Italian National Agency for New Technologies,
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Detection of RF emission by runaway electrons

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- *SPC:*
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Presented by P. Buratti

Motivation and questions

- Generation of runaway electron (RE) beams is a **machine safety** issue for ITER
- RE beams can be generated
  - at disruptions (high electric field)
  - or at plasma startup (low density)

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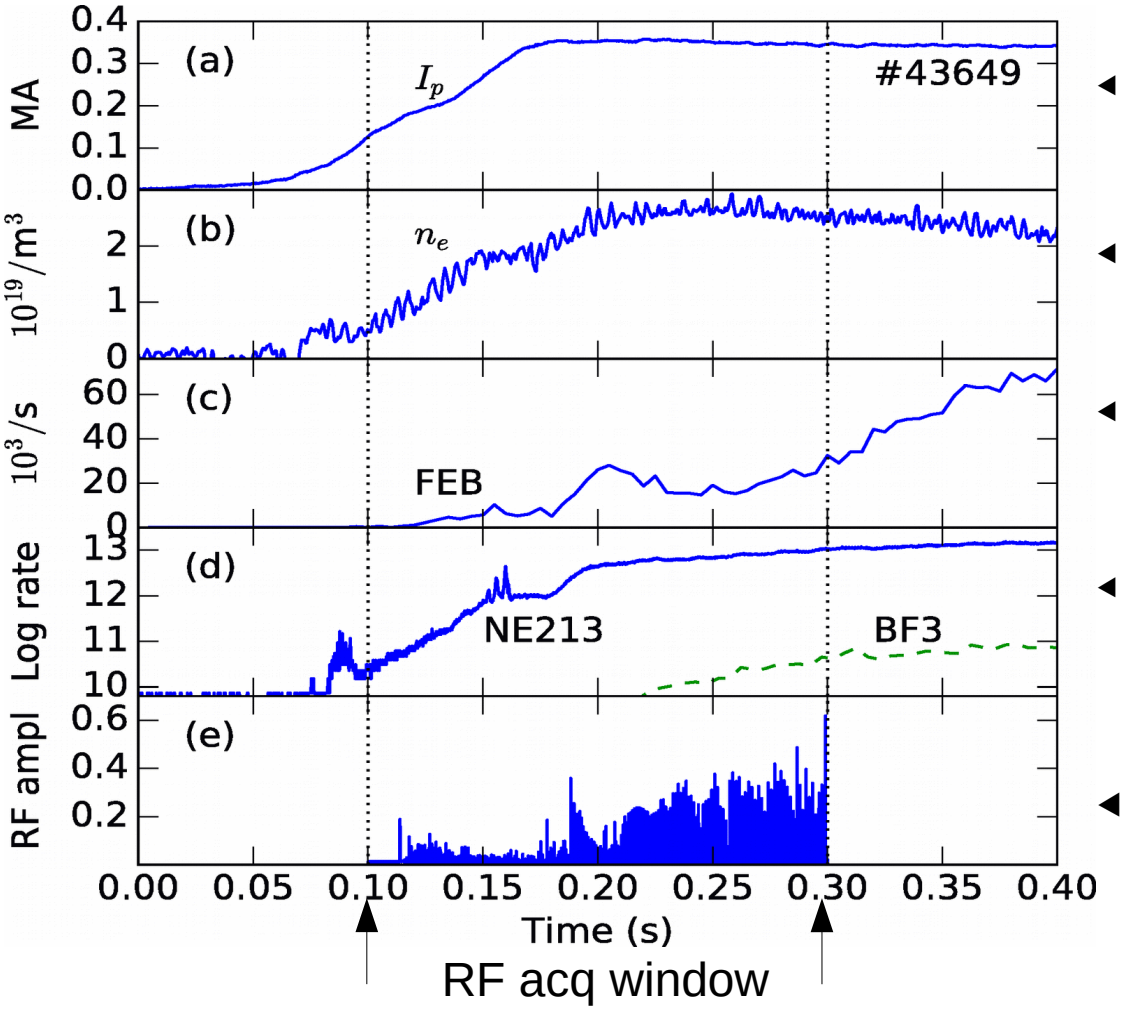
- In the following: results from FTU, TCV and COMPASS

Smoking gun for RE-wave interactions (FTU)

P Buratti et al 2021 Plasma Phys. Control. Fusion **63** 095007



- Plasma current
- Line average density
- Hard-x from in-flight RE
- Hard-x + neutrons (NE213) & neutrons only (BF3)
- **RADIO EMISSION**
  RMS amplitude

- Bursty instabilities affect RE already in the formation phase
- RF detection is the most sensitive diagnostic for such instabilities

Wave detection

- Wideband (log-periodic) antenna placed *outside* the vacuum vessel, in front of the exit of a vertical port closed by a dielectric window.

NI PXIe-5186 8 bit resolution
12.5 Gs/s max. sampling rate

- Antenna signal acquired by NI PXIe-5186 fast digitizer.
- ~400 MHz cutoff due to propagation in the port.

