NSTX-U

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Prediction of the likelihood of Alfvénic mode chirping in ITER baseline scenarios

Vinícius Duarte and Nikolai Gorelenkov
Princeton Plasma Physics Laboratory, Princeton, NJ, USA

In collaboration with M. Podestà, E. Fredrickson, M. Van Zeeland,
W. Heidbrink, M. Schneller and H. Berk

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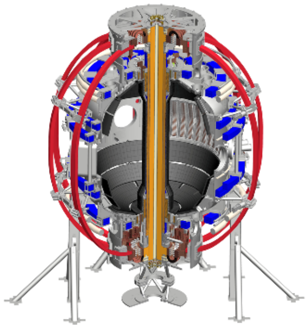
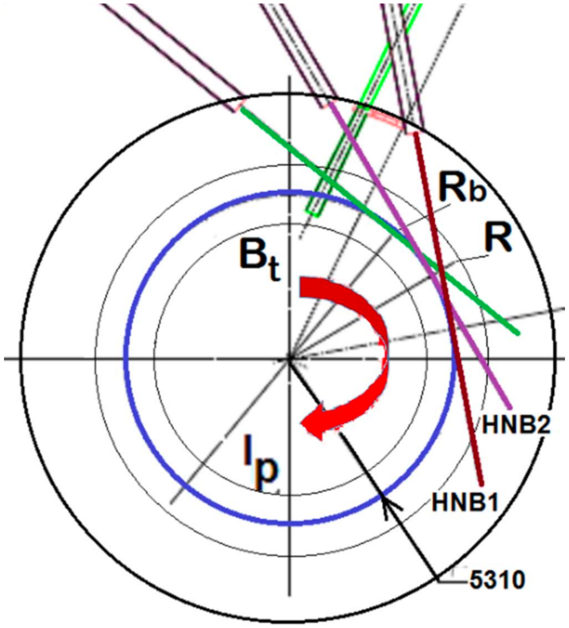
PPPL



The confinement of fast ions is a crucial issue for the success of ITER

Neutral beam injection geometry in ITER

Singh et al, New J. Phys., 2017



ITER burning plasma design specification tolerates 5% of fast ion losses[1]

In ITER, two negative-ion-based neutral beam injection sources, which will account for 33MW of injected power (up to 50MW after upgrade installation of third beam).

