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WP6: Linear and non-linear characterization of transient waves and their interactions

Review meeting for EnR project on non-linear interaction of Alfvénic and turbulent fluctuations in burning plasmas

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Outline

- **Deliverables**
- **NTI Wavelet Tools**
- **Mode structure analysis**
  - **Toroidal** (applying phase corrections, assuming integer mode numbers, so no restrictions by sampling theorem)
  - **Poloidal** (straight B-field coordinates, more methods)
  - **Radial** (corrections for fast chirping, diagnostic effects)
- **Bicoherence analysis** (hypothesis testing for significance at each point)
- **Bandpower-correlation analysis** (complementing bicoherence analysis)
- **Analysis of simulated signals** (HAGIS, HMGC, ORB5?)
- **Summary and outlook**
- **Publications**

Deliverables

- **Deliverable for 2017:**

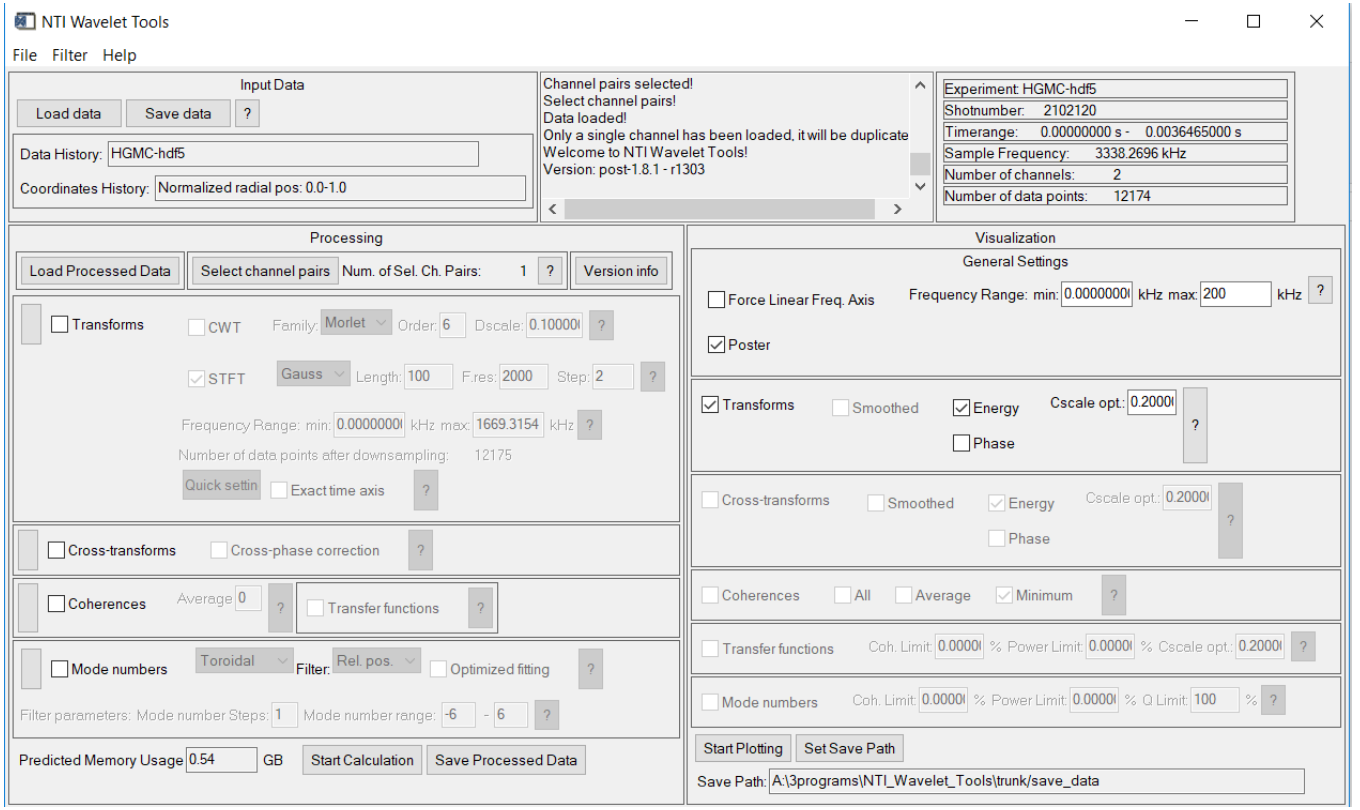
Develop a standard set of tools for the linear characterisation of chirping modes, comparison to simulations; linear characterization of chirping modes demonstrated on EGAMs, BAEs and bursting TAEs at the ASDEX Upgrade tokamak.

