Experimental investigation of geodesic acoustic modes on JET using Doppler reflectometry

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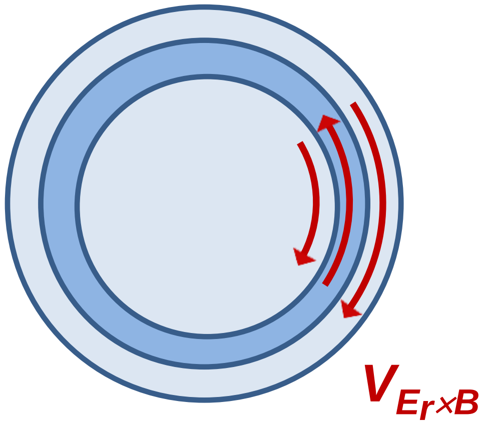
** See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

Geodesic Acoustic Modes

- GAMs are symmetric (n = 0, m = 0) and radially-localized ($k_r \neq 0$) potential structures with $f_{GAM} \propto c_s/R$
- n = 0, m = 1 density and n = 0, m = 2 magnetic structure
- Oscillating $E_r \times B$ flows driven by turbulence
- May play role in triggering the L-H transition
- Strongly damped at low q (exist edge plasma)
- Extensively characterized in different devices



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Background

- Experiment aim: assessing the possible connection between properties of large scale flows (GAMs) and isotope physics
  - Characterize GAMs and local turbulence in H and D plasmas when approaching L-H transition

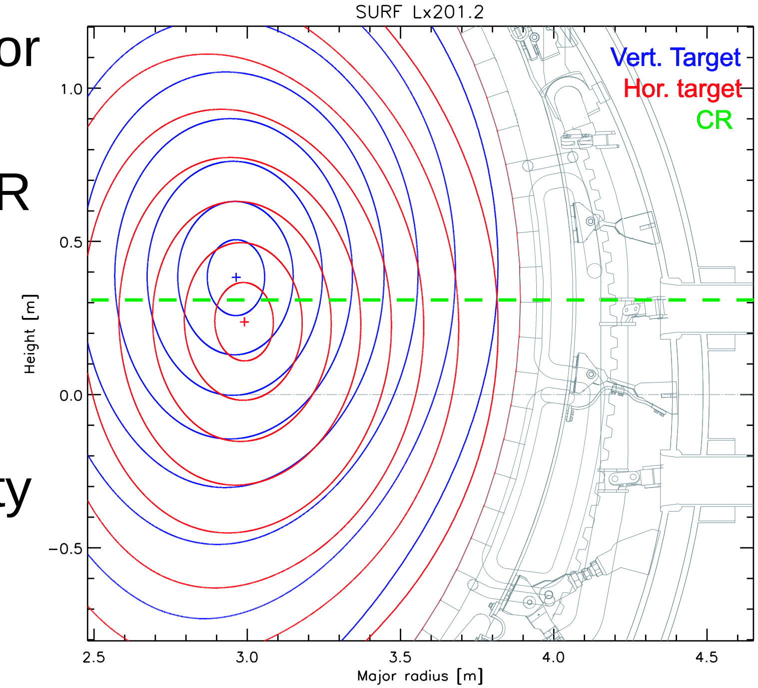
- Characterization performed in hydrogen Ohmic plasmas due to NBI unavailability

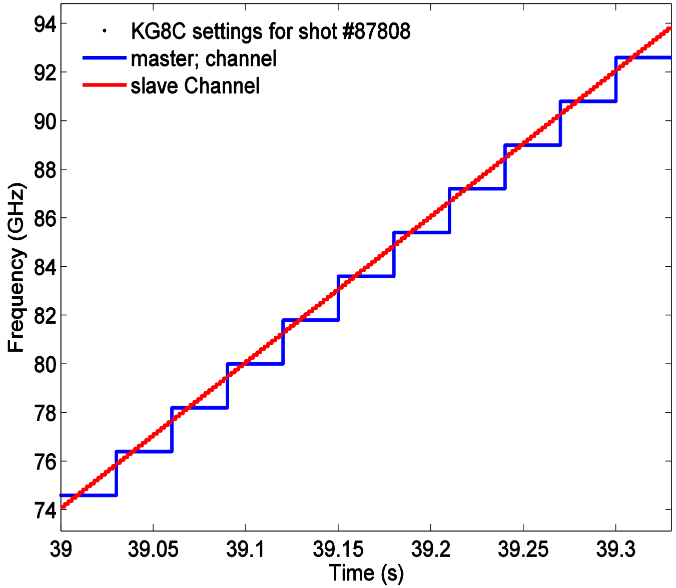
Dataset in H

Pulse	B_T (T)	I_p (MA)	Density (10^{19} m^{-3})
87801	3	2.0	1.5 – 2.4 – 3.2
87802	3	2.5	1.6 – 2.8 – 3.6
87803	3	2.25	1.6 – 2.7 – 3.6
87804	3	1.75	1.5 – 2.6
87805	3	1.5	1.5 – 2.5
87808	3	2.75	2.8 – 3.9

JET radial correlation reflectometer (RCR)

- Radial correlation reflectometer designed for normal incidence
- For the vertical target configuration the RCR works for Doppler reflectometry
- Backscattered signal:
  - Amplitude: density fluctuation level
  - Doppler shift: turbulence lab frame velocity





RCR: two X-mode hopping channels

- **Master**: 11 point frequency sweep (30 ms)
- **Slave**: 15 point each master step (2 ms)
  Full sweep: 330 ms
- Density range (3 T): ~0.7 - 3x10^{19} m^{-3}