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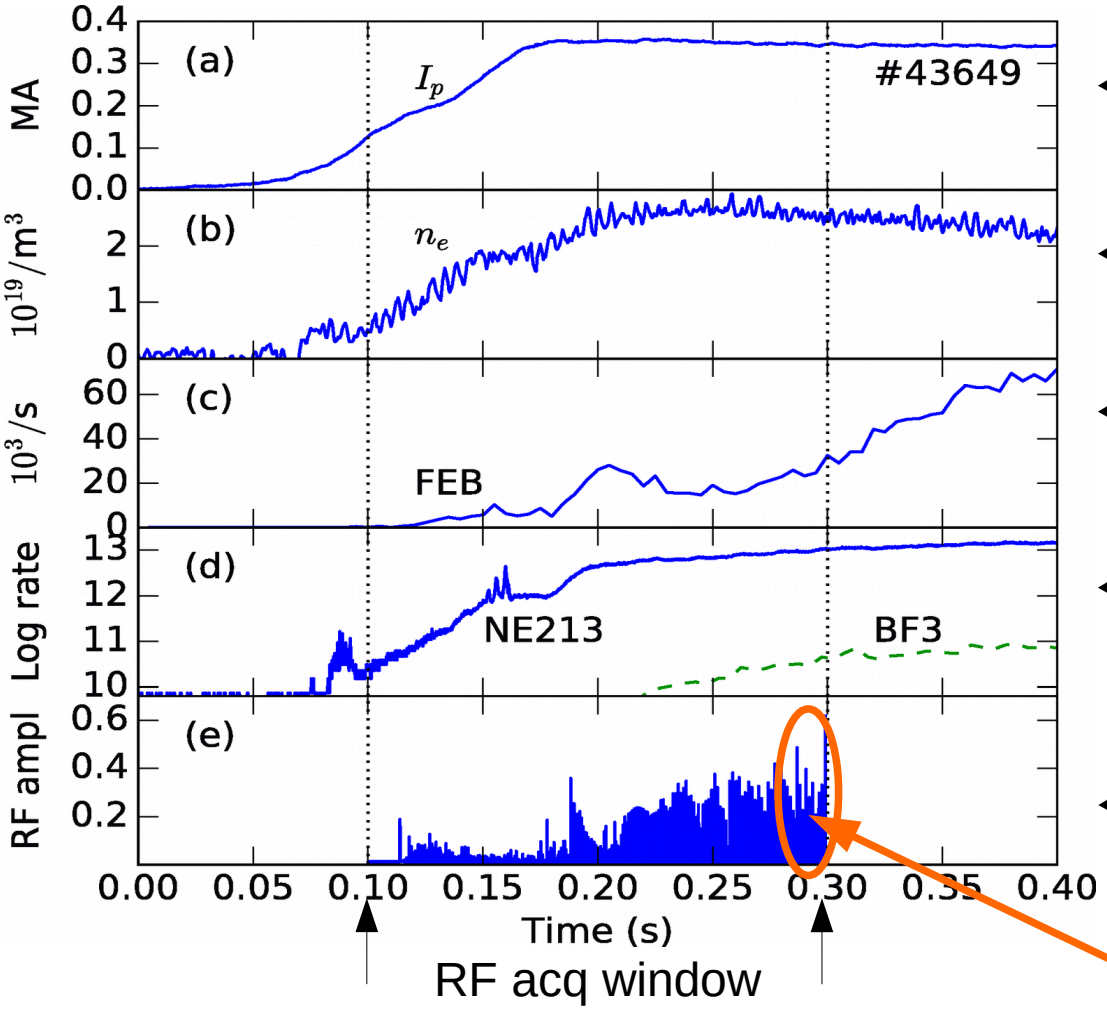

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Next: zoom one of these bursts