- **Deliverable for 2018:**

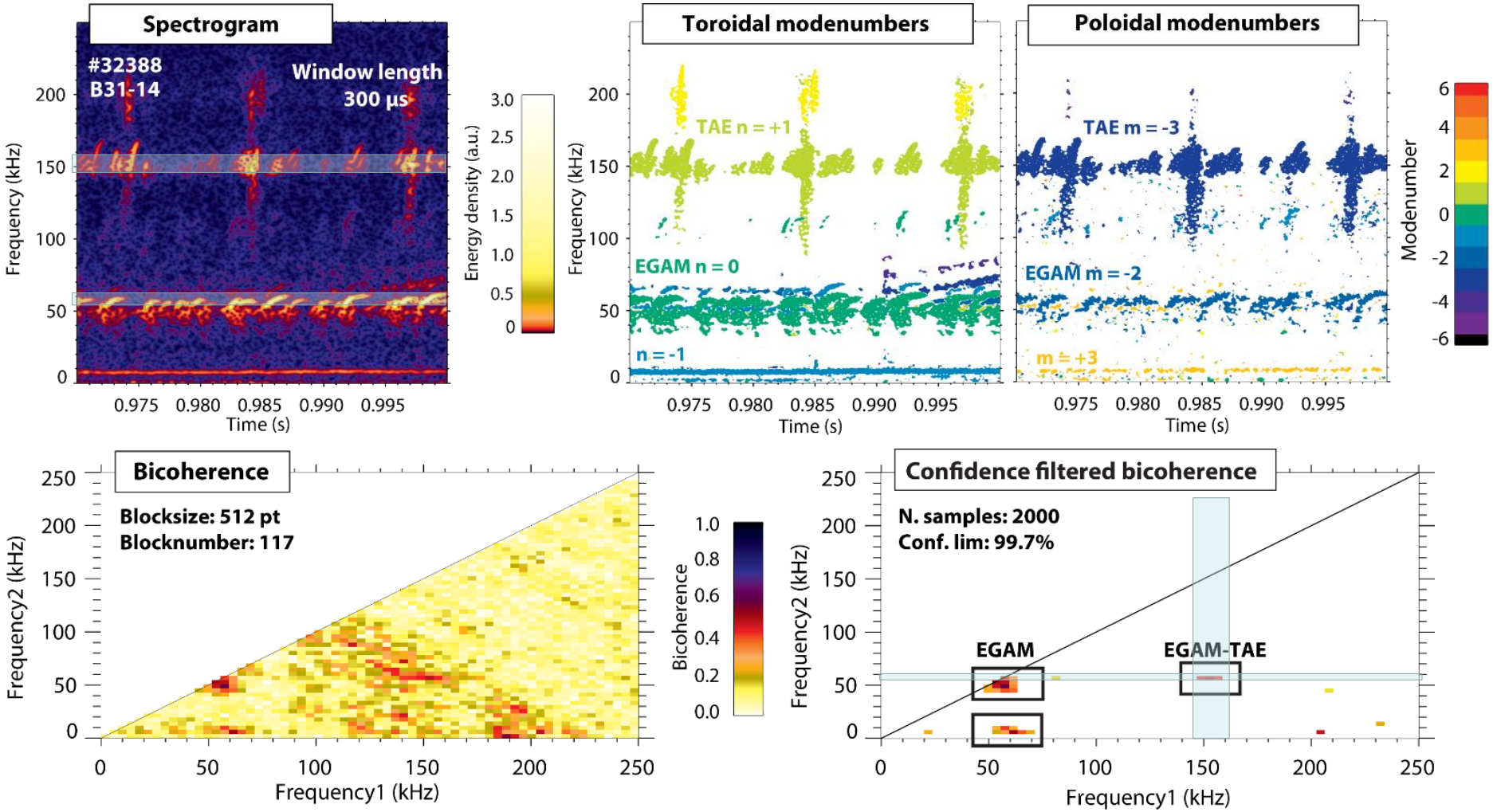
Characterise the non-linear interactions by higher order spectra and band-power correlation with careful consideration of error propagation and significance levels, comparison to simulations; (quantitative study of non-linear interactions of various fast particle-related transient modes e.g. EGAMs, BAEs and/or bursting TAEs) with special emphasis on detecting wave-wave coupling.

