# Ion cyclotron emission as a diagnostic of the time evolution of edge density during ELM crashes in KSTAR plasmas


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04/12/2017

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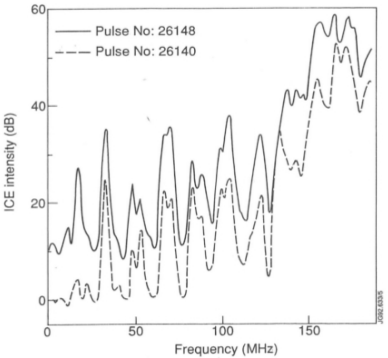
# Outline

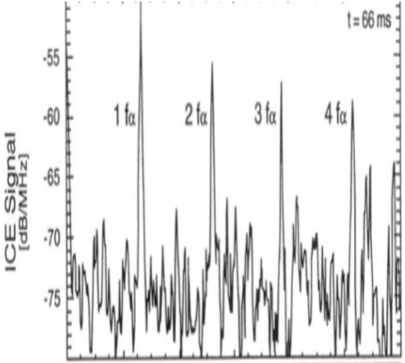
1. What is Ion Cyclotron Emission (ICE) and Where is it Observed?
2. Contemporary Results from KSTAR
3. Model Using Particle in Cell (PIC) Simulations.
4. Simulations of Density Chirping During KSTAR ELM crashes
5. High Time Resolution of Local Plasma Density During the ELM Crash

# Characteristics of ICE

- A sequence of peaks at multiples of the ion cyclotron frequency.
- Indicator of energetic ion physics.
- Fully self-consistent non-linear PIC simulations needed to model the dynamics.



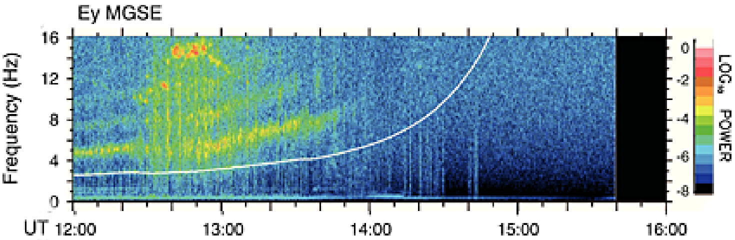

[1]




[2]

[1]**G A Cottrell et al**, **Nucl Fusion 33 1365 (1993)**.
[2]**S C Cauffman et al**, **Nucl Fusion 35 1597 (1995)**.

# ICE in Space




- Spectrogram of $E_y$ component.[3]
- Data obtained using Van Allen probes.
- Excitation of compressional waves at several low cyclotron harmonics of hydrogen.

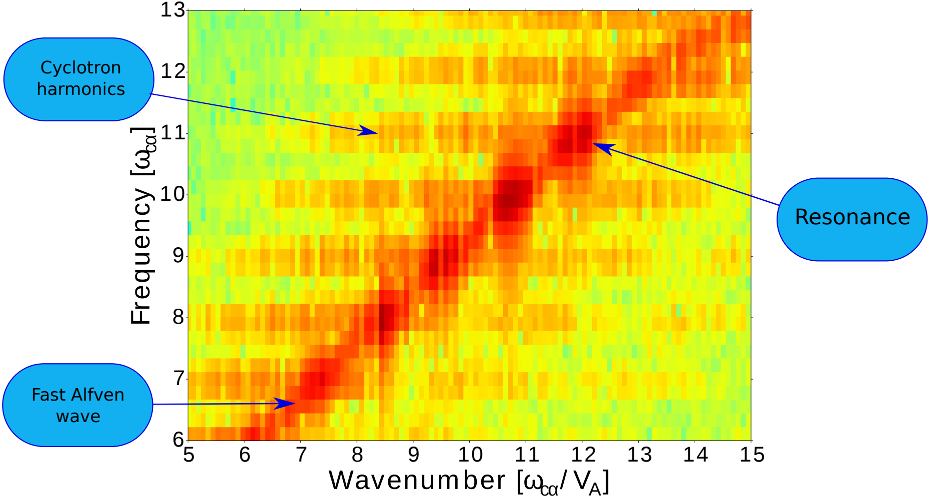
[3] **J L Posch et al**, **Journal of Geophysical Research: Space Physics**, **120**, **8**, **6230-6257** **(2015)** .