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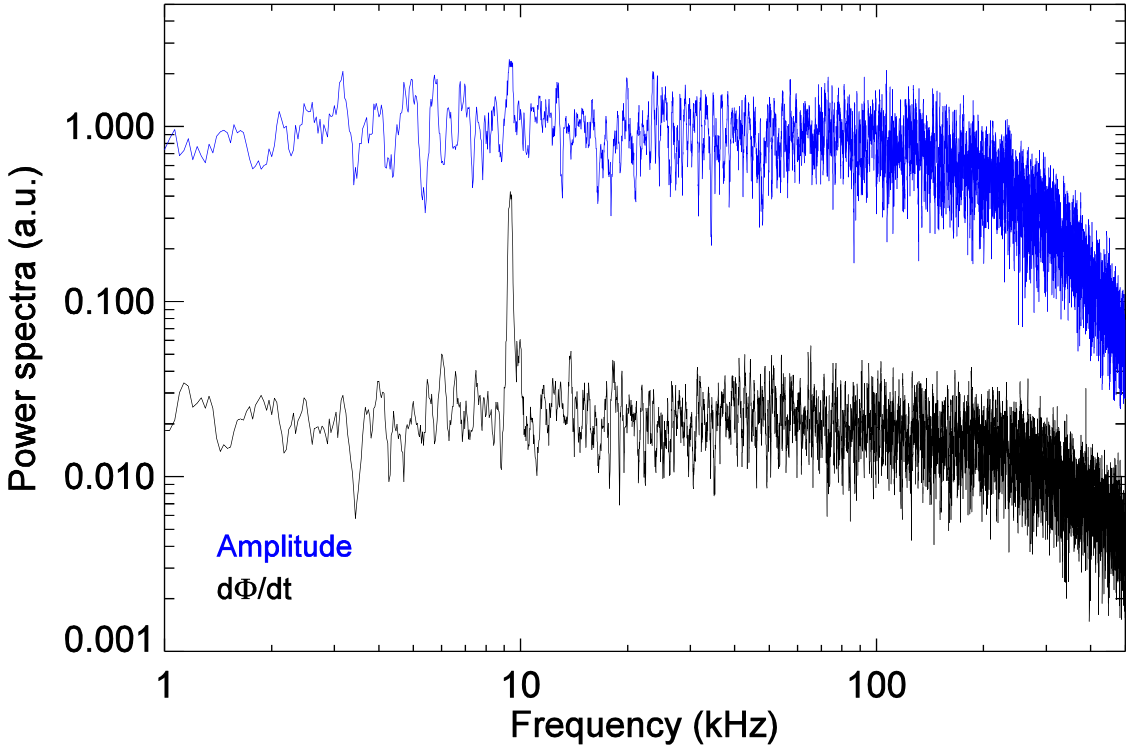
GAM observation with RCR

Signals digitized: I, Q

- $A = \sqrt{(I^2+Q^2)}$
- $\phi = \arctan(Q/I)$
- $\omega_D = d\phi / dt$
- $v_\perp \approx \omega_D / k_\perp$

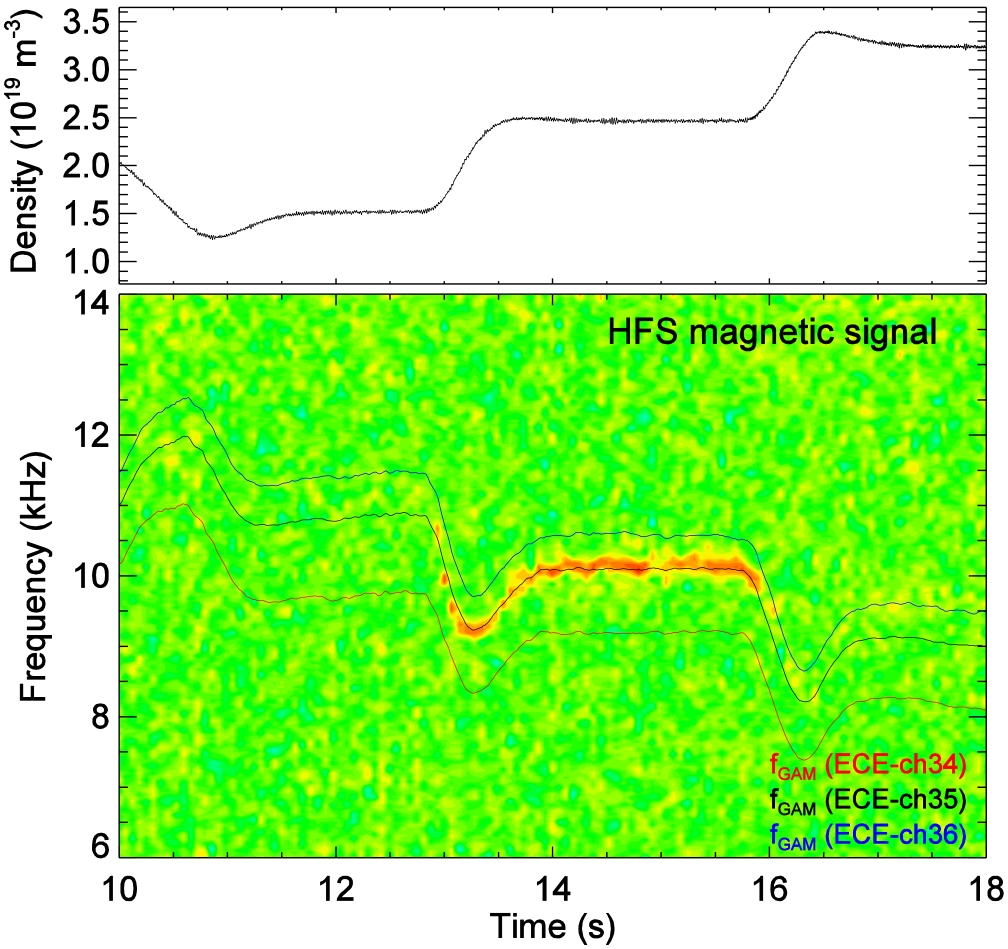
$k_\perp \approx 3$ cm^{-1}(from ray tracing calculations)