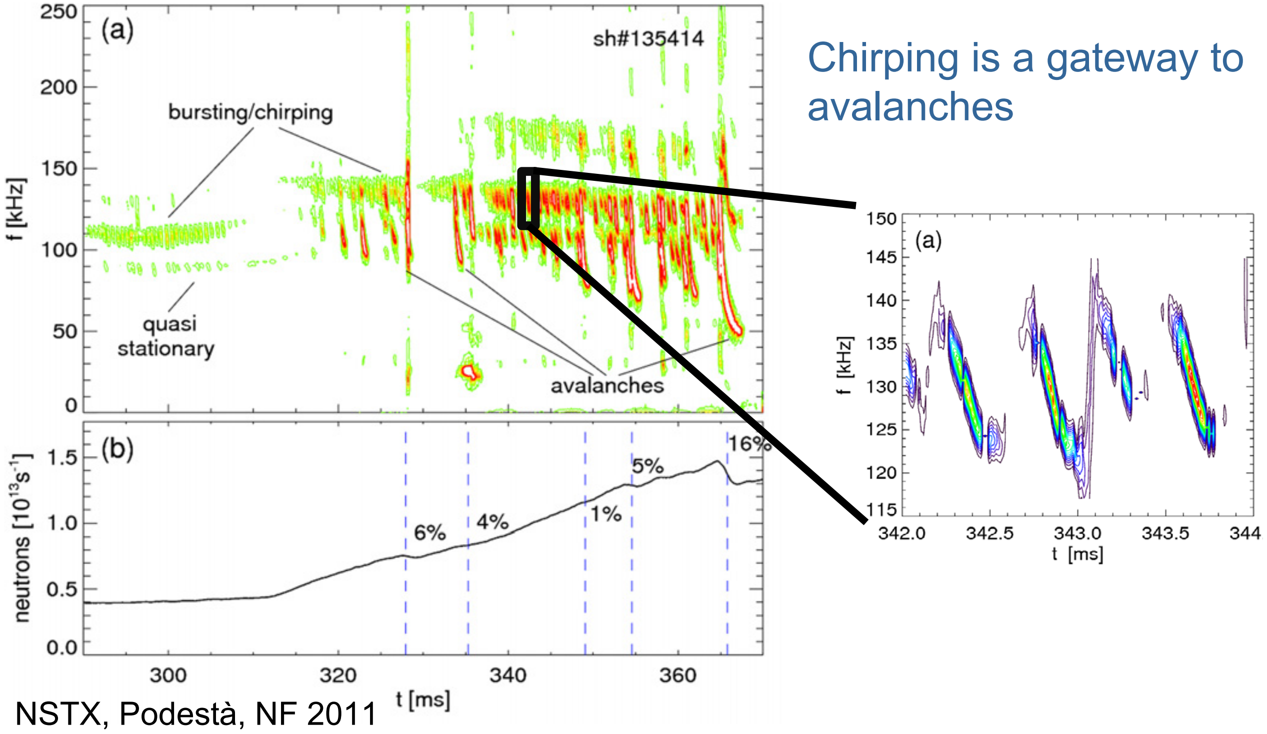
In ITER, both the 3.5MeV fusion-born alpha particles and the tangentially injected 1MeV NBI ions will have *supra-Alfvénic velocities:* $v_{NBI}/v_{Alfvén} \lesssim 2$ fast ions will interact with TAEs via their main resonance.

In this presentation: a study of the likely nonlinear evolution scenario of Alfvénic instabilities upon their interaction with fast ions in ITER is addressed

The prediction of the conditions that lead to each type of nonlinear scenario helps to understand the applicability of reduced models

[1] ITER Physics Expert Group on Energetic Particles, Heating, Current Drive and ITER Physics Basis Editors 1999 Nucl. Fusion 39 2471

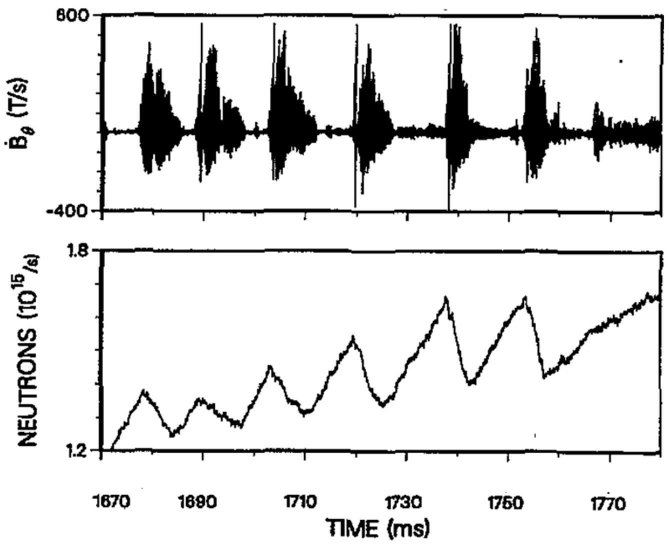
Alfvén waves can exhibit a range of bifurcations upon their interaction with fast ions in present day devices (≤40% of fast ion loss)