NTI Wavelet Tools

- **Maintenance and development of transient signal analysis toolbox at AUG following the needs of users**
- **Regular use for energy distributions and toroidal mode numbers**
- **New algorithms for poloidal mode numbers being implemented**
- **Regularly used**

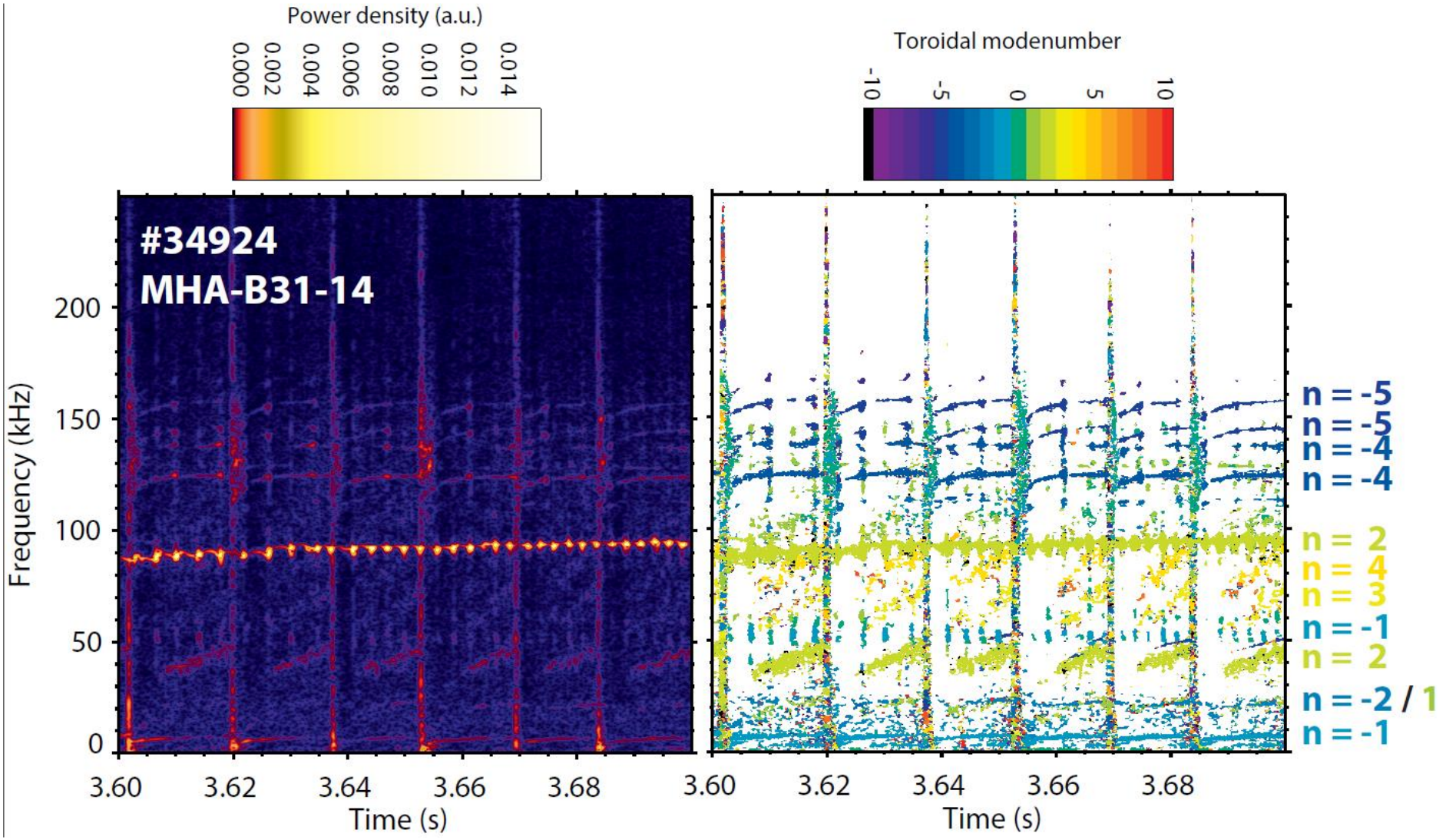


EGAM-TAE coupling

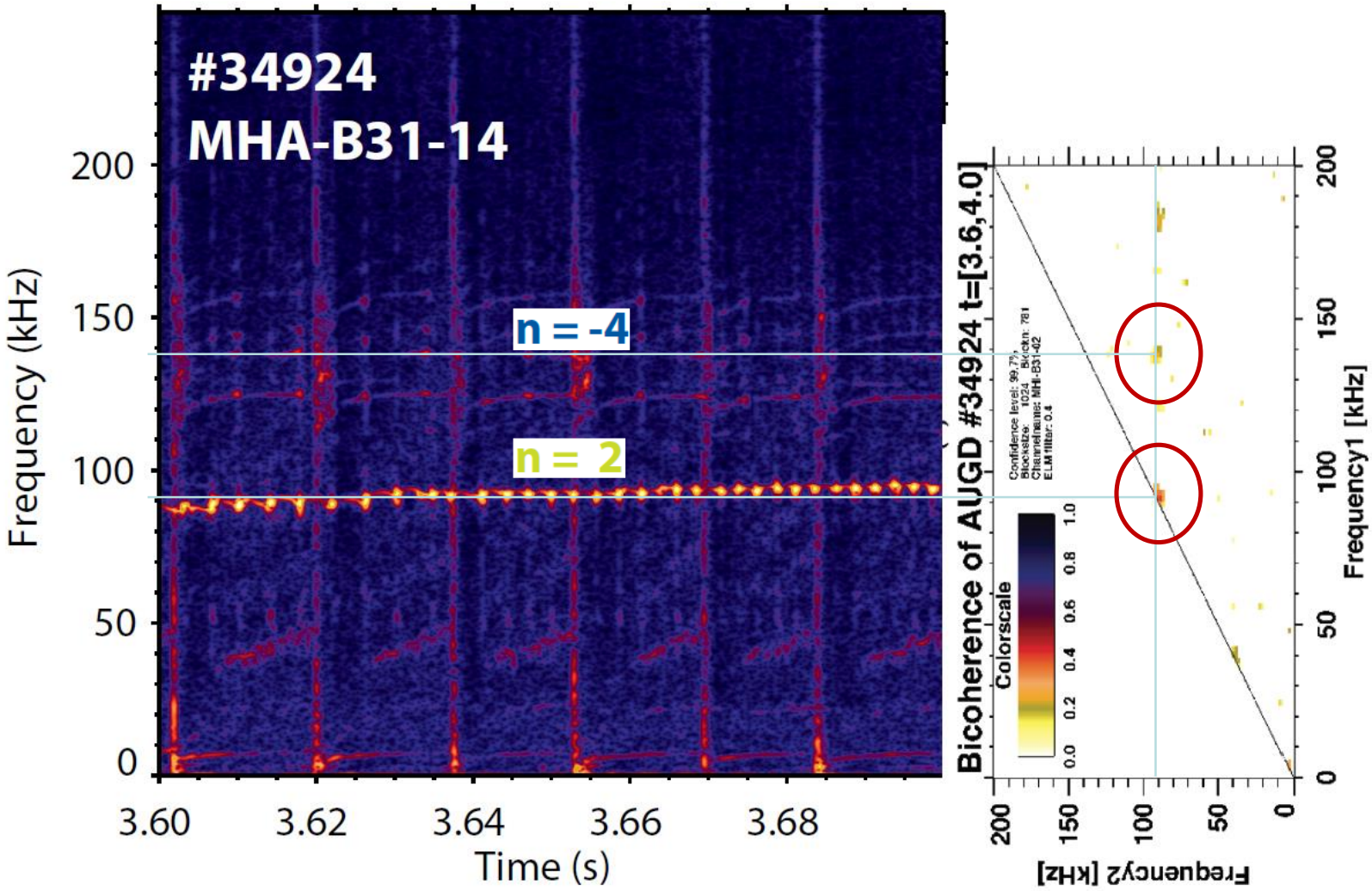


Non-linear coupling only at high amplitude part of the EGAM chirp

New scenario with lots of modes



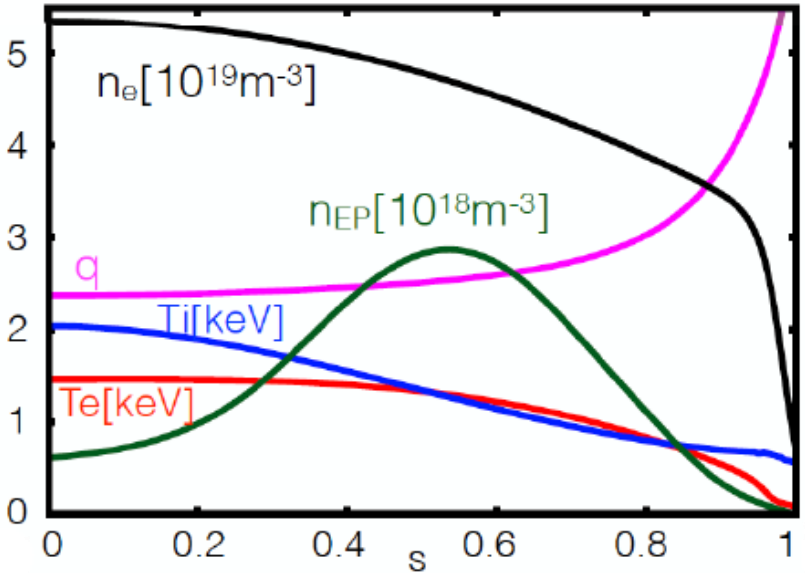
Coupling of co- and counter-propagating TAE