GAM peak clearly visible in $d\phi/dt$ at ~10 kHz but not in the amplitude signal

- GAM amplitude ~one order magnitude larger than background

GAM identification on magnetic signals



- GAM peak (~10 kHz) clearly seem magnetic signals mainly at HFS
- m = 2 structure identified
- Frequency follows the local T_e ($f_{GAM} = c_s/2\pi R$, $T_i = T_e$, $\gamma_i = 1$)
- Narrow frequency peak ($\Delta f<0.5$ kHz) suggesting either very localized mode or constant frequency across mode

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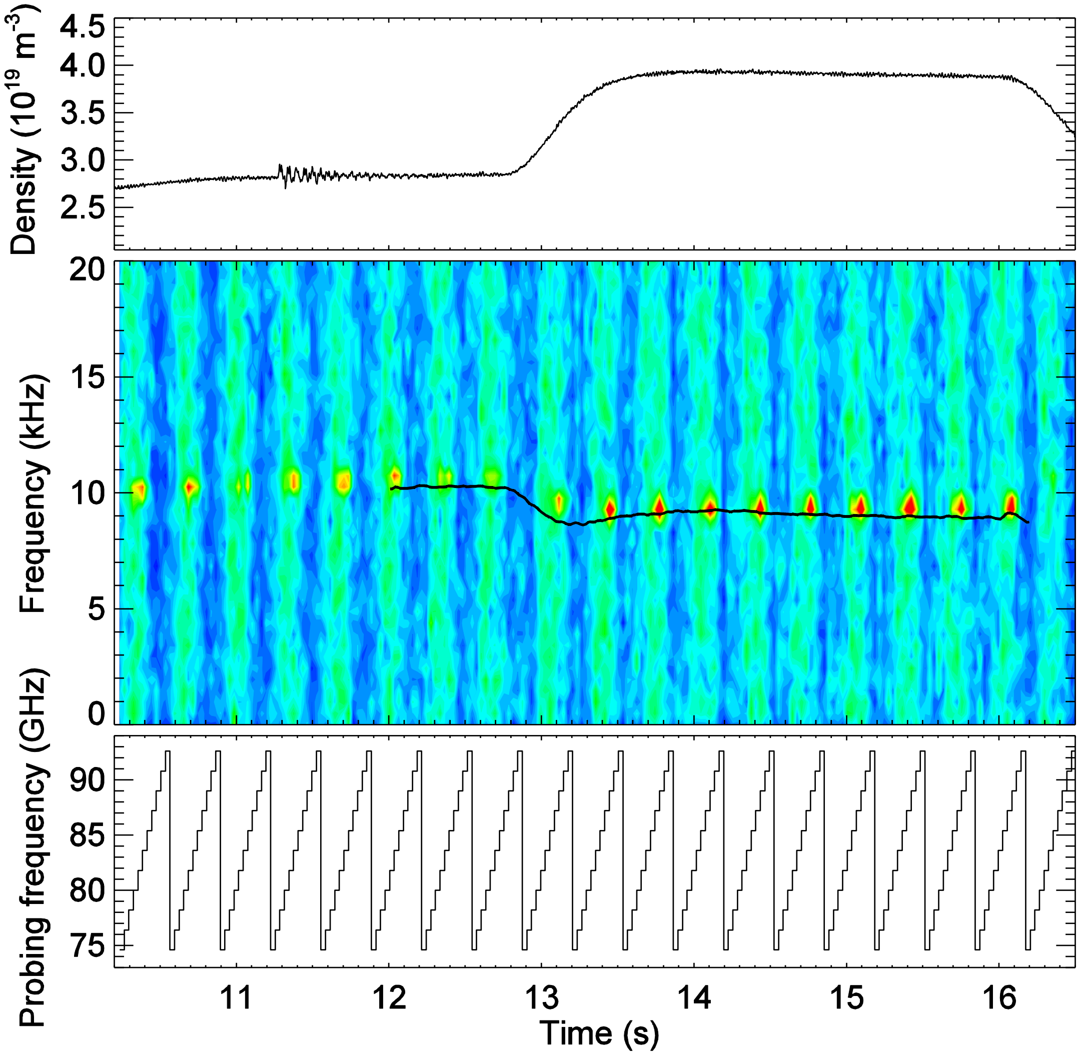
GAM evolution with RCR



- GAM clearly observed in $d\phi/dt$ signal
- Frequency depends on local temperature
- GAM amplitude:
  - $|FFT(d\phi/dt)|$
  - rms of $d\phi/dt$ bandpass filtered (f_{GAM})