NSTX, Podestà, NF 2011

Chirping is a gateway to avalanches

Each chirp induces fast ion losses

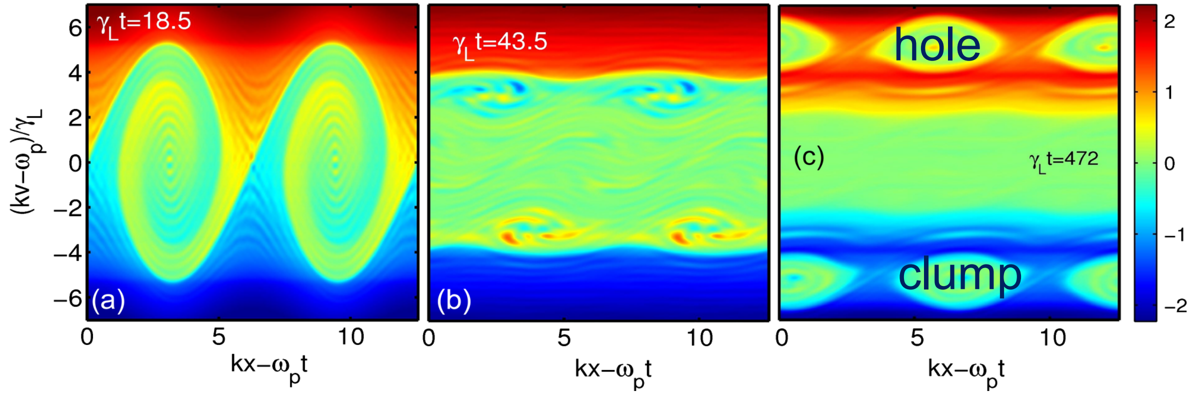


DIII-D, Heidbrink, NF 1995

Major question in the field: why chirping is common in STs and rare in conventional tokamaks?
We develop and validate a criterion that indicates the likelihood of chirping in terms of plasma parameters

Chirping is supported by phase-space structures: holes and clumps

Lilley and Nyqvist, PRL 2014



Stochasticity prevents the formation of holes and clumps. Multiple sources for it: RF fields, collisions, NTMs, 3D fields, resonance overlap,…

Two typical scenarios for fast ion losses:

- **Diffusive transport (typical for fixed-frequency modes):** can be modeled using reduced theories, such as quasilinear
- **Convective transport (typical for chirping frequency modes):** needs to retain full nonlinear features of the wave, is sustained by nonlinear phase-space structures (numerically costly)

