Structure and scaling of GAMs in TCV

Z. Huang, S. Coda, G. Merlo, C.A. de Meijere,
J.P. Graves, S. Brunner, M. Fontana, L. Porte,
L. Vermare[1], L. Villard, C. Wahlberg[2],
J. Dominski, P. Hennequin[1], A. Krämer-Flecken[3]

[1]LPP, CNRS-Ecole Polytechnique, Palaiseau, France

[2]Uppsala University, Sweden

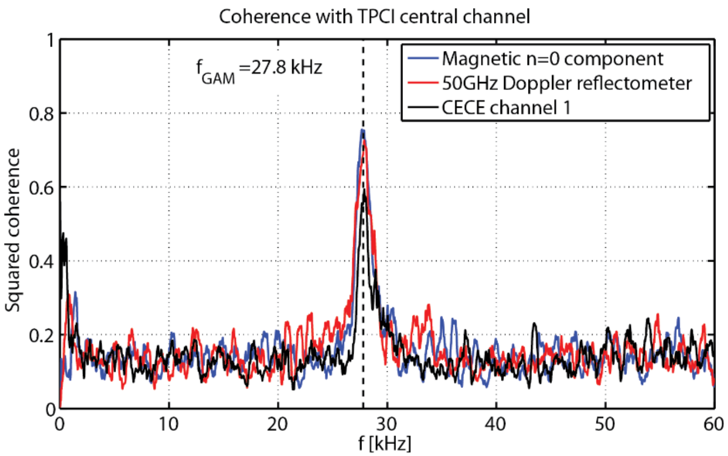
[3]Forschungszentrum Jülich, Germany

Outline

- Introduction
- Multi-diagnostic characterization
  - Tangential phase contrast imaging
    - Radial structure
    - Eigenmode and multimode regimes
  - Mirnov coil: Poloidal and toroidal structure
  - Doppler backscattering
  - Correlation ECE
- Parametric studies for GAM drive and damping
- Summary and outlook

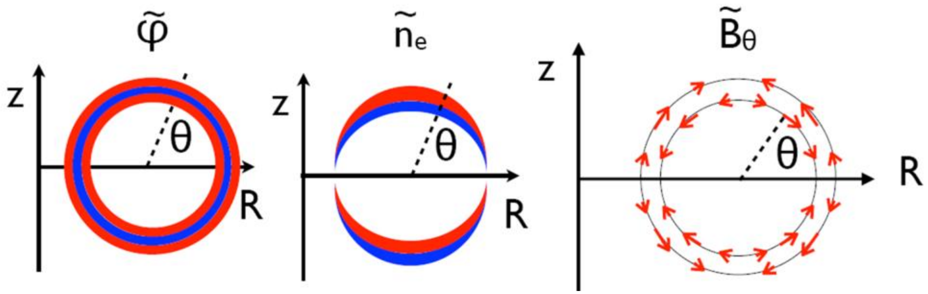
GAMs on TCV

- Unique, correlated multi-diagnostic observation with full determination of 3D wave number, frequency and spatial distribution
  - E×B flow – **Doppler backscattering**
  - Density – **Tangential phase contrast imaging**
  - Magnetic field – **Mirnov coils**
  - Temperature – **Correlation ECE**