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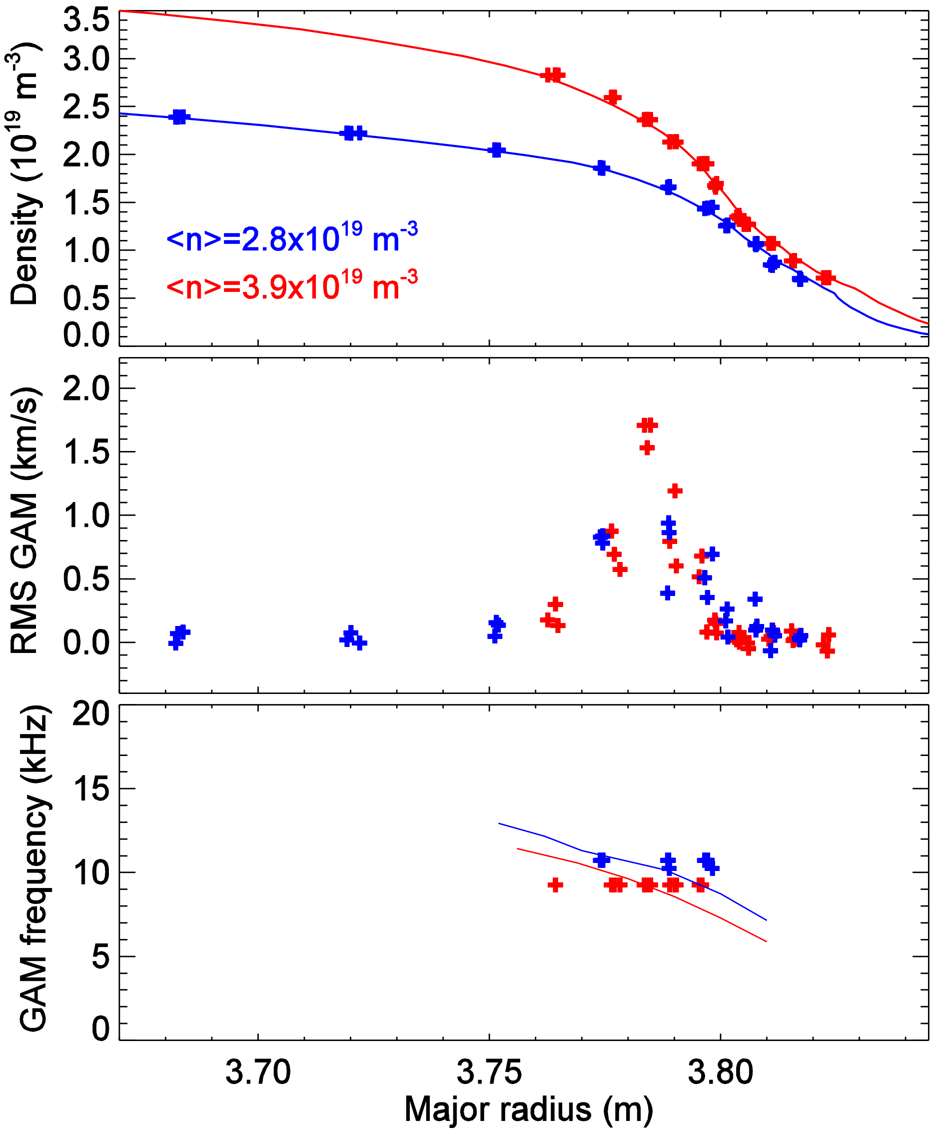
GAM localization and amplitude



- Profile reflectometer used to determine RCR radial measurement location
- GAM located at the edge density gradient region in a narrow layer of ~ 2 cm
- GAM frequency roughly constant with radius
- Larger f_{GAM} radial variation expected from T_e profile

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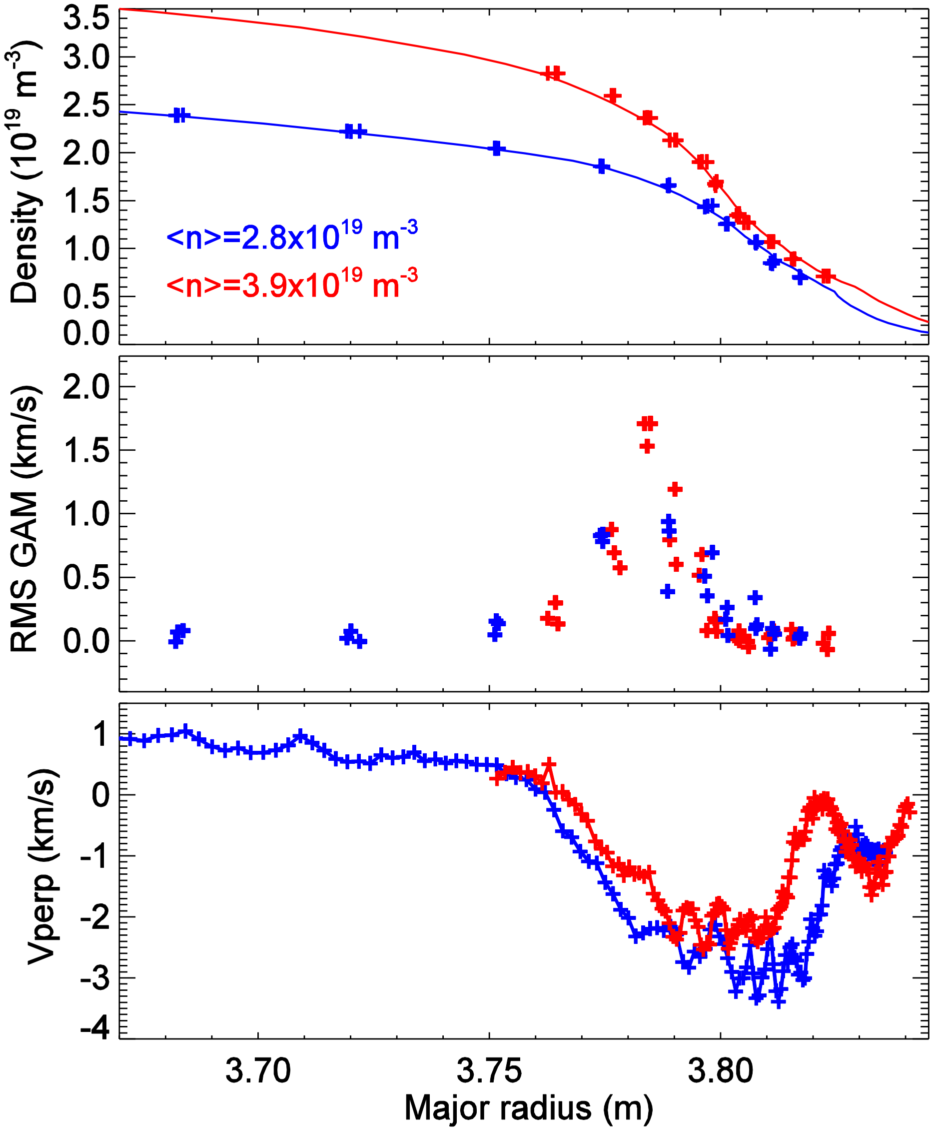
GAM localization and amplitude