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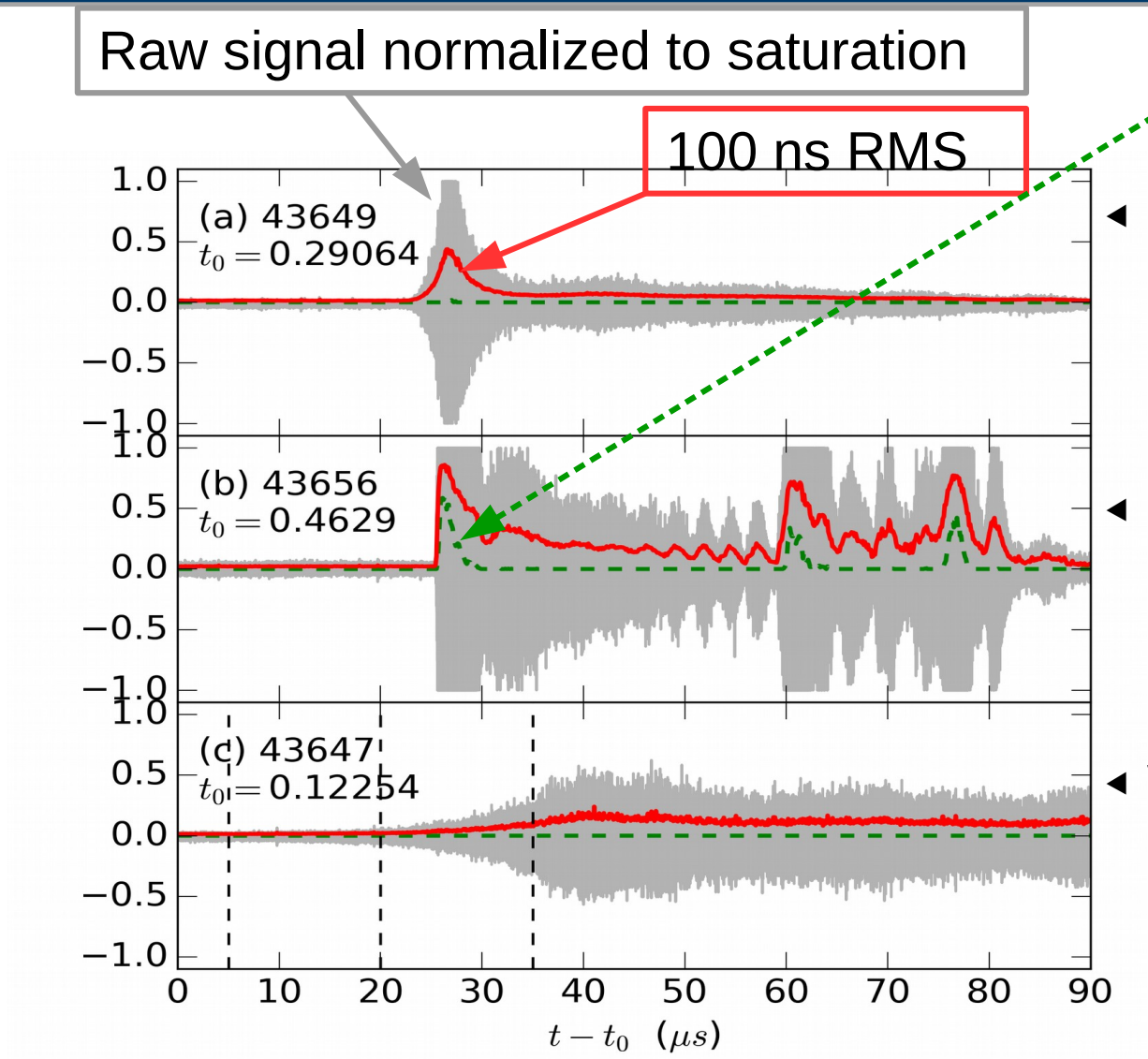
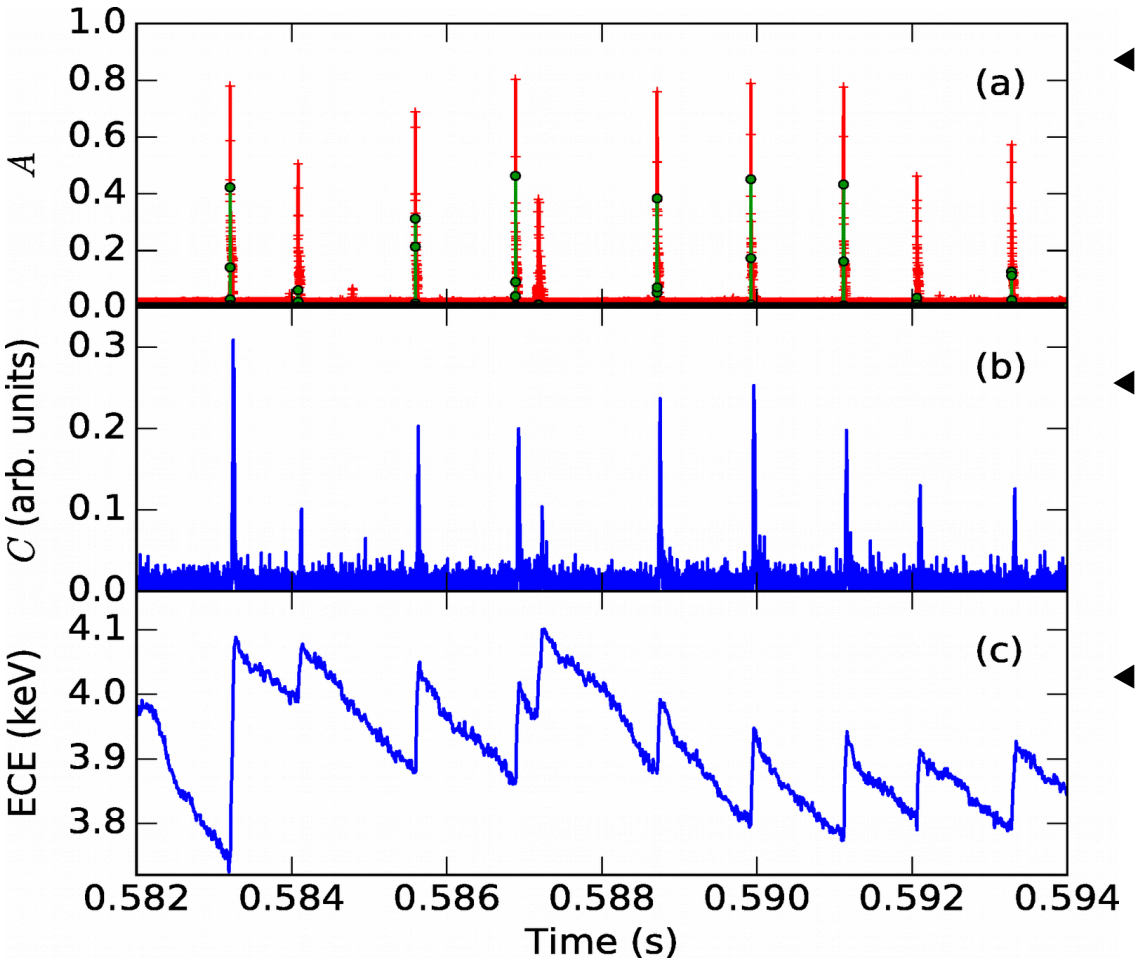
Wave burst structure



- Mild RE population: exponential front end with 1.1×10^6 s^{-1} growth rate
- Substantial RE: very sharp; complex tail
- Weak RE: much slower growth rate $\sim 10^5$ s^{-1}