# Driving Mechanism for ICE - the Magnetoacoustic Cyclotron Instability (MCI)

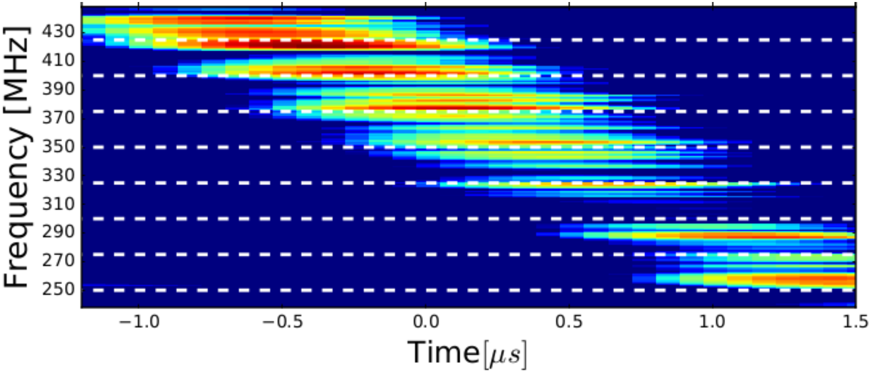
- Linear theory developed in terms of the MCI being the driving mechanism for ICE, simulations confirm this.
- Fast Alfvén wave, propagating nearly perpendicular to the tokamak magnetic field.
- The fast ion population can enter into cyclotron resonance with this wave at frequencies $\omega_{Alfven} \approx kv_{Alfven} = n\Omega_\alpha$.
- This resonance can be either wave-wave[4] or wave-particle[5].
- Requires a population inversion in velocity space (ring beam distribution, $n_\alpha / n_{th} \sim 10^{-3}$).

[4] **V S Belikov and Ya I Kolesnichenko**, **Sov Phys Tech Phys 20**, **1146 (1976)**.
[5] **R O Dendy et al**, **Phys Plasmas 1**, **1918 (1994)**.

# Driving Mechanism for ICE - the Magnetoacoustic Cyclotron Instability (MCI)

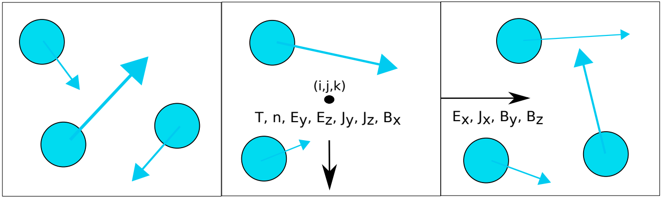


# ICE during KSTAR ELM crashes[6]




[6]**S G Thatipamula, G S Yun et al. Plasma Phys. Controlled Fusion 58, 065003 (2016)**.

# PIC Method - EPOCH




- Use the Warwick developed PIC code "EPOCH".[7]
- Fully self-consistent, solves full Maxwell equations with Lorentz force.
- Currents from particles $\rightarrow$ advance EB fields $\rightarrow$ push particles.
- Represent several physical particles as a computational macro particle.
- Challenge to run a fully non-linear simulation as many macro particles are required ($\sim 10^7$ here) for a high signal to noise ratio.

[7] **T D Arber**, **K Bennett**, **C S Brady et al**, **PPCF 57**, **1-26 (2015)**.