- Mean $v_\perp$ also determined from Doppler reflectometer
- GAM located in the E_r well with amplitude up to 50% of mean $v_\perp$
- Similar to AUG/DIII-D observations
- Amplitude and width of the GAM region and E_r well depends on the density

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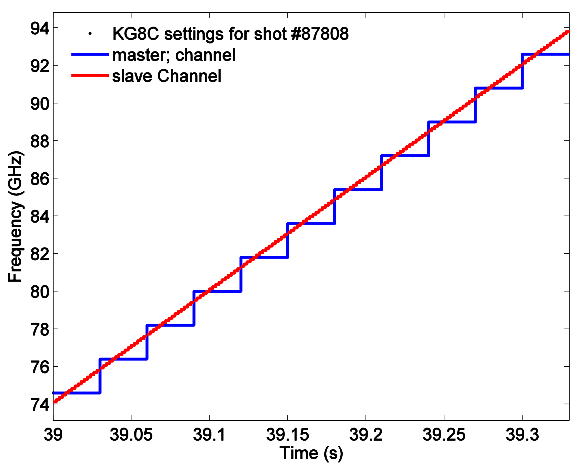
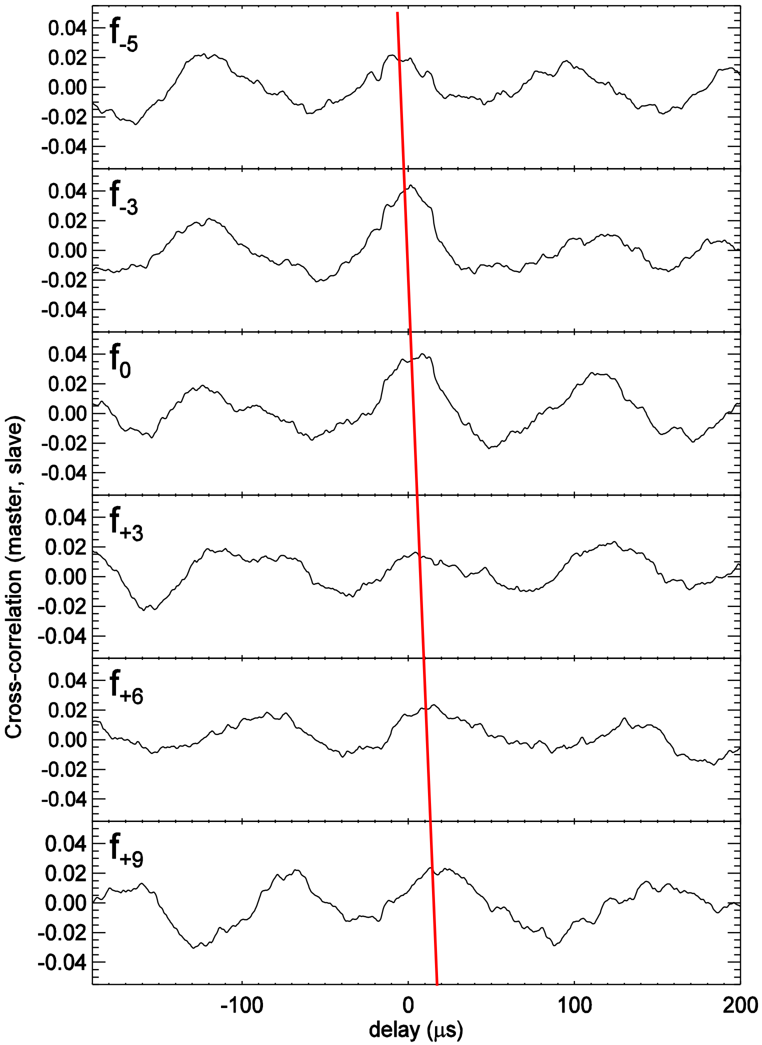
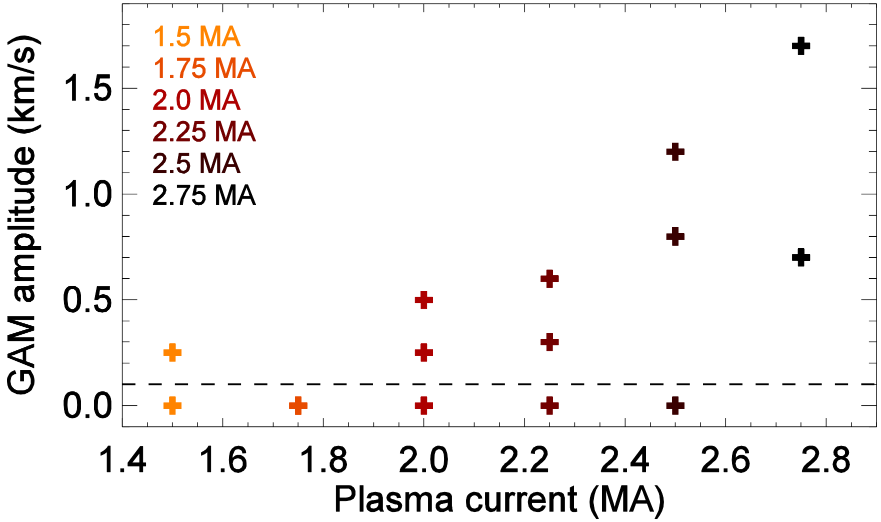
GAM radial structure

- Correlation between master and slave signals used to determine radial structure
- Delay ~20 μs across slave freq: ~$T_{GAM}/5$
- Slave sweep covers ~0.5 cm radially ⇒ $\lambda_r \approx 2.5$ cm
- Radial wavelength >~ dimension of GAM existence region