Spot out qualitative features and measure instability growth rate

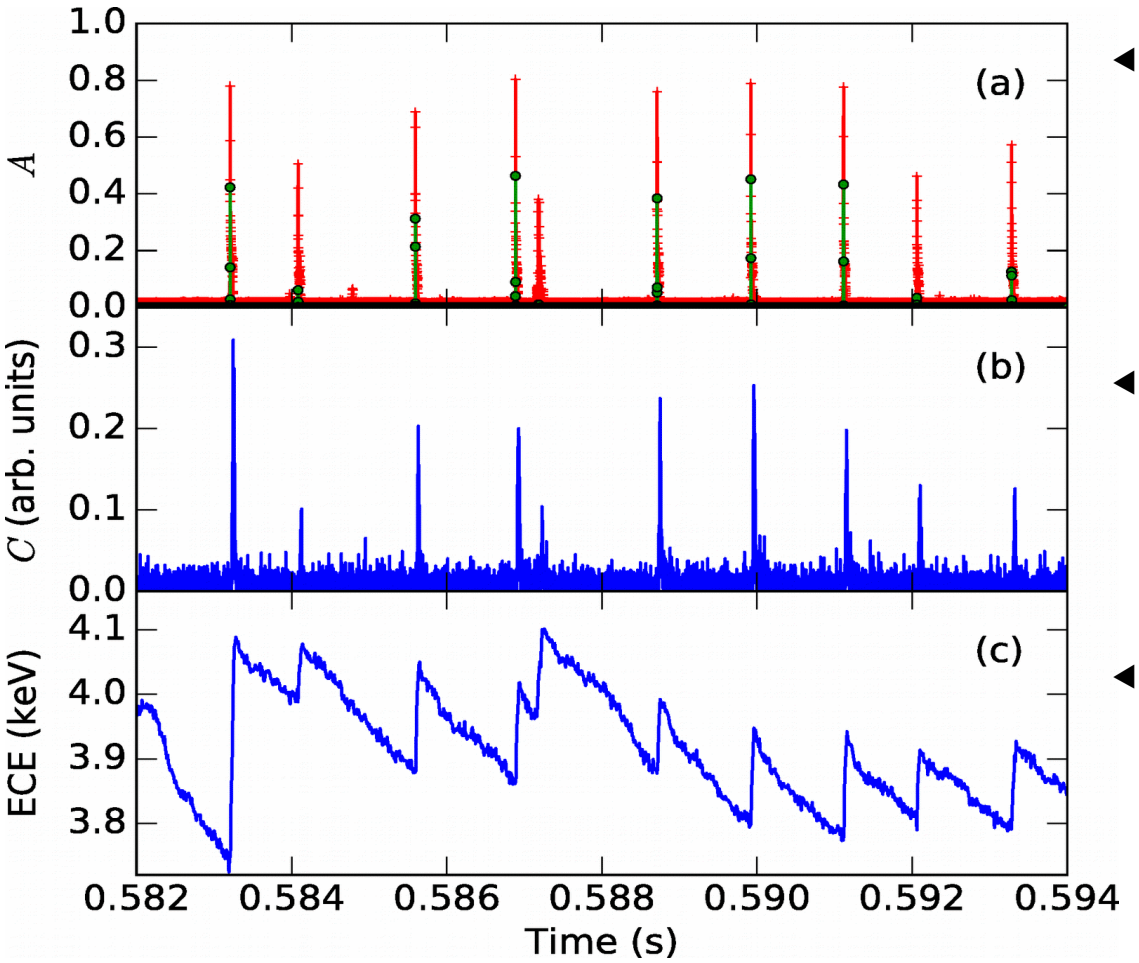
Integration of diagnostic data



- RMS RF amplitude (red) and fraction of saturated data (green).
- Cherenkov probe signal showing RE losses
- Suprathermal ECE showing RE pitch-angle scattering

- Identify RF bursts as signs of anomalous Doppler instabilities

Integration of diagnostic data



- RMS RF amplitude (red) and fraction of saturated data (green).
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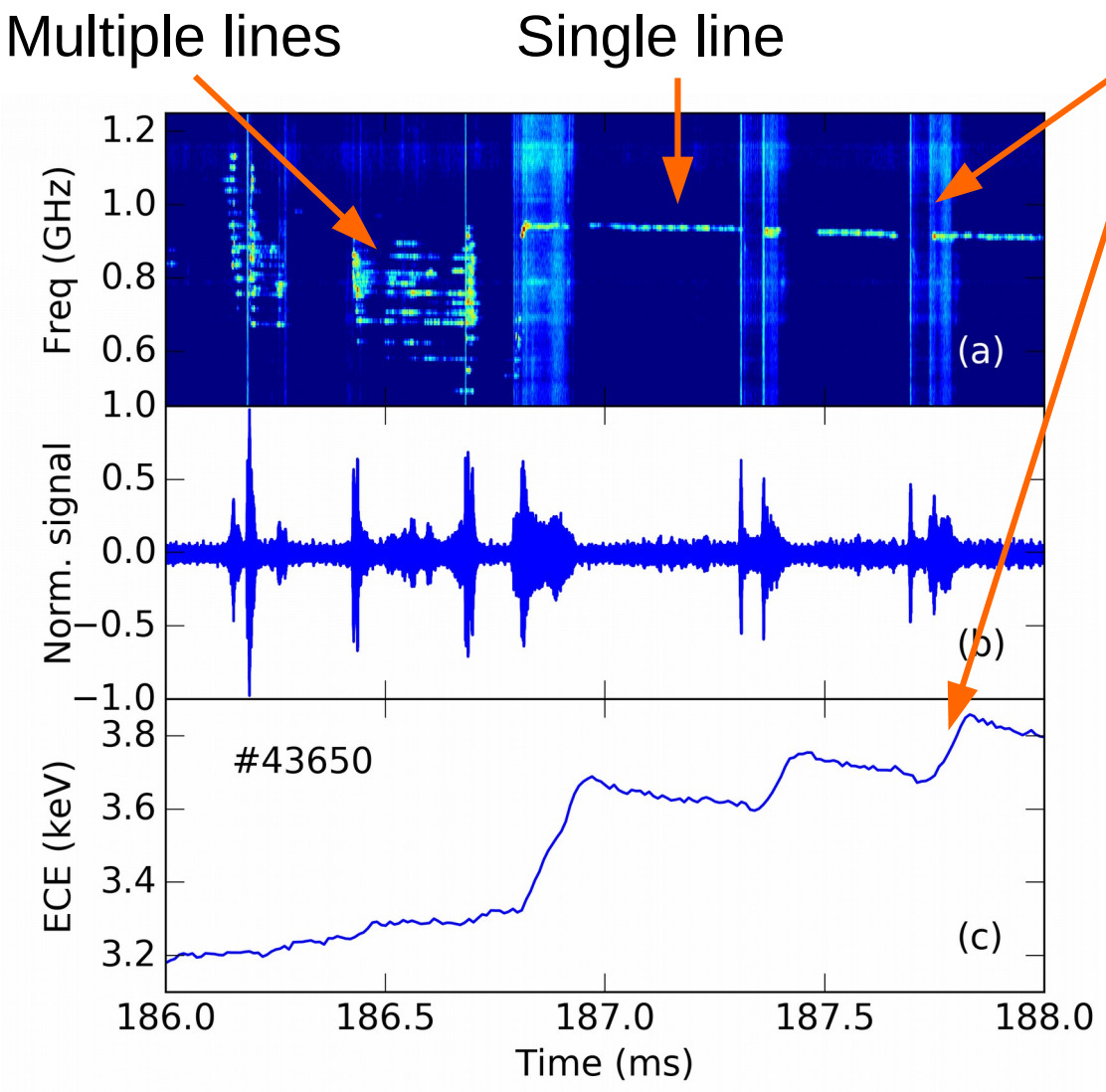
- Identify RF bursts as signs of anomalous Doppler instabilities
- ADI enhance by x2-x3 the critical *E*-field for RE avalanche