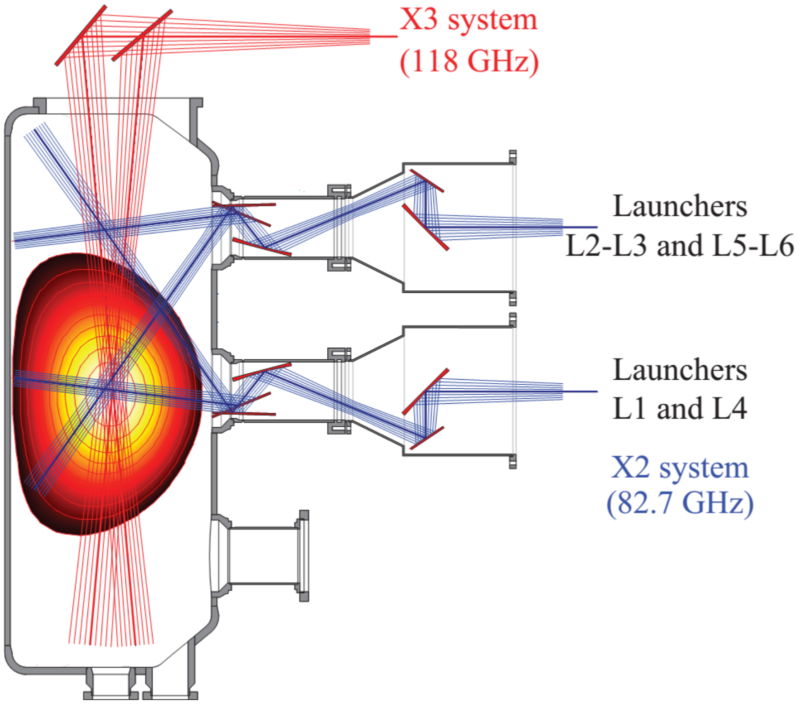
Finite frequency $\omega_{\mathrm{GAM}} \propto c_s/R$

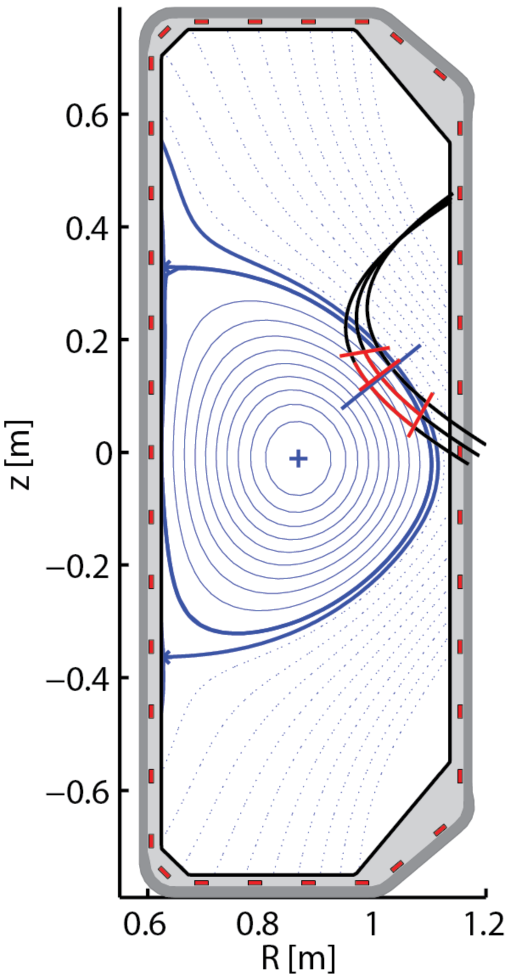
- m=0, n=0 $\widetilde{E_r}$ (& flow) component
- m=1, n=0 $\tilde{n}$ component ($\propto \sin\theta$)
- m=2, n=0 $\widetilde{B_\perp}$ component ($\propto \sin 2\theta$)



The TCV tokamak

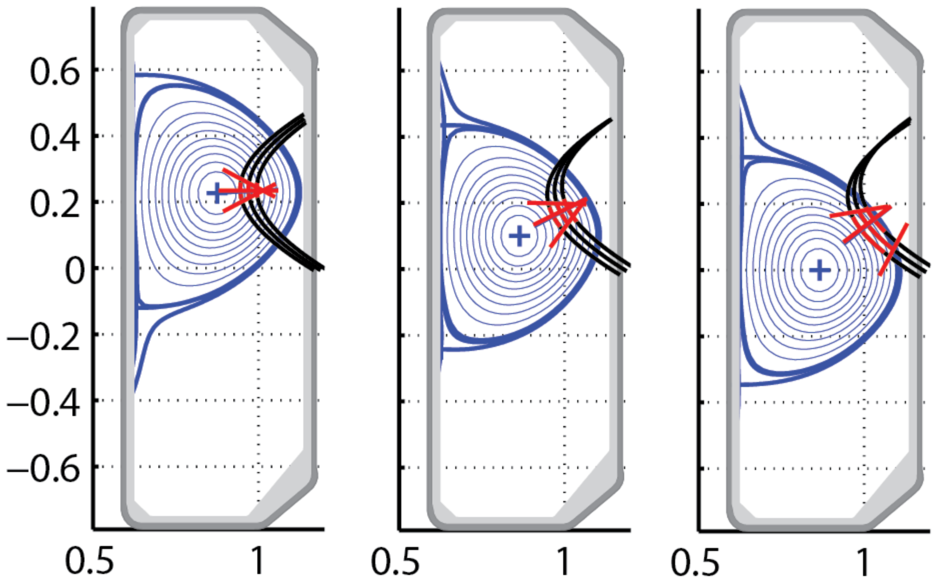
- High flexibility of plasma shape and divertor configurations.
- Strong EC heating and current drive.