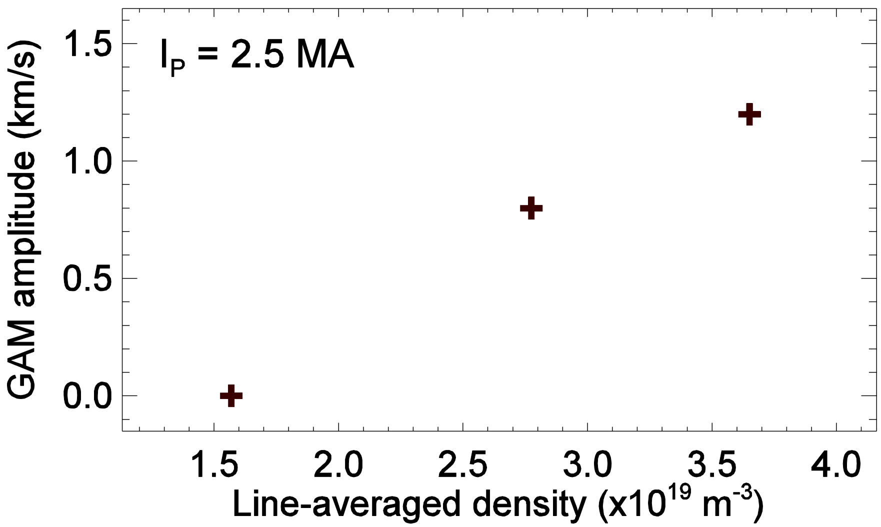
GAM dependence on plasma current and density

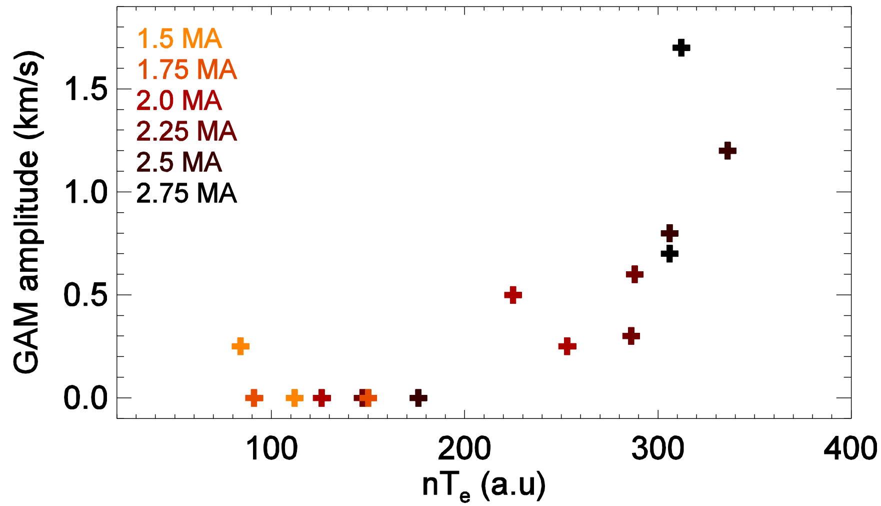


Dataset (H): $1.5 < I_p < 2.75$ MA, $1.5 < n < 4{\times}10^{19}$ m^{-3}

GAM amplitude

- ❑ Increases with I_p and n (at high I_p)
- ❑ Depends on the edge pressure





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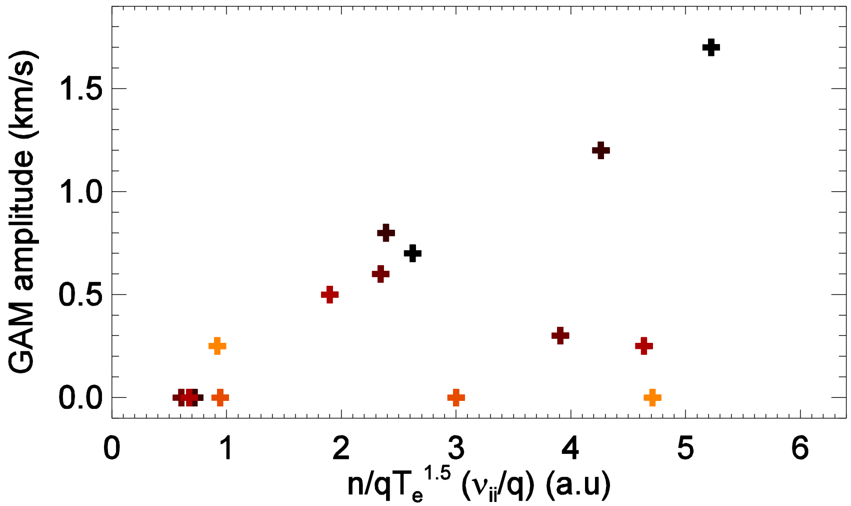
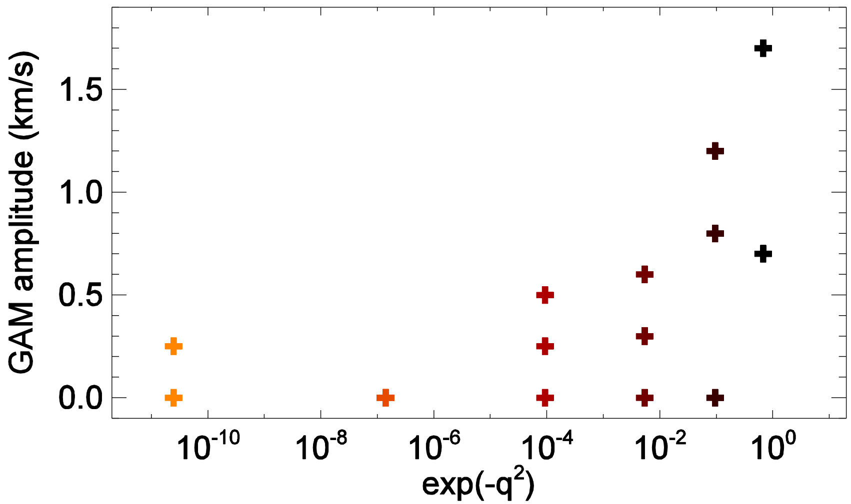
GAM damping rate