D. Carnevale et al 2021 Nucl. Fusion **61** 116050

Spectral analysis

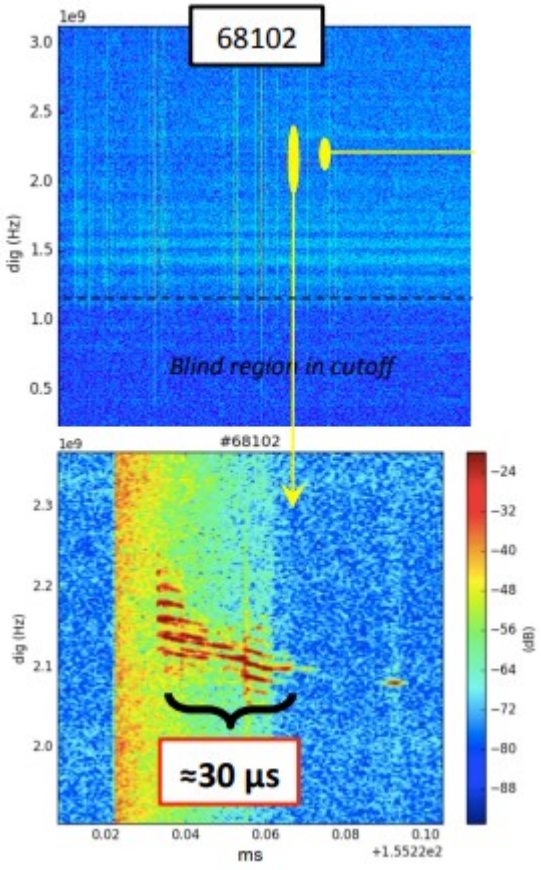


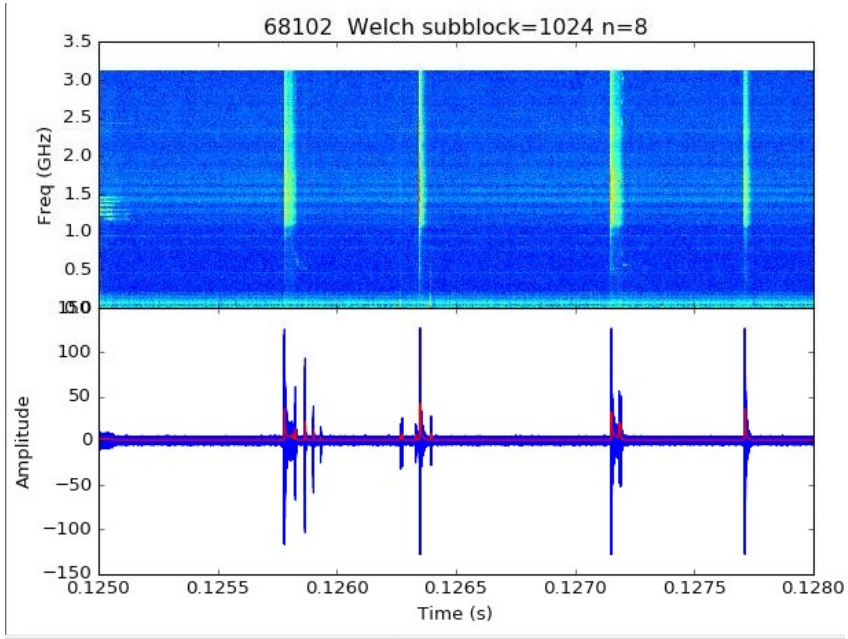
- RF spectrogram zoomed 0.5 - 1.2 GHz
- Raw signal normalized to saturation voltage
- Suprathermal ECE at 370 GHz, showing jumps at broadband bursts

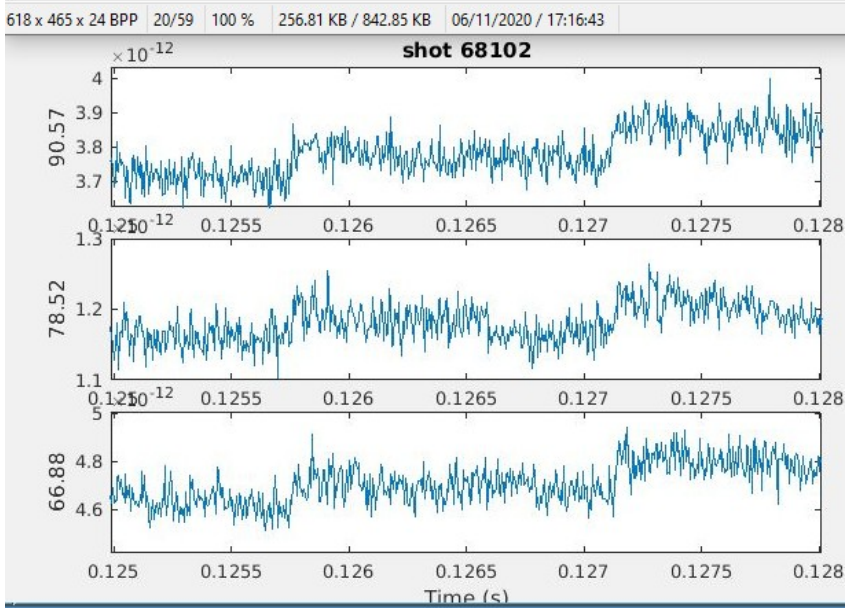
Besides impulsive anomalous Doppler instabilities, there are saturated ones producing coherent RF lines