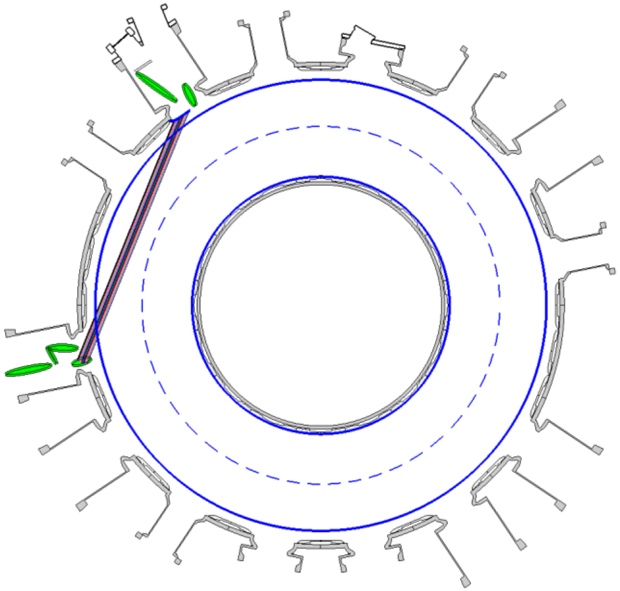




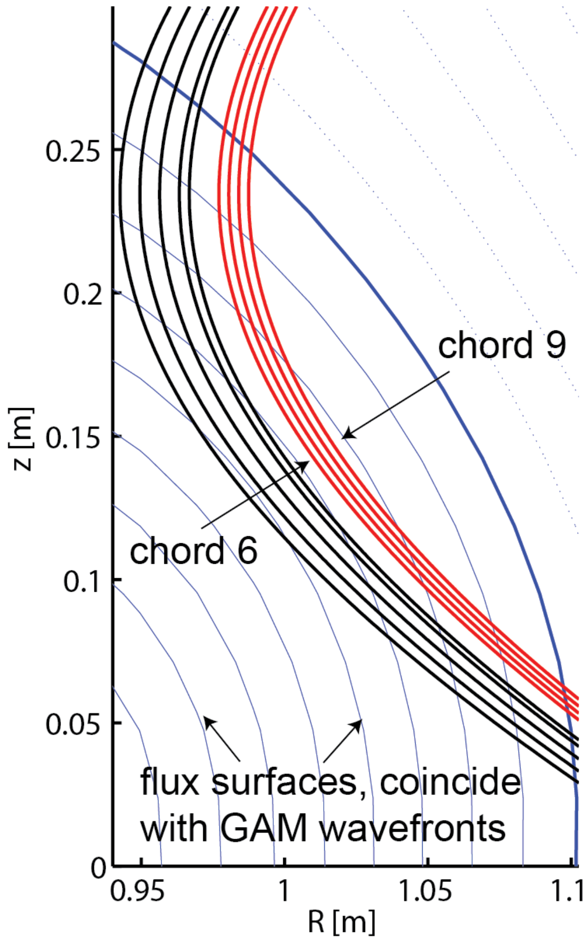
Tangential phase contrast imaging (TPCI)

- Density fluctuation measurement
- $1\ \mathrm{cm}^{-1} < k < 9\ \mathrm{cm}^{-1}$; $1.5\ \mathrm{MHz}$ bandwidth
- Signal for $\tilde{n}$ with radial $\vec{k}$ comes from tangency point
- Scan ρ by moving plasma vertically





