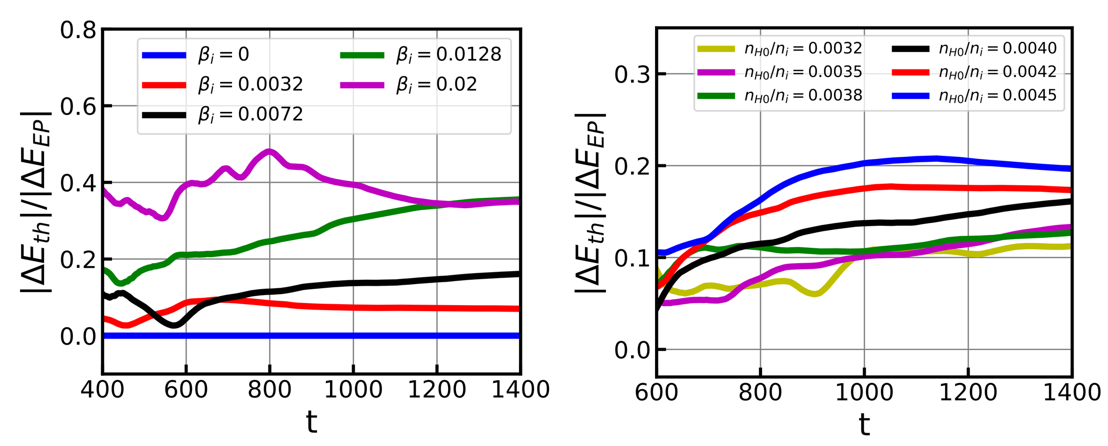
Density perturbation in phase space for co-passing case

The figures shown here are corresponding to $\beta_i = 0.0072$ and $n_{h0}/n_i = 0.004$ case.



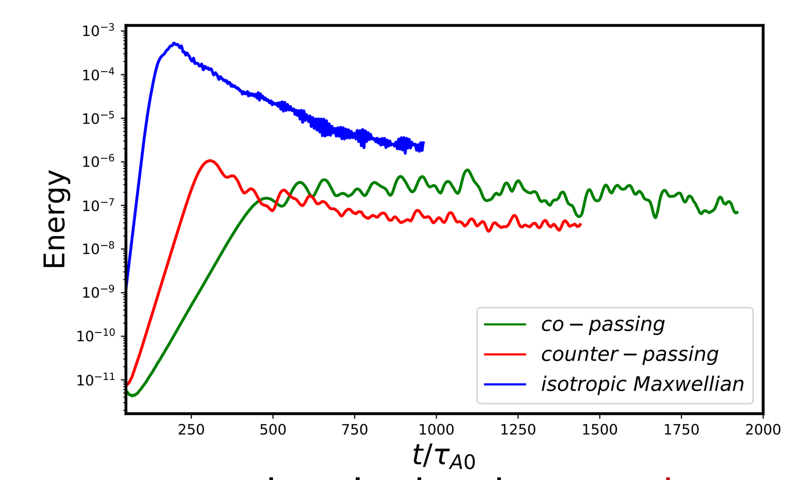
- Strongly modified mode structure is indicated by magenta dashed line.
- Density perturbation is extended both in radial direction and $v_\parallel$ direction.

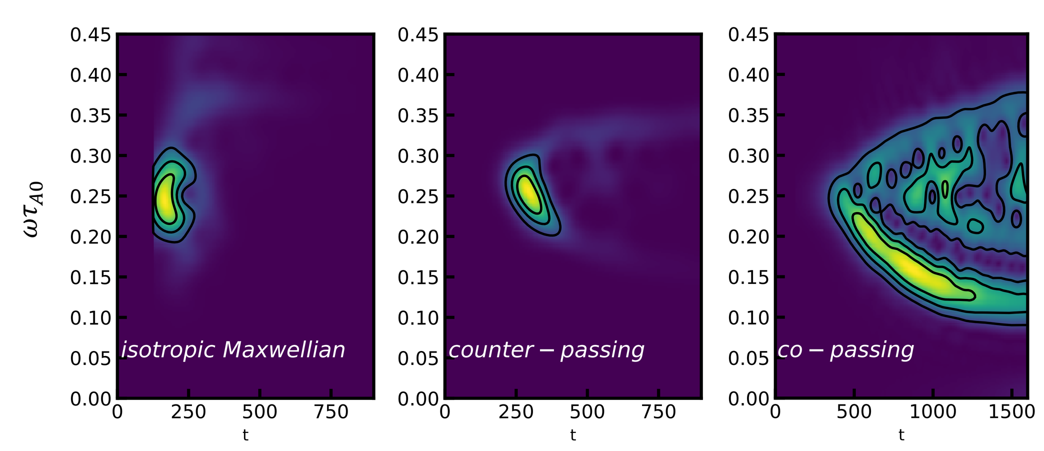
Energy transfer from EP to thermal ions for co-passing cases



- Bulk ions can exchange energy with the waves through landau damping.
- The ratio between energy absorbed by bulk ions to the energy lost by the energetic particles are shown on the left figures.
- The ratio can be increased by increasing the bulk ion beta or the energetic particle drive when fixed bulk ion beta.

Frequency chirping by using different distribution functions





green: co-passing slowing down , red: counter-passing slowing down, blue: isotropic Maxwellian
Nonlinear evolutions of mode energy take place depending on the energetic particle distributions.

Conclusions

– Co-passing cases:
- Mode frequency can chirp across shear Alfvén continuum. The down-chirping is dominated.
- The 'saturation' level can reach higher level compared to the fixed mode structure and constant frequency case. The saturation scaling rules (both for resonance detuning and radial decoupling) are broken.
- During chirping, the mode structure are strongly modified.
- Larger particle redistribution in phase space is observed.
- By varying both bulk ion beta or by varying EP density, the mode are found to chirp down to BAE frequency.
- Down-chirping modes can transfer energy to thermal ions in an easier way, as the ion Landau damping is more effective at low frequency.

– Different EP distributions can dramatically change the nonlinear evolution of mode dynamics.

References

[1] L. Chen and F. Zonca, Reviews of Modern Physics 88, 015008–p1-p72, (2016)
[2] S. Briguglio et al., Phys. Plasmas 2, 3711 (1995).
[3] X. Wang, S. Briguglio et al., Phys. Plasmas 18, 052504 (2011).
[4] X. Wang, S. Briguglio et al., Physics of Plasmas 23 (1), 012514 (2016)

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