TCV results with ex-vessel antenna (2020)

- Bursts and ECE jumps like in FTU
- Port cutoff at 1 GHz
- Coherent waves after bursts

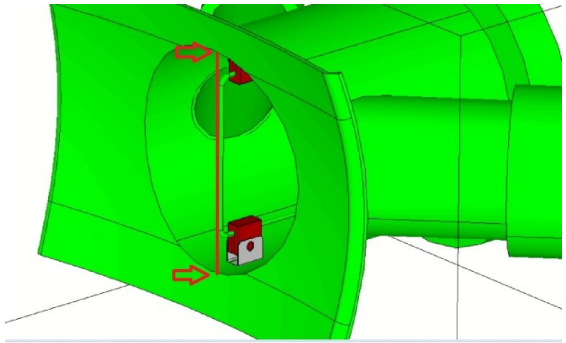


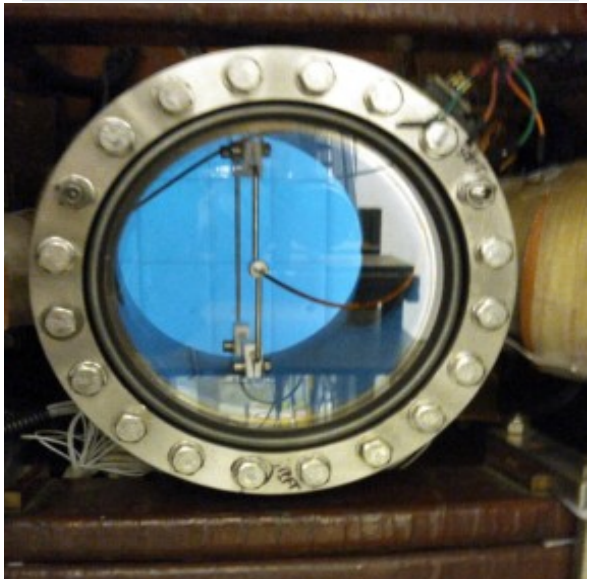




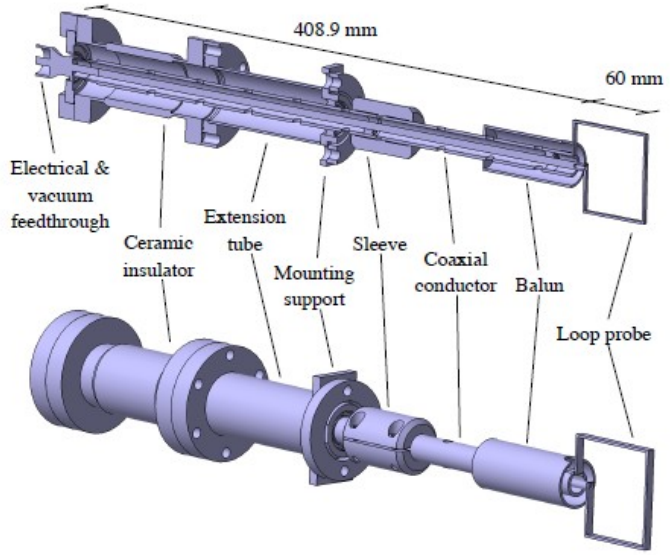
In-vessel antennas to avoid cutoff

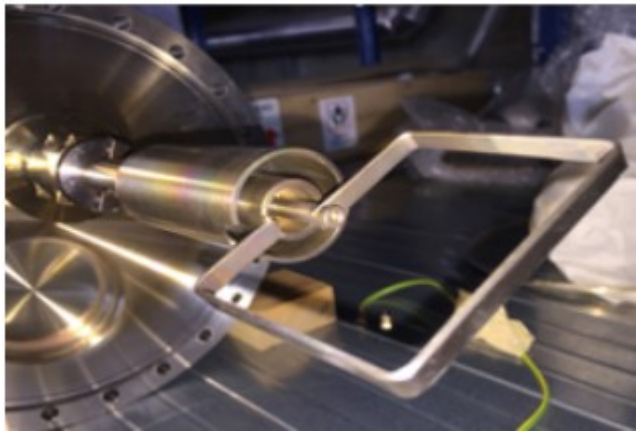
COMPASS - Dec. 2020
Also 500 MHz wave injection