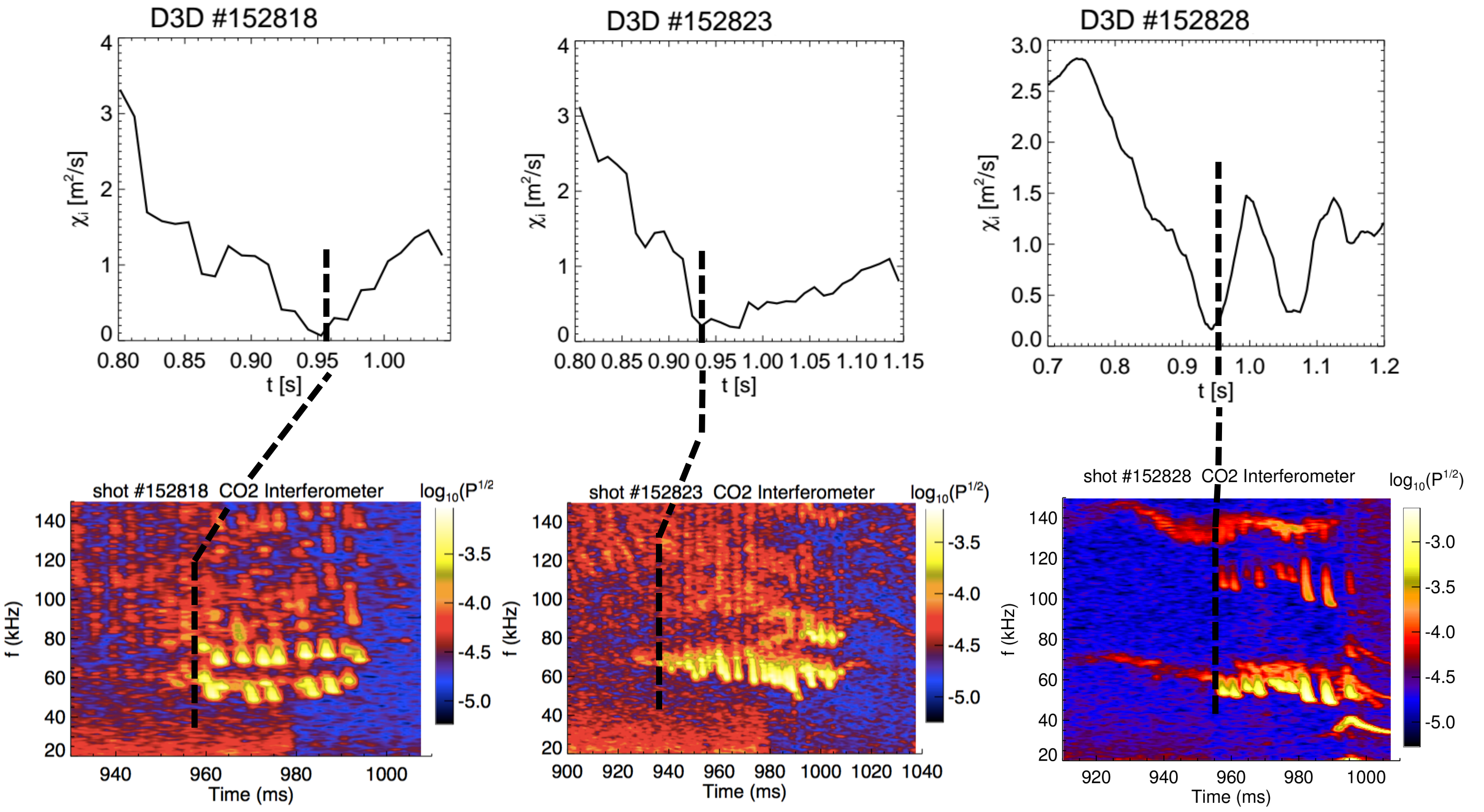
Chirping criterion (nonlinear prediction from linear physics elements) :

$$Crt = \frac{1}{N}\sum_{j,\sigma_\parallel}\int dP_\varphi \int d\mu \frac{|V_j|^4}{\omega_\theta \nu_{drag}^4}\left|\frac{\partial\,\Omega_j}{\partial I}\right|\frac{\partial f}{\partial I}Int$$

>0: fixed-frequency solution likely
<0: chirping likely to occur

Turbulence is predicted to be a major chirping prevention mechanism

Marked reductions of the turbulent activity causes chirping onset in DIII-D



The thermal ion heat conductivity is used as a proxy for the fast ion anomalous transport

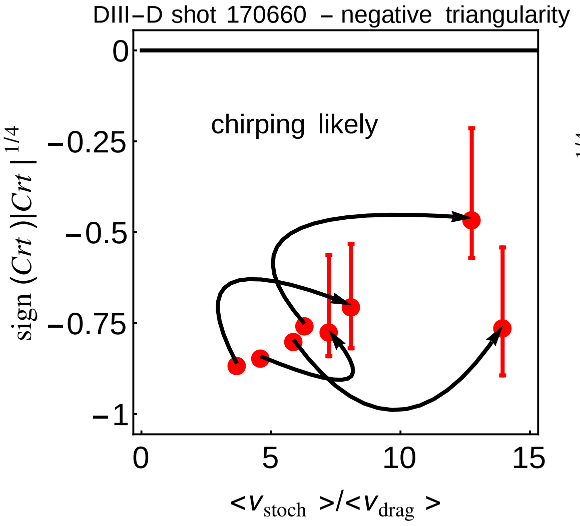
These observations are consistent with the proposed criterion for chirping onset