# Simulation details

**Hypothesis**: Chirping is due to a change in local density during the ELM crash.

**Test**: Run multiple simulations at different densities.[8]

Approximations:

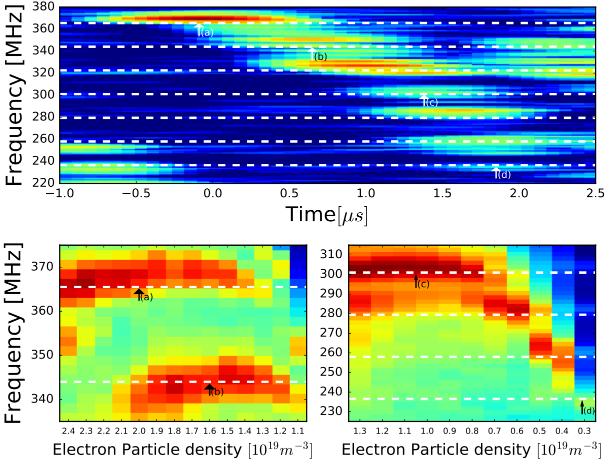
- 1D3V simulation - not tokamak geometry (but full 3D phase space and all 3 components of E and B).
- Assume magnetic field is constant during the ELM crash.
- Not modelling density gradients etc that are in this region of the plasma.
- $\mathbf{k} \perp \mathbf{B}$

[8] **B. Chapman**, **R. O. Dendy**, **K. G. McClements**, **S. C. Chapman**, **G. S. Yun**, **S. G. Thatipamula**, **and M. H. Kim**, **Nucl. Fusion. 57**, **12 (2017)**.

# Downward Chirping in KSTAR

Top: Experiment

Bottom: Simulation

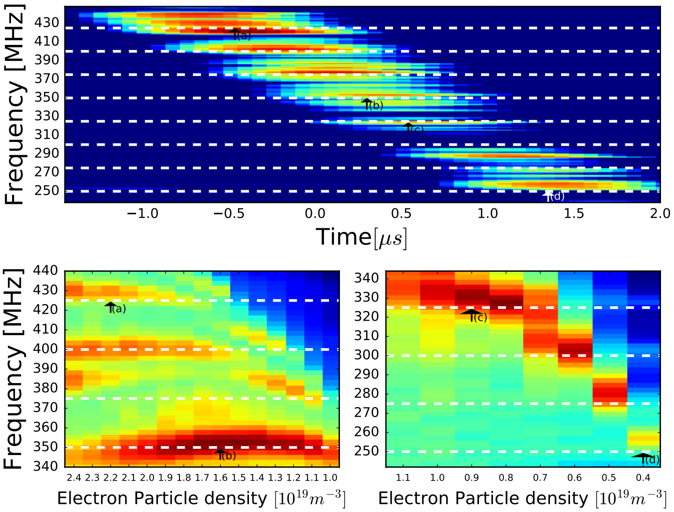



Signal $\sim$ 3 orders of magnitude higher than the thermal plasma signal.