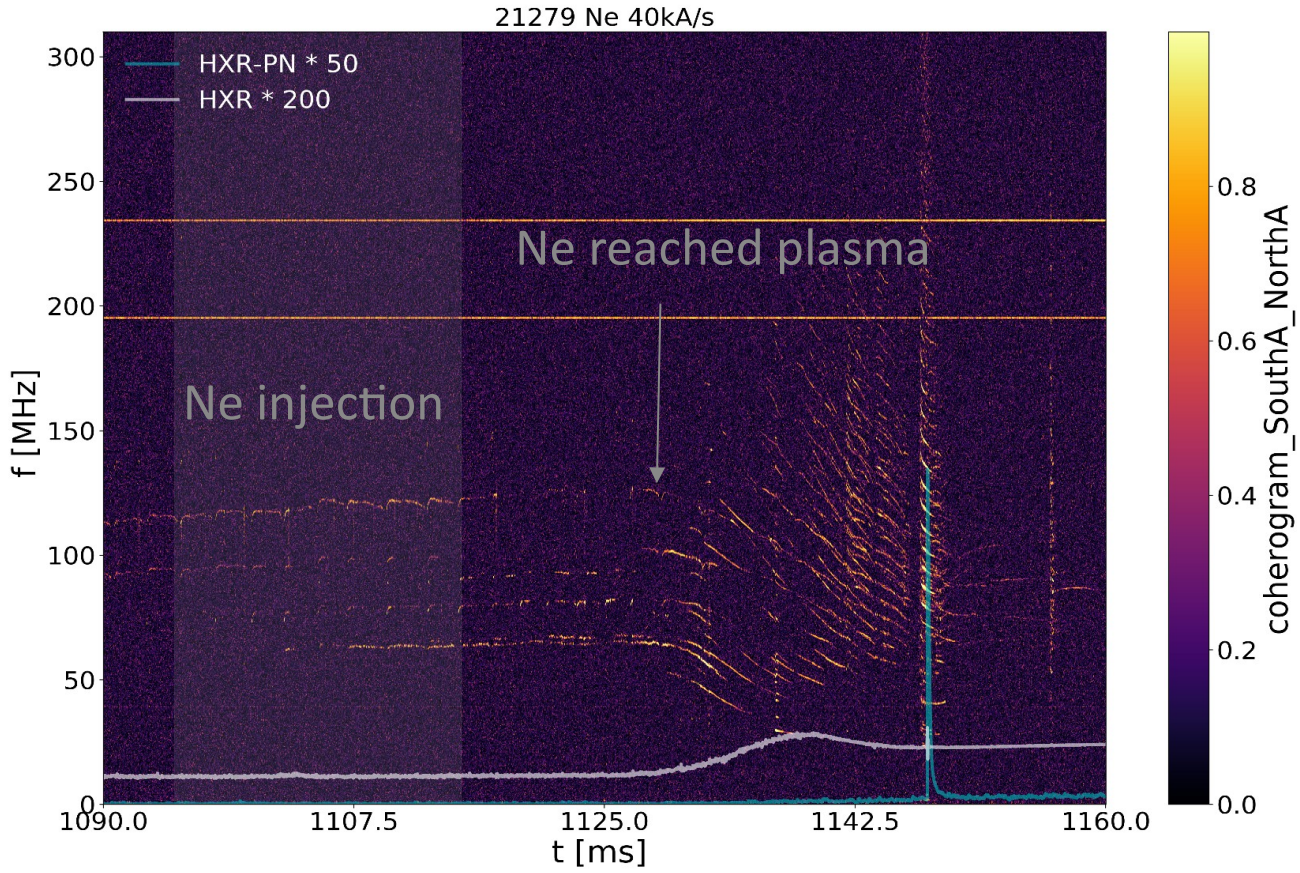
TCV - Ongoing





COMPASS 2020

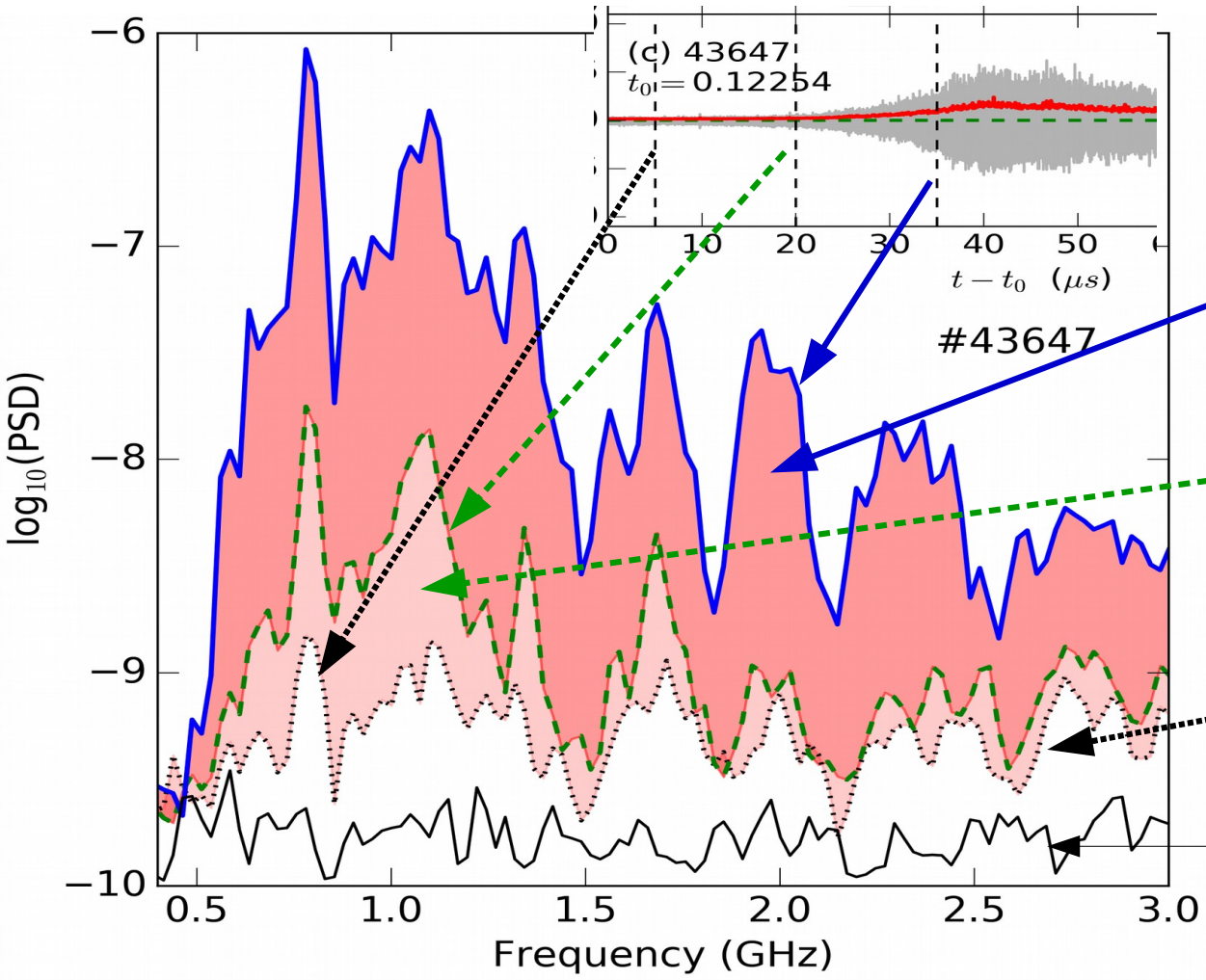
- Two in-vessel antennas
- Interesting dynamics in the 100 MHz range
- Other diagnostics can only detect the final burst