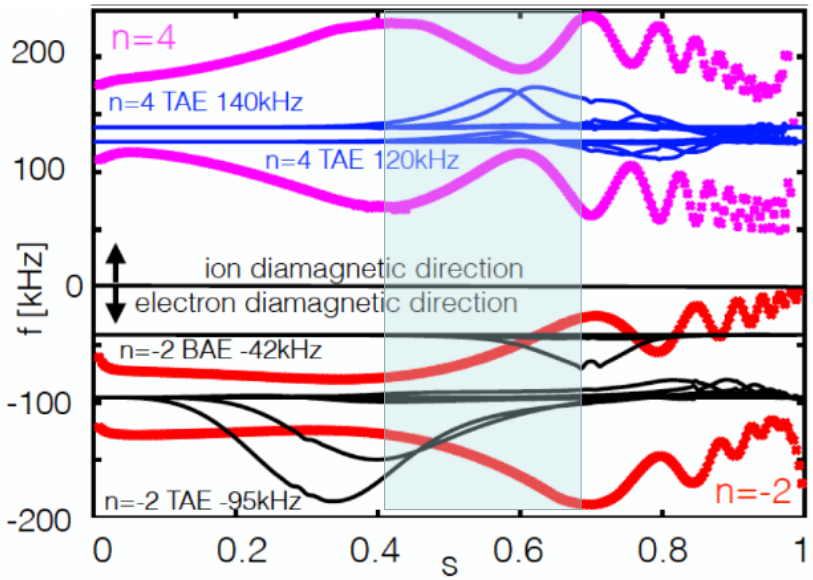


Coupling of co- and counter-propagating TAE

Non-linear coupling between co- and counter-propagating modes **possible because**:

1. Frequency is the same in plasma frame (~7 kHz plasma rotation)
2. Overlap in radial structure





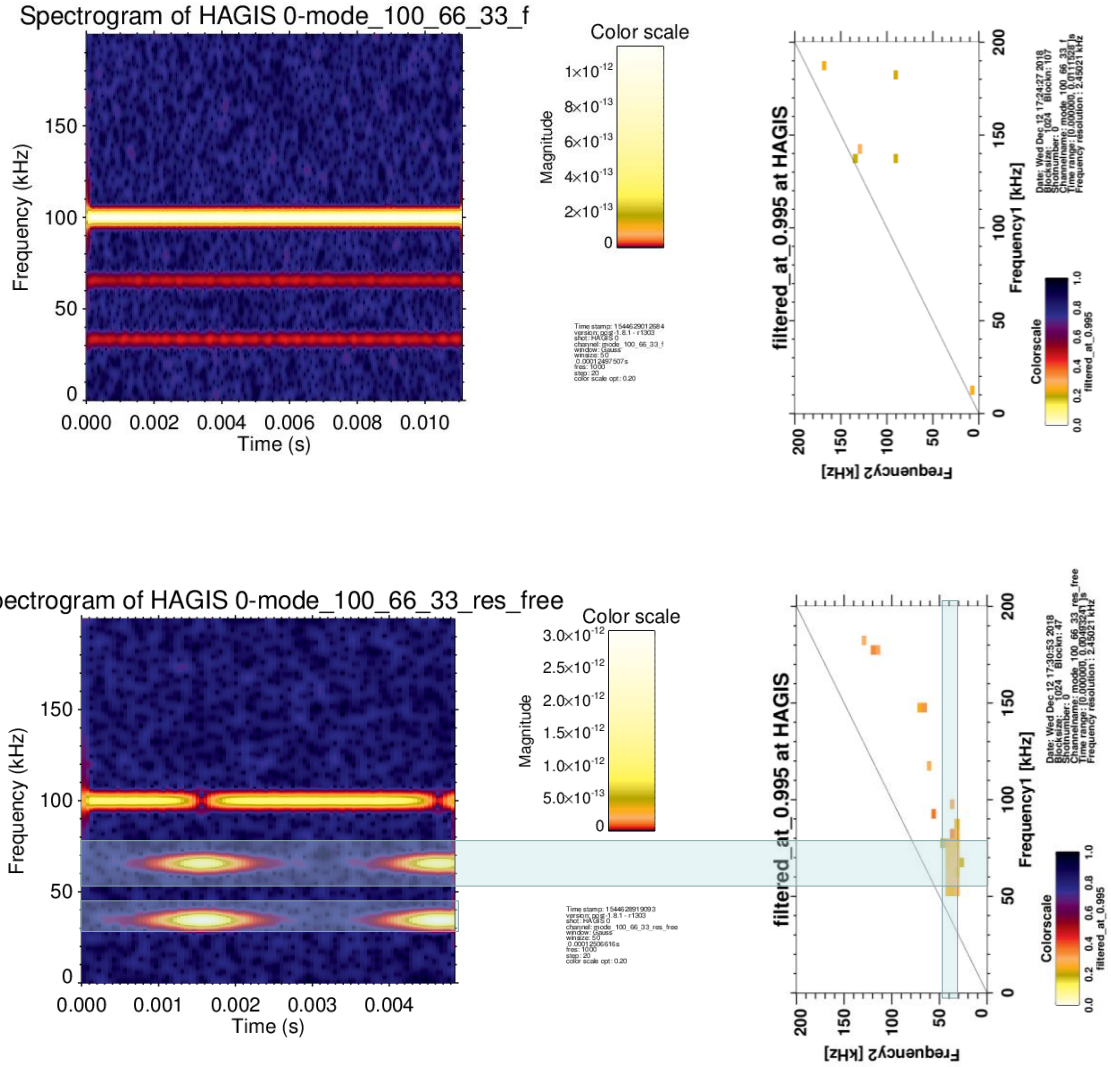
By Philipp

Preliminary results on HAGIS data

Simulated signals exported from HAGIS, weak white noise added

Frequency mismatch of 2%
→ No clearly significant bicoherence, might be weak bicoherence at difference frequencies