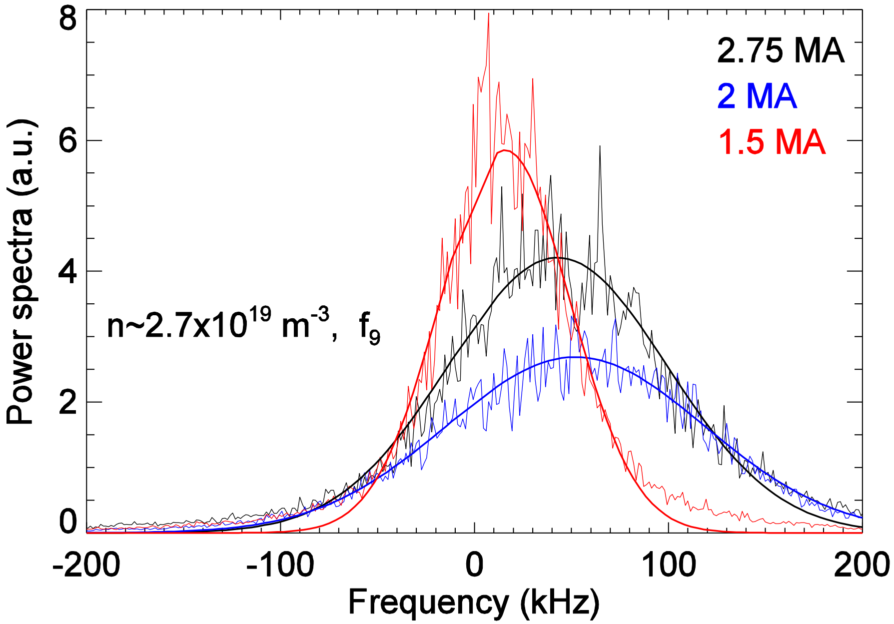


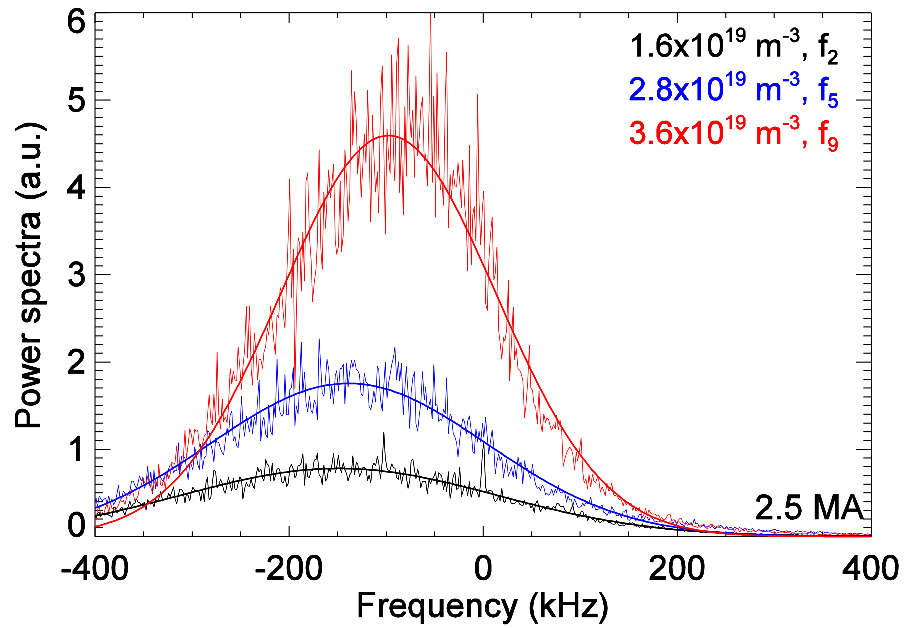


A_{GAM} determined by its drive and damping mechanisms

- Collisionless damping rate: $\gamma \sim \exp(-q^2)$
  Collisional damping rate: $\gamma \sim \nu_{ii}/q$
- A_{GAM} increases with both $\exp(-q^2)$ and ν_{ii}/q in disagreement with theory
- GAM amplitude not determined by its damping rate