Conclusions

- Radio emission provides a sensitive diagnostic for kinetic instabilities affecting RE beams.
- Analysis of RE collective interactions provides inputs to:
  - improve predictive RE tools
  - optimize RE mitigation strategies.

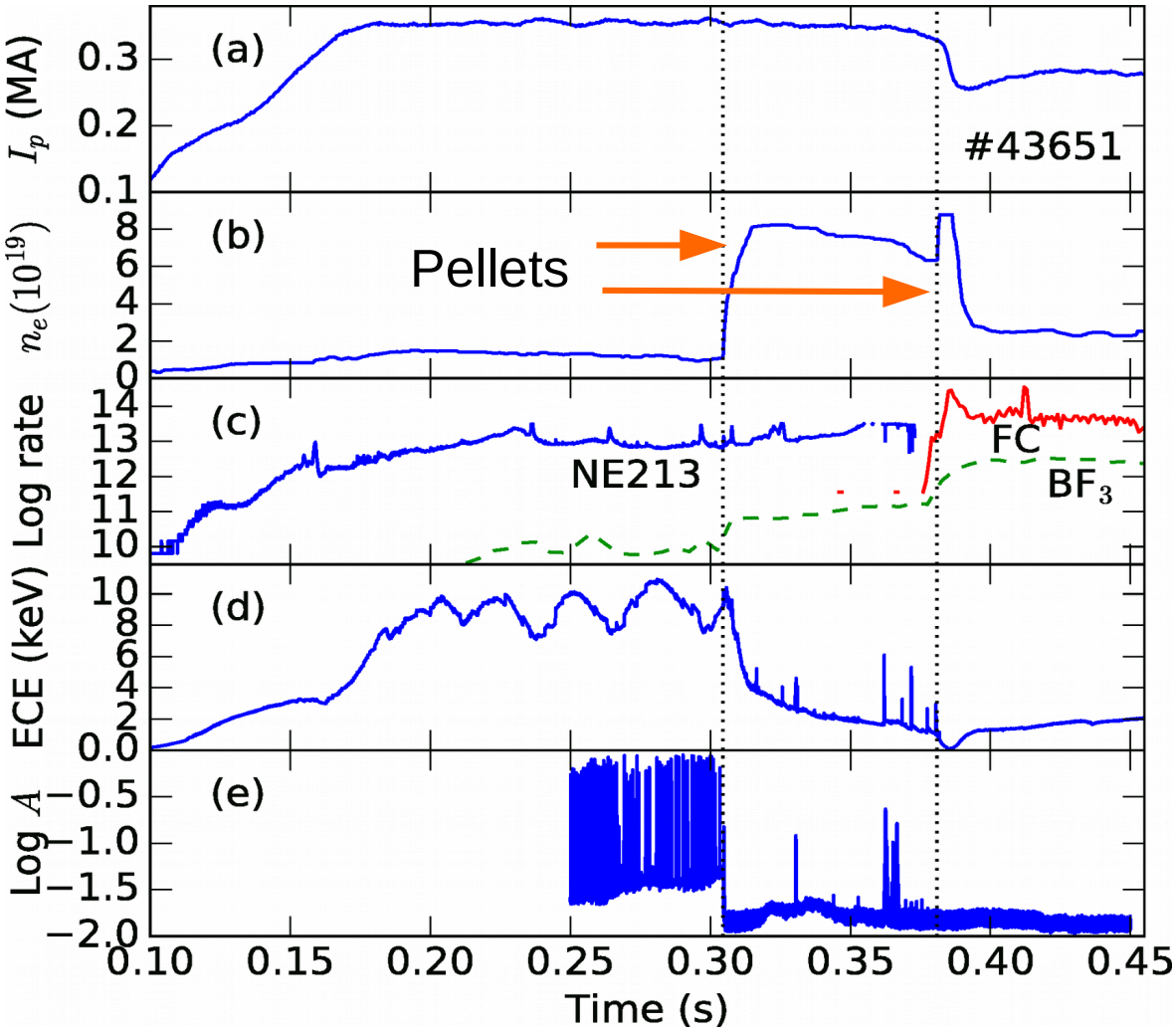
Spectral analysis 2



- Broadening near saturation (solid)
- Enhancement at 0.6–1.7 GHz during early exponential growth (dashed)
- Baseline before the burst (dotted)
- Noise floor in the absence of RE

- Spectrum dynamics can provide input to modellers
- Local spectral features due to transfer function should be calibrated

Response to plasma collisionality



- Plasma current
- Line average density
- Hard-x & photoneutrons
- ECE
- Radio emission in log scale

RE survive pellets, while RF bursts are quenched, likely by collisional wave damping