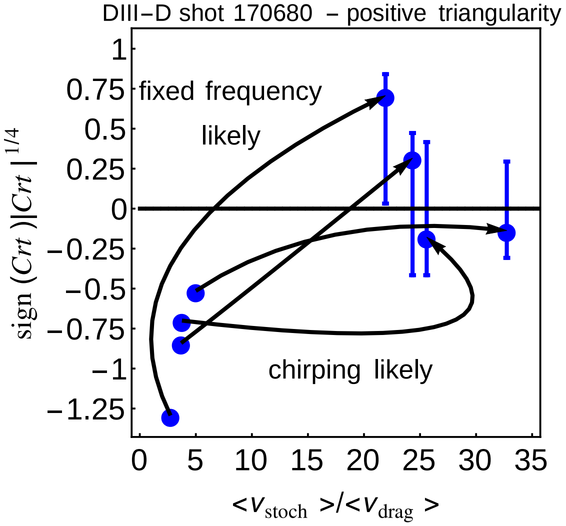
Duarte et al, NF 2017.

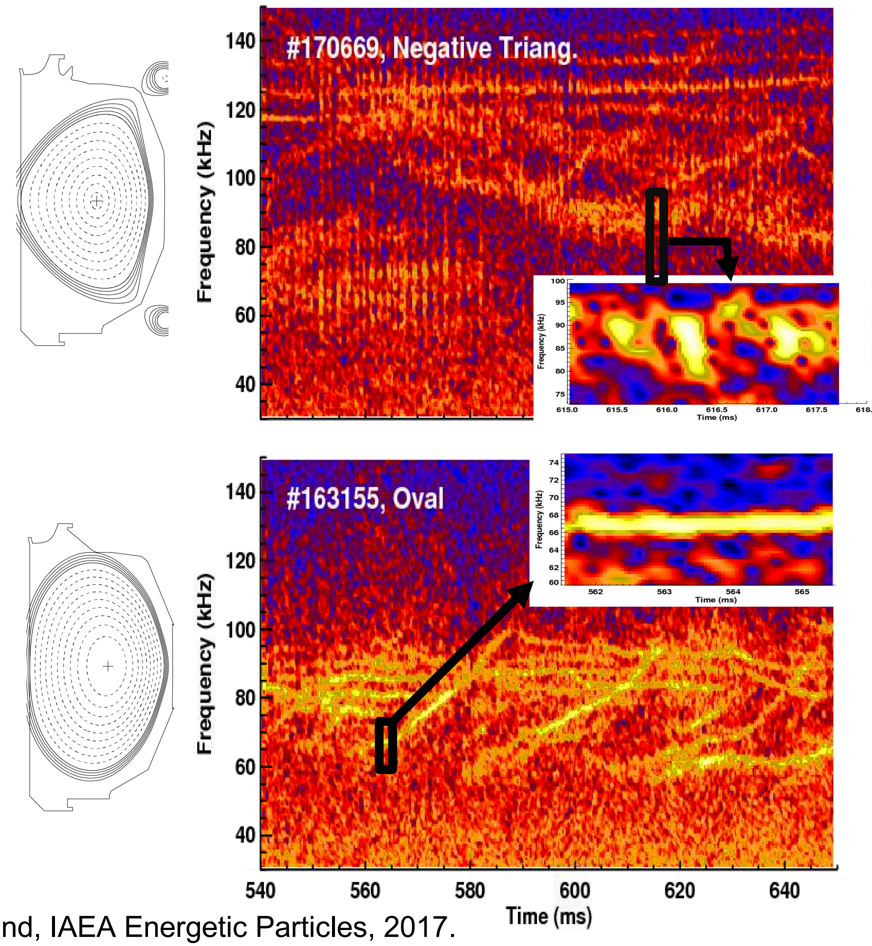
Experimental scenario developed based on the theory: dedicated experiments showed that chirping is more prevalent in negative triangularity DIII-D shots