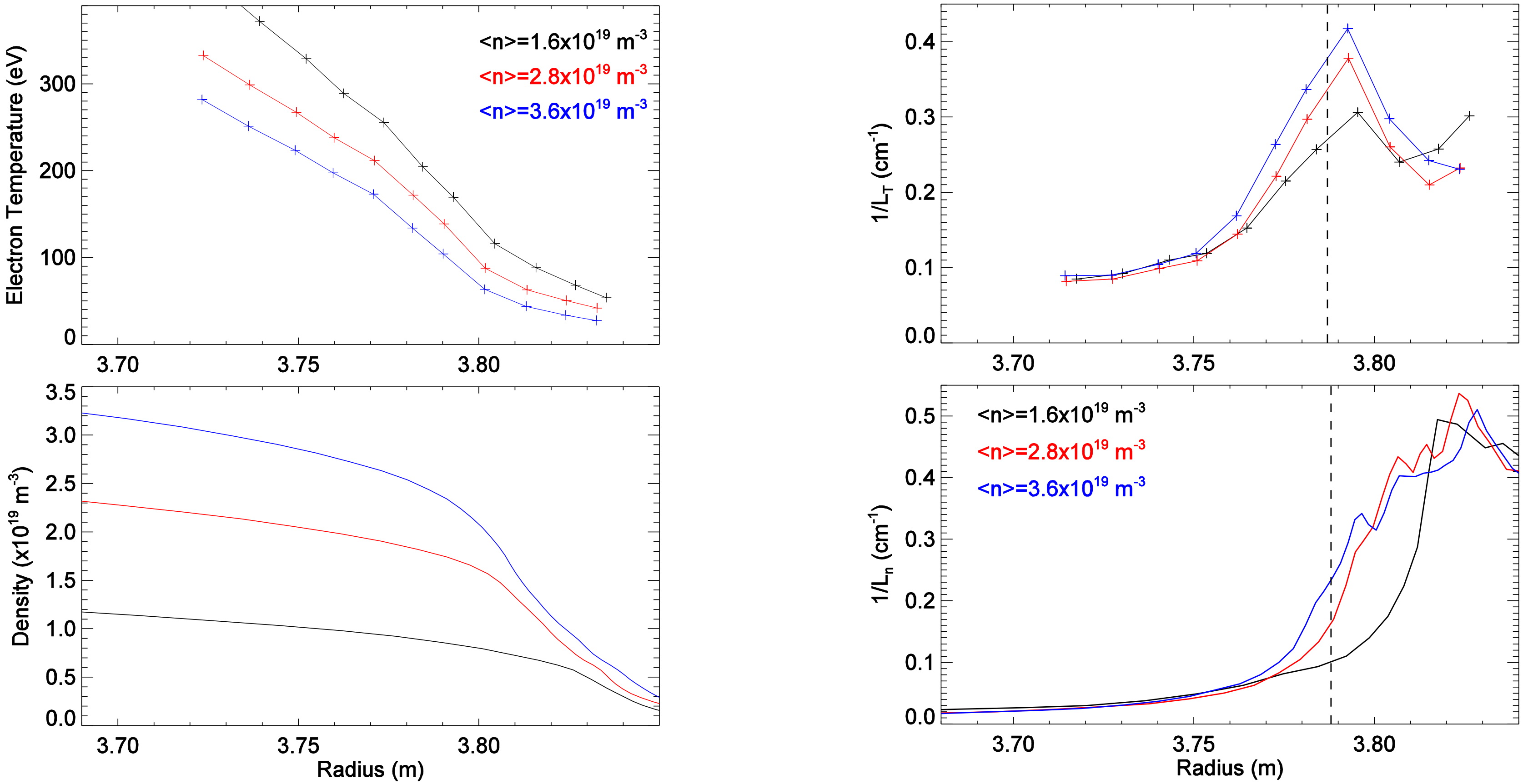
GAM drive: turbulence – density fluctuations





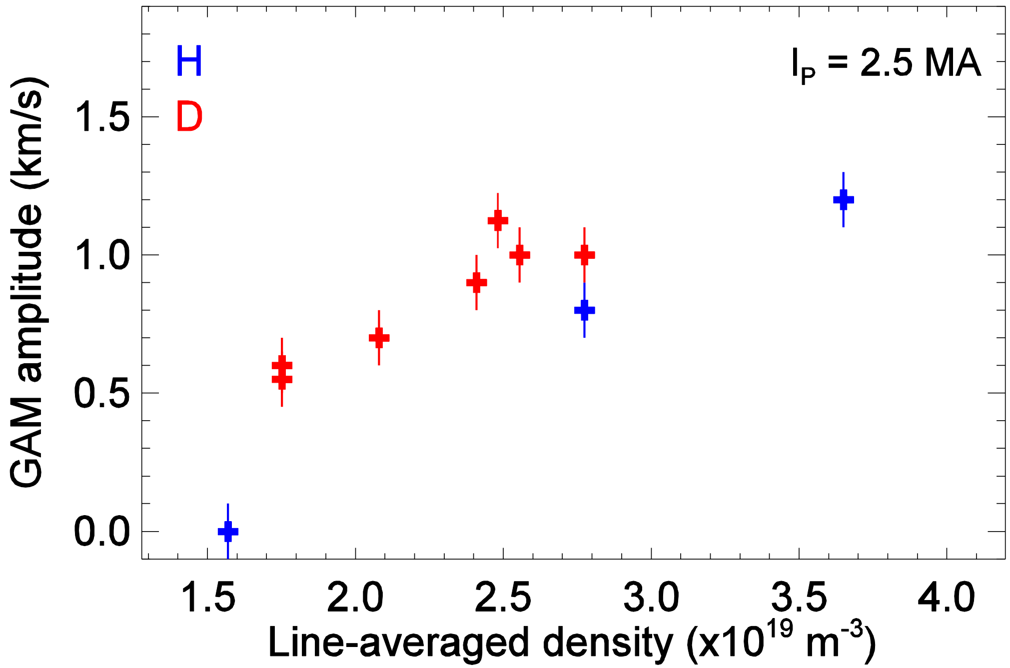
- Density fluctuations $\propto$ amplitude backscattered signal
- Fluctuations increase with <n> and I_p, similarly to the GAM amplitude dependence

GAM drive: turbulence – scale length



- **Density dependence:** T_e and n inverse scale length increase with <n> in the GAM region, indicating an increase in the turbulence drive (in agreement with the larger GAM amplitude)

Isotopic effect



- GAM amplitude is apparently larger for D plasmas but complex dependence on plasma parameters prevents a more definitive conclusion
- Consistent with results on TEXTOR, FT-2, TJ-II and ISTTOK supporting a multi-scale mechanism to explain the isotope effect

Summary

- GAMs investigated JET edge plasma using Doppler reflectometry
- GAM clearly observed with RCR and magnetics, located edge density gradient region in a narrow layer with frequency radially constant
- GAM amplitude up to 50% of the mean E_r
- A_{GAM} in agreement with turbulence drive but not with theoretical damping rate
- A_{GAM} is apparently larger for D plasmas but complex dependence on plasma parameters prevents a more definitive conclusion

Outlook

- Explore the importance of GAMs when approaching L-H transition