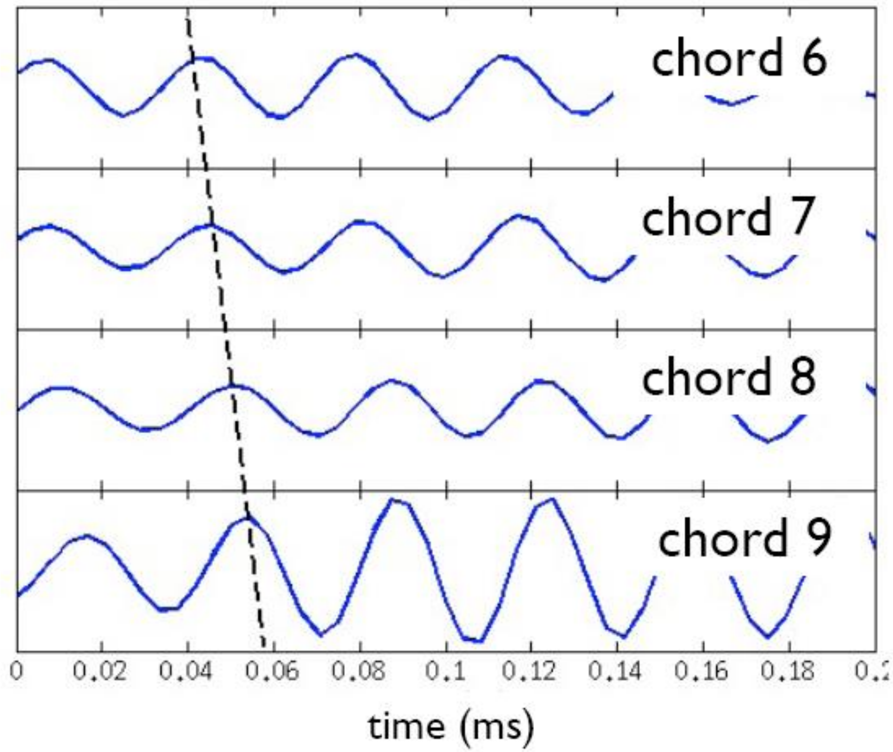
GAM spatial distribution and radial wavenumber