Exact match
→ Significant bicoherence



By Philipp

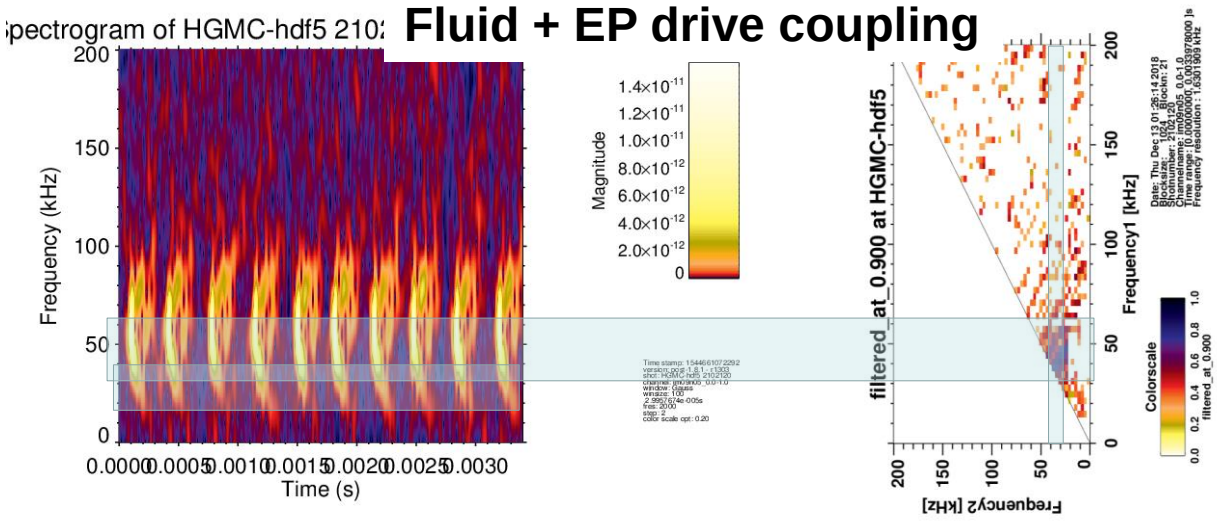
Preliminary results on HMGC data

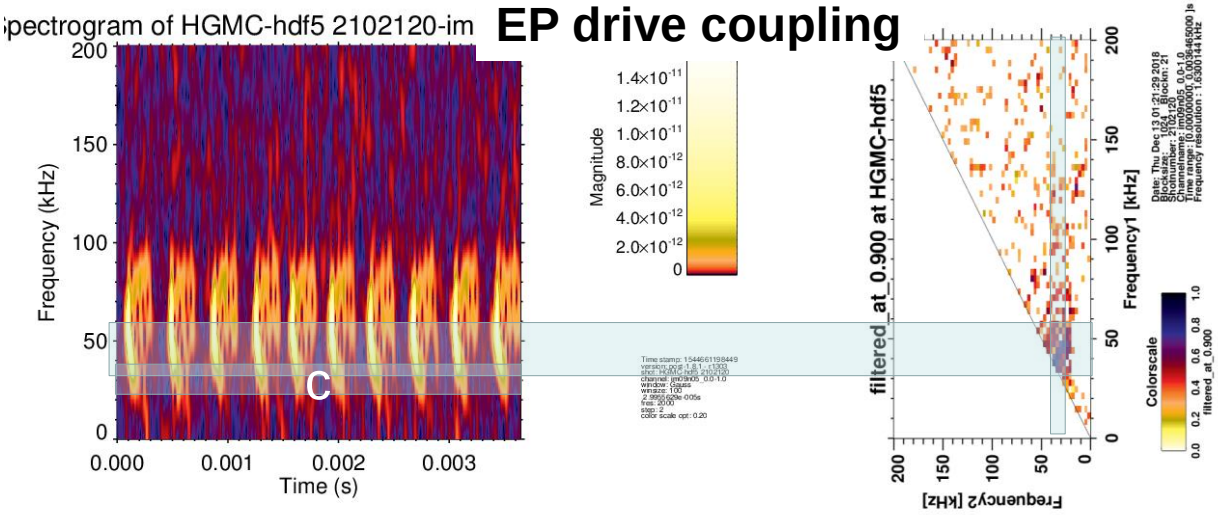
Simulated modes added, radial amplitude weighted by a factor inversely proportional to the distance to the probe and integrated, some white noise added.

Both simulations yield significant bicoherence in the high amplitude regions

Results still to be understood

By Xin





Summary and Outlook

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- **Deliverable for 2018:**

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- **Future plans:**

Continue with characterization of various EP-related modes observed at AUG (utilize diagnostic enhancements)

Extend on simulation analysis: HAGIS, HMGC, ORB5 (+ advanced synthetic diag.)

Proceed with interpretation of turbulence-mode bicoherence

Publish papers

Publications

- **2017:**

P. Zs. Poloskei, G. Papp, G. I. Pokol, Ph. W. Lauber, X. Wang, L. Horvath and the ASDEX Upgrade team: Bicoherence analysis of fast ion driven transient plasma waves. 44th EPS Conference on Plasma Physics, P5.179, 2017