- Transport coefficients calculated in TRANSP are 2-3 times lower in negative triangularity, as compared to the the usual positive/oval

$$Crt = \frac{1}{N}\sum_{j,\sigma_\parallel}\int \mathrm{d}P_\varphi \int \mathrm{d}\mu \frac{\left|V_j\right|^4}{\omega_\theta \nu_{\mathrm{drag}}^4}\left|\frac{\partial\,\Omega_j}{\partial I}\right| \frac{\partial f}{\partial I}_{Int} \begin{cases} >0\text{: fixed-frequency} \\ <0\text{: chirping} \end{cases}$$

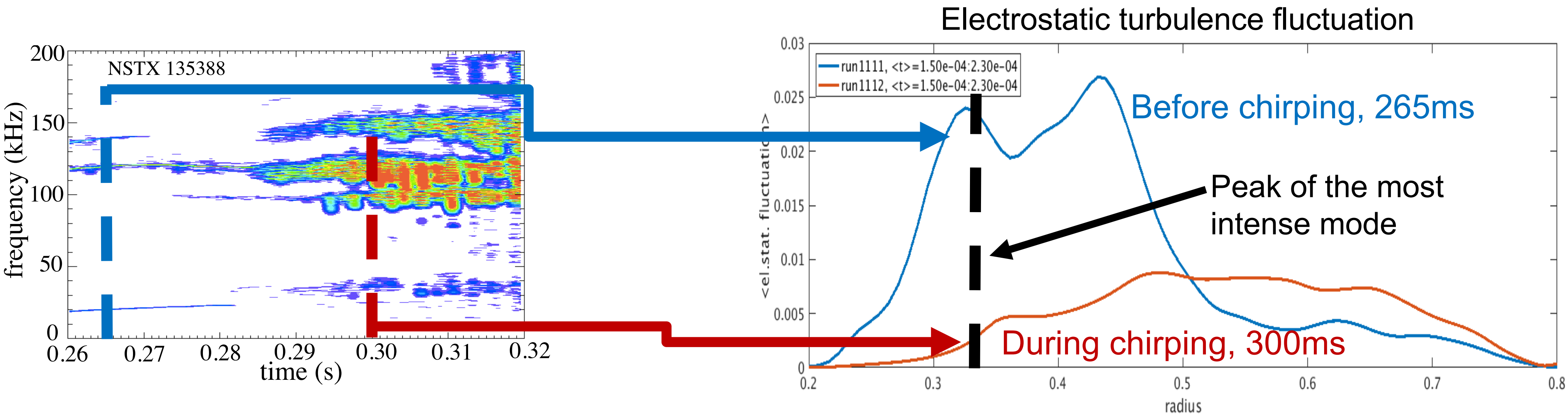






M. Van Zeeland, IAEA Energetic Particles, 2017.

GTS global gyrokinetics analyses show turbulence reduction for rare NSTX TAE transitions from fixed-frequency to chirping