# Downward Chirping in KSTAR

Top: Experiment

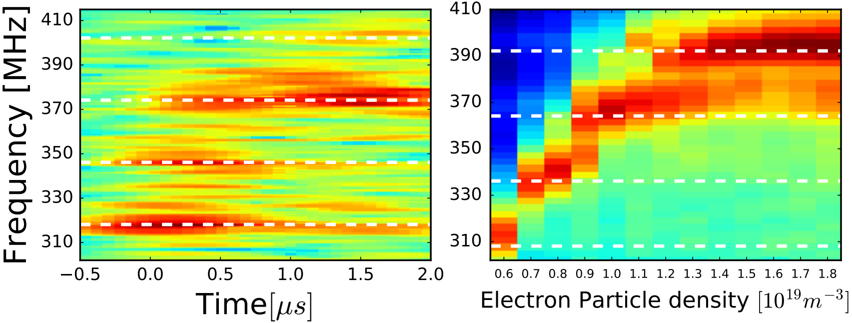
Bottom: Simulation



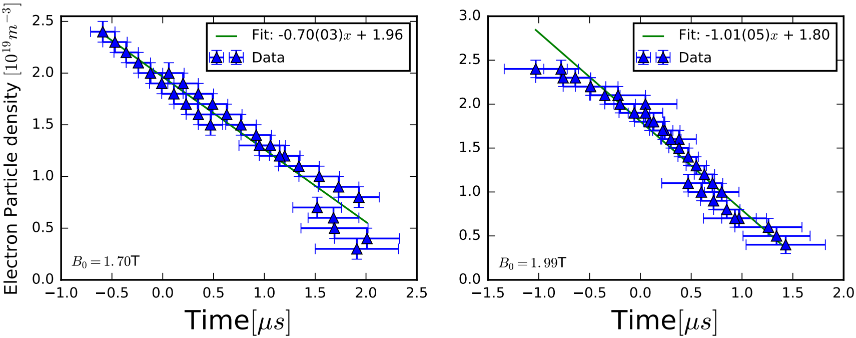
# Upward Chirping in KSTAR

Left: Experiment

Right: Simulation



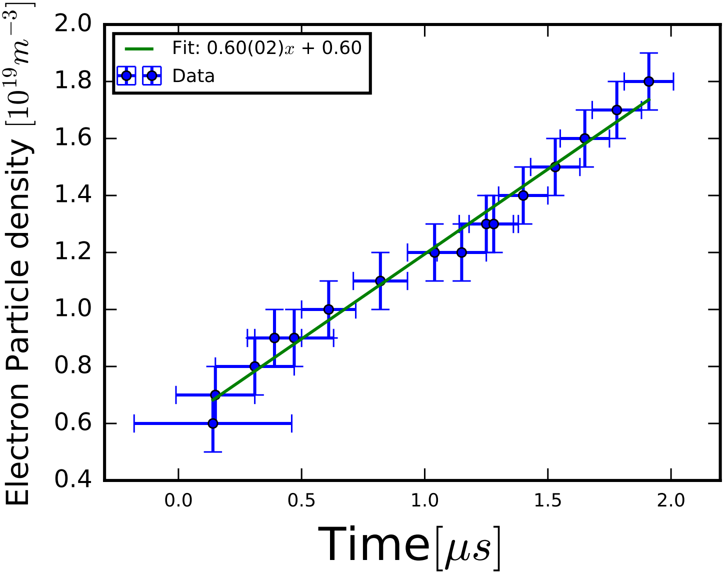
# Evolution of Edge Plasma Density with Time




Horizontal error bars - Start/end time of experimental spectral features.

Vertical error bars - Finite steps in density between simulations.

# Evolution of Local Plasma Density with Time



# Summary

- Compared simulation field spectra at different densities with experimentally obtained spectrograms.
- Chirping ICE may originate from ELMs.
- Obtained sub-microsecond time resolution for local density evolution during the ELM crash.
- ICE suggests an attractive way forward for future energetic ion measurements in the ITER tokamak.

# References

1. G A Cottrell et al, Nucl. Fus., 33, 1365 (1993)
2. S C Cauffman et al, Nucl. Fus., 35, 1597 (1995)
3. J L Posch et al, Journal of Geophysical Research: Space Physics, 120, 8, 6230-6257 (2015)
4. V S Belikov and Ya I Kolesnichenko, Sov Phys Tech Phys 20, 1146 (1976)
5. R O Dendy, C N Lashmore-Davies, K G McClements et al, Phys Plasmas 1, 1918 (1994)
6. S G Thatipamula, G S Yun et al. Plasma Phys. Controlled Fusion 58, 065003 (2016)
7. T D Arber, K Bennett, C S Brady et al, Plasma Phys. Controlled Fusion 57, 1-26 (2015)
8. B. Chapman, R. O. Dendy, K. G. McClements, S. C. Chapman, G. S. Yun, S. G. Thatipamula, and M. H. Kim, Nucl. Fusion. 57, 12 (2017)