P. Zs. Poloskei, G. Papp, G. I. Pokol, Ph. W. Lauber, X. Wang, L. Horvath and the ASDEX Upgrade team: Analysis of the nonlinear interaction of fast ion driven plasma waves. 15th IAEA TcM on EPs, P-24, 2017

- **2018:**

Ph. Lauber et al: *Strongly non-linear energetic particle dynamics in ASDEX Upgrade scenarios with core impurity accumulation*, Oral at the 27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018, EX1/1;

P. Zs. Poloskei, G. Papp, L. Horvath, G. Por, and G. I. Pokol: *Bicoherence analysis of nonstationary, nonlinear processes*, JOURNAL OF IEEE TRANSACTIONS ON SIGNAL PROCESSING, **submitted**

L. Horvath, G. Papp and G. I. Pokol: *Reconstruction of Rapidly Changing Amplitude of Chirping Signals Using Time-Frequency Analysis*, JOURNAL OF IEEE TRANSACTIONS ON SIGNAL PROCESSING, **to be submitted in 2018**

- **2019:**

P. Zs. Poloskei, G. Por, G. Papp, L. Horvath, Ph. Lauber and G. I. Pokol: *Experimental observation of the nonlinear interactions of fast-ion driven modes*, Some Letter?, **to be submitted**

Ph. Lauber et al: *Strongly non-linear energetic particle dynamics in ASDEX Upgrade scenarios with core impurity accumulation*, Nuclear Fusion, **to be submitted**

+ Something on bicoherence analysis of simulation results