Low frequency sawtooth precursor in ASDEX upgrade

G. Papp\textsuperscript{1,2}, G. I. Pokol\textsuperscript{1}, G. Por\textsuperscript{1}, N. Lazányi\textsuperscript{1}, L. Horváth\textsuperscript{1}, A. Magyarkuti\textsuperscript{1}, V. Igochine\textsuperscript{3}, M. Maraschek\textsuperscript{3} and ASDEX Upgrade Team\textsuperscript{3}

1) Budapest University of Technology and Economics, Budapest, Hungary
2) Chalmers University of Technology, Göteborg, Sweden
3) Max-Planck-Institut für Plasmaphysik, Garching, Germany
Introduction

• For a safe tokamak operation the sawteeth have to be controlled. We lack a complete understanding of the crash.
• We have to take into account the transient precursor oscillations.
• A Low Frequency Sawtooth Precursor (LFSP) - lower than the (1,1) mode - was observed on several tokamaks\textsuperscript{1-3}

\begin{itemize}
  \item The LFSP on ASDEX Upgrade was analysed in detail
  \item It may play an important role in the sawtooth crash
\end{itemize}

• Frequent experimental observation: sawtooth-like jumps of the soft x-ray emission in the core plasma.

• Quasi-periodic flattening of the radial parameter profiles - CRASH

• Precursor oscillations before the crash - kink mode with (m,n)=(1,1) spatial structure
The stochastic model

• Local ergodic zones arise and lead to the transient transport
• This theory is consistent with the measurements (q-prof. evolution, postcursor mode, etc.) - but exact cause is unknown
• Experimental result: a Low Frequency Sawtooth Precursor (LFSP) is observable in the precursor phase with lower frequency than the kink - Properties? Role in the crash?

Time-frequency evolution

- Analysis of $O(100)$ crashes from several years of data
- The LFSP appears in most of the crashes investigated
- Crash occurs a few (~5) ms after the energy gain of the LFSP
- Average growth rate ~400 1/s => possibly a core MHD mode
Time-frequency evolution

- Ridge following algorithm based on graph theory to analyse low energy modes - global shortest path search
- $0.5 < \text{LFSP}/(1,1) < 0.7$ - not a small order rational
- (So far) no correlation was observed with plasma parameters
Connection between the modes

- Integrate the spectrogram in frequency for a given frequency range $\Rightarrow$ time fluctuation of the bandpower
- > 50% Cross-correlation between the bandpowers
  $\Rightarrow$ Energy fluctuations of the two modes are connected
  $\Rightarrow$ Spatial localisation: inside, and slightly outside of $q=1$
Connection between the modes

- Significant **bicoherence** (phase coupling) between the (1,1) and the LFSP, already 15 ms before crash

- **Clear signs of interaction before the crash**
  - LFSP excited by the (1,1) kink?

### Auto-spectrum

- LFSP: 8-9 kHz
- LFSP+ (1,1): 21-22 kHz
- (2,2): 25 kHz

### Bicoherence

- (1,1) - (2,2)
- LFSP - (1,1)
Toroidal mode number

- Two Identical SXR cameras at different toroidal positions

ASDEX-U Top view
Toroidal modenumber

- Modenumbers are based on phase difference, calculated in the time-frequency plane (cont. wavelet analysis)
- Filtering to globally coherent modes and goodness-of-fit.
- Toroidal modenumber is n=1, same as (1,1)
Poloidal modal number

- Tangential channels in the same toroidal cross-section

“Detector position” (Straight field line coord.)
Poloidal modenumber

- Poloidal modenumber $m=1$, same as $(1,1)$
- **Spatial structure is the same as for the $(1,1)$ kink!**
- Interaction of the two is very likely (magnetic coupling?)

![Poloidal modenumber](image)
The possible role of the LFSP

- Interaction may lead to the generation of a broader ergodic zone around the (1,1) island
- Steep gradient can onset fast MHD instabilities that speed up the collapse

Conclusions

• The stochastic model is a promising theoretical description for the sawtooth crash

• Precursor oscillations are of key importance
  ➡ Time-frequency evolution, spatial localisation and structure of the LFSP was determined\textsuperscript{6}
  ➡ Clear signs of interaction between the two modes
  ➡ The LFSP is most probably an MHD mode that might play an important role in the collapse mechanism

• MHD simulations could aid our understanding

\[6\] G. Papp et al, PPCF 53 065007, 2011.