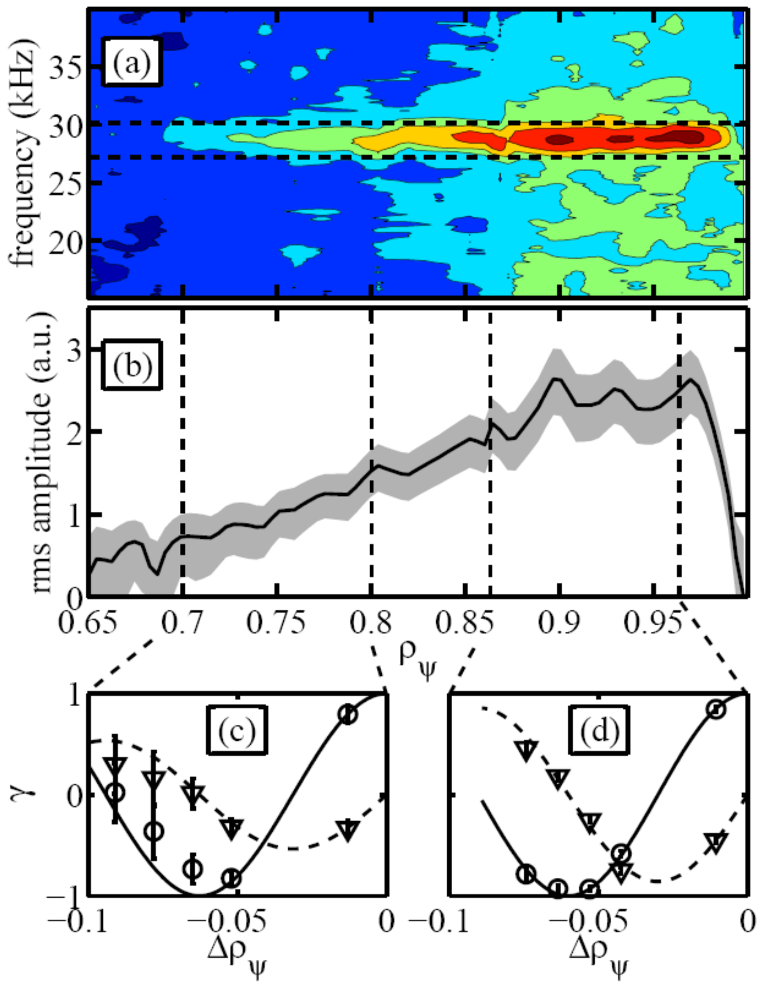
Mainly outward propagating

$k_\rho \sim 1.7 - 2.1\ \mathrm{cm}^{-1}$

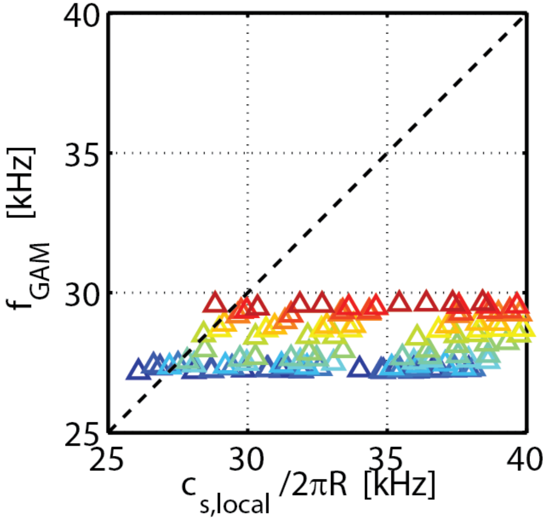
$k\rho_s \sim 0.4 - 0.5$



GAM eigenmode

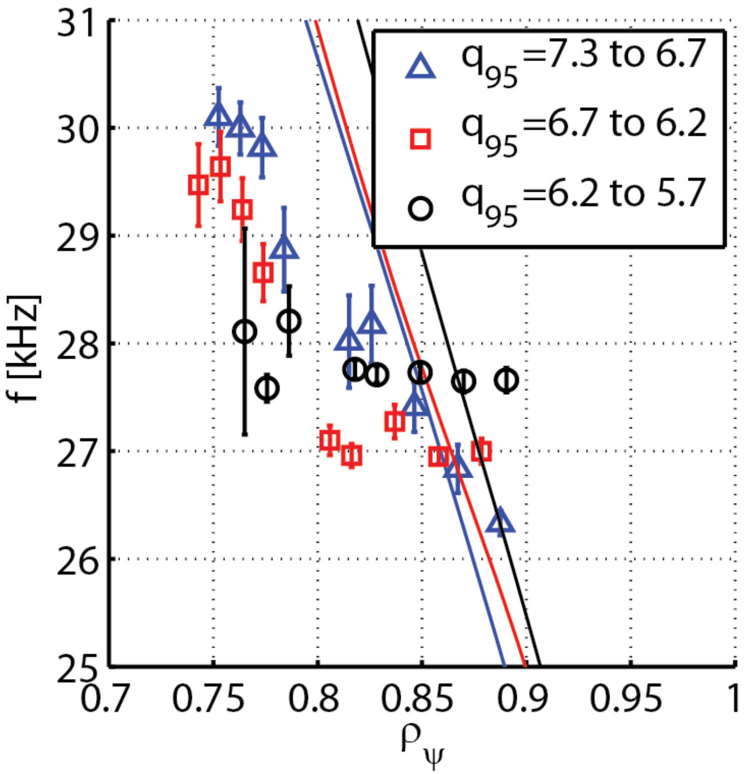


- Local GAM frequency doesn't depend on local T_e, however it still roughly follows the scaling law when changing T_e globally.



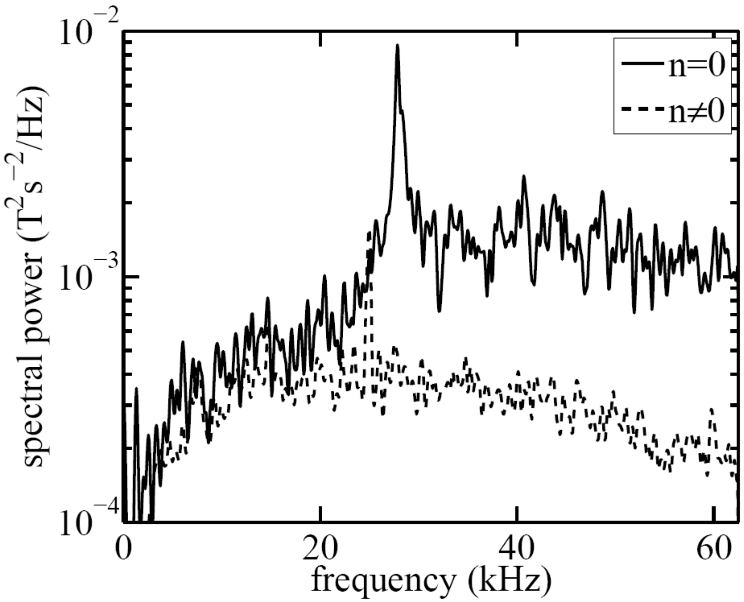
Global eigenmode vs multimode regimes

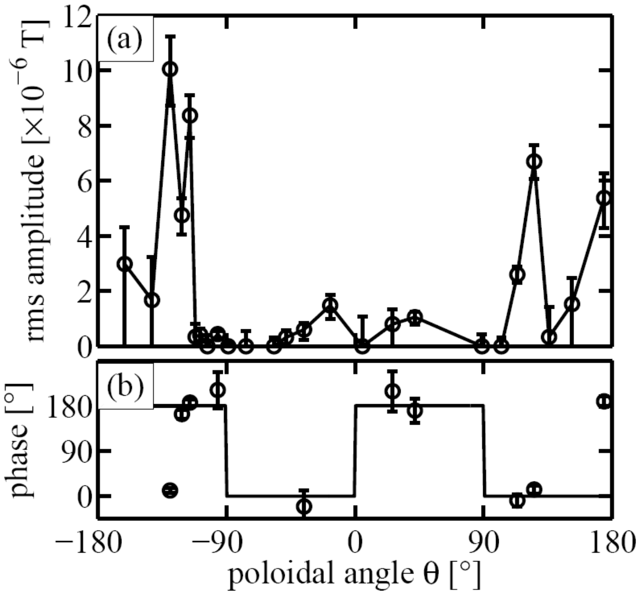
- Eigenmode more commonly observed in TCV (limited plasma only)
- Multimode observed in both divertor and limiter shots, mainly with high safety factor.
- Transition observed in a single q-scan shot, however also with a divertor-limiter transition.
- Fundamental cause of the transition is not yet conclusively known.



Strong magnetic component in GAM eigenmode

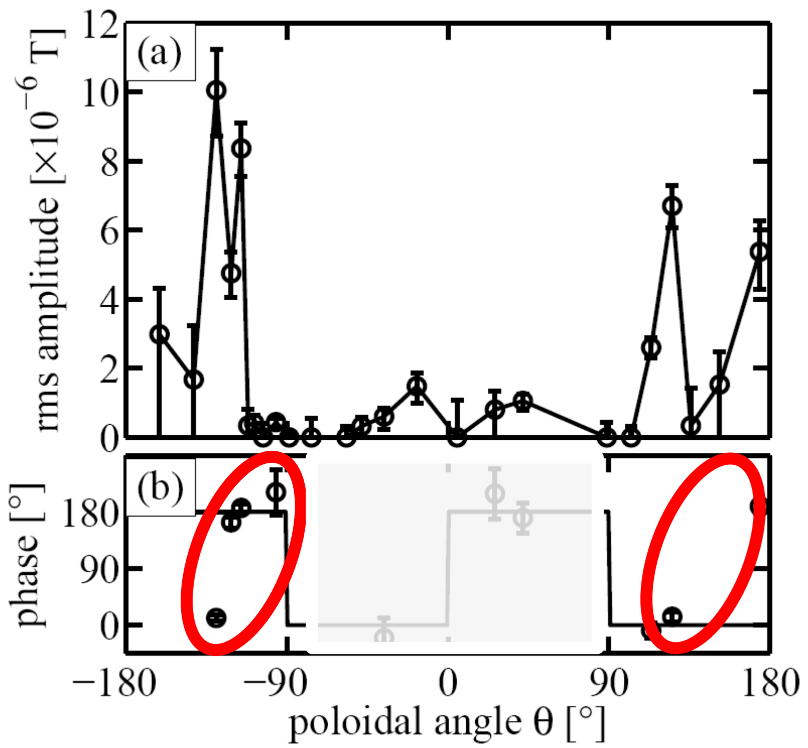
- The single-frequency global GAM eigenmode over a large radial region results a strong magnetic component
- n=0, axisymmetric; m=2 standing wave as predicted by theory and GENE simulation



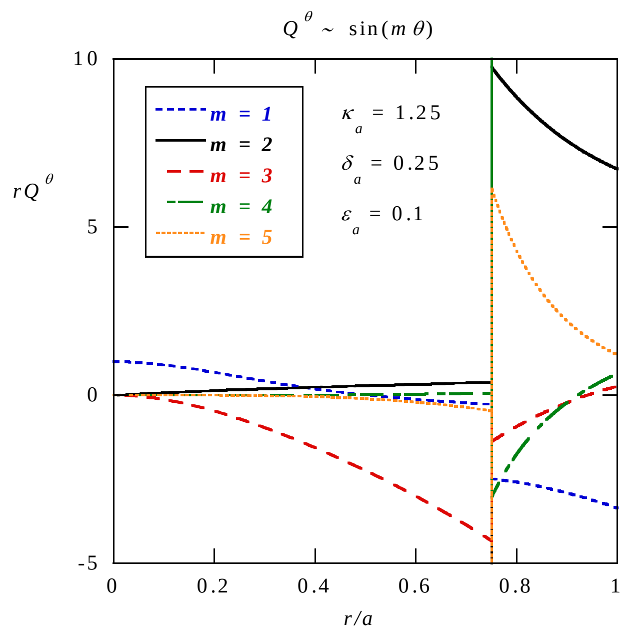


Poloidal mode structure of GAM magnetic component

- HFS phasing indicates presence of m>2 components

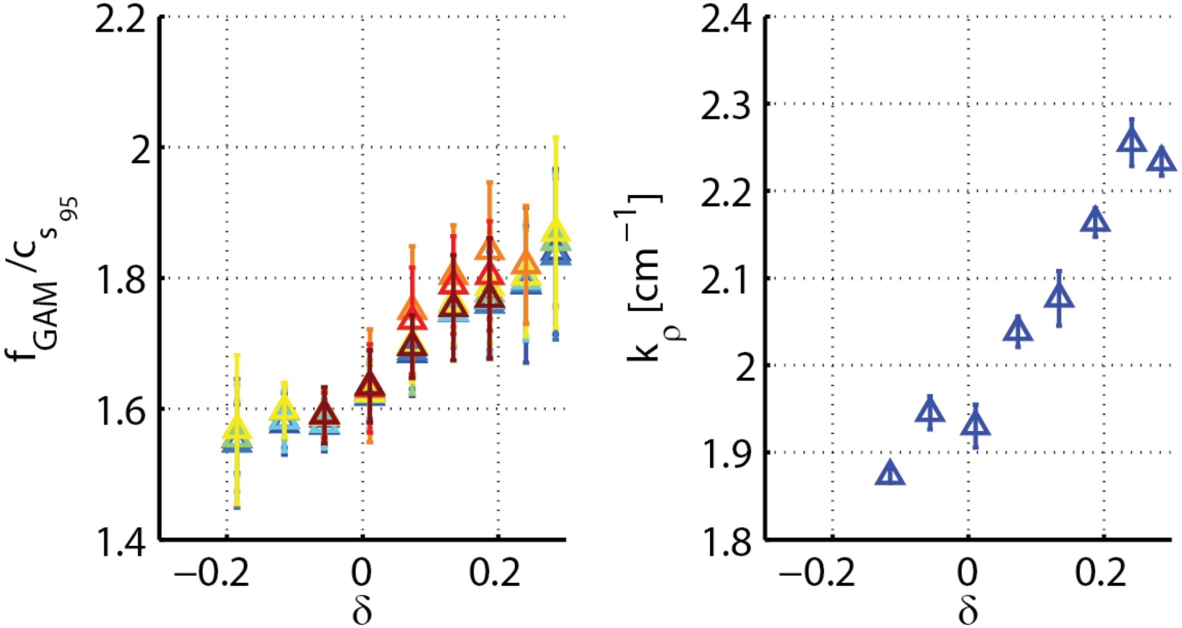


- MHD model extension to non-circular plasma predicts additional poloidal modes



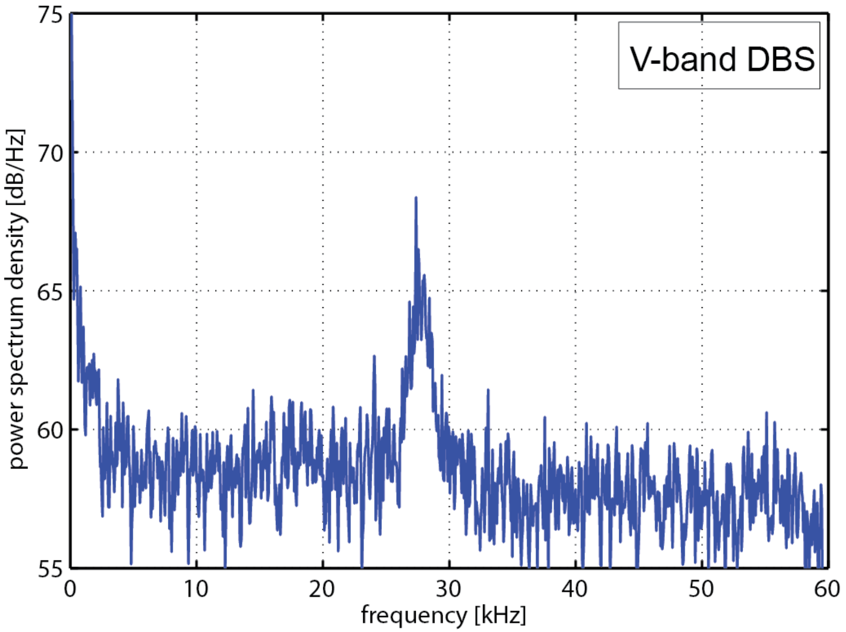
GAM dependence on triangularity

- No magnetic component observed for $\delta < 0$
- $\tilde{n}$ component can be observed till $\delta > -0.2$
- Frequency and wavenumber both increases with triangularity.



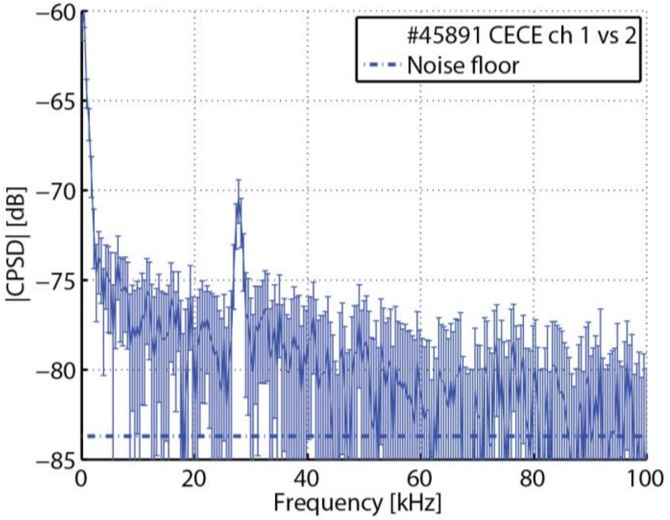
Electric field and E×B flow component by DBS

- Oscillating E×B flow observed by Doppler backscattering in the edge region.
- GAM flow ~0.7 km/s rms (background flow ~2 km/s)



GAM also observed by C-ECE

- A few puzzles remain:
  - $k_\rho \sim 1.7 - 2.1\ \mathrm{cm}^{-1}$ for TPCI (mainly above midplane); $k_\rho \sim 0.9\ \mathrm{cm}^