Electrostatic turbulence fluctuation

Before chirping, 265ms

Peak of the most intense mode

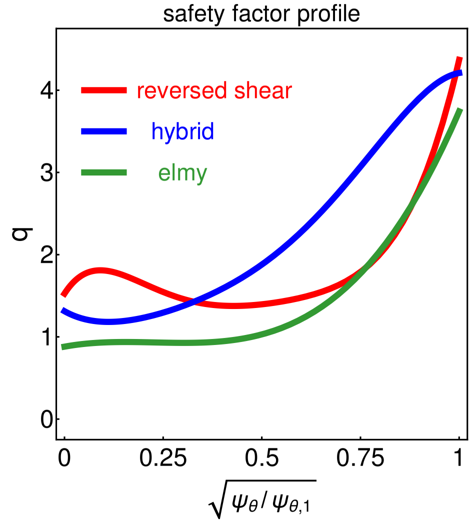
During chirping, 300ms

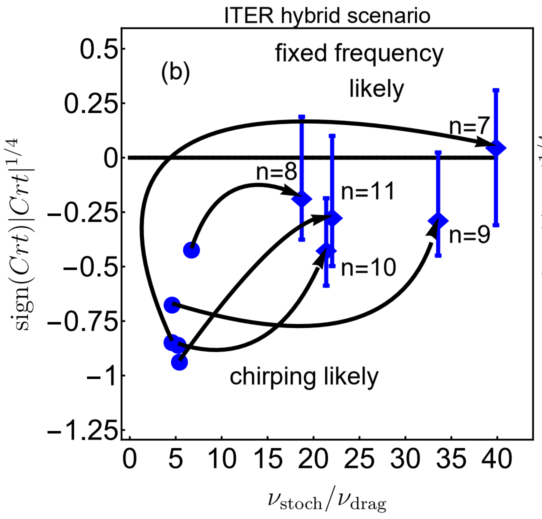
V. N. Duarte et al, NF 2018

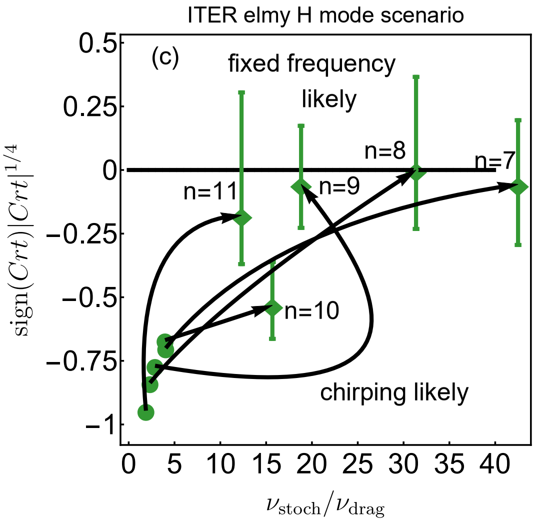
Predictions for the most unstable n=7-11 TAEs and RSAEs[1] in ITER are near boundary between fixed frequency and chirping

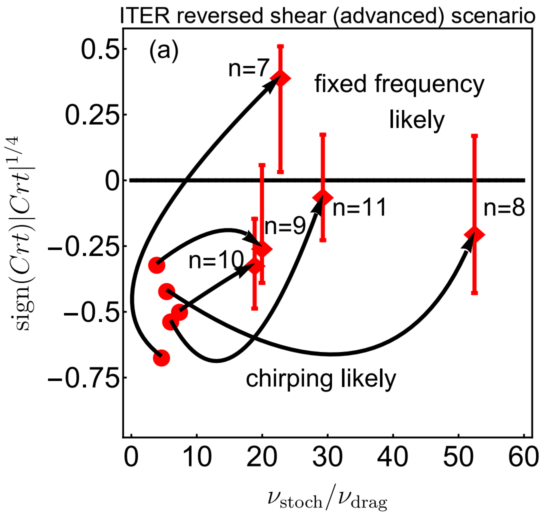
Analysis based on TRANSP modeling, requiring Q>10

Arrows show how radial turbulence diffusion[2,3] changes the prediction with respect to the purely collisional dynamics









Chirping can occur in ITER. New theoretical and numerical tools need to be developed for modeling.

[1] DOE OFES Theory Joule Milestone FY2007, Gorelenkov et al, PPPL Preprint number 4287 (2008), [2]Lang & Fu, PoP 2011, [3]Duarte et al, NF 2018.

Summary

- The proposed chirping criterion has been validated against NSTX and DIII-D data

- **Chirping cannot be ruled out in ITER!**

Q<10 and other decorrelation mechanisms, such as RF heating and resonance overlap, will however enforce constant Alfvénic frequency.

- Theoretical and numerical tools should be developed for fully nonlinear energetic particle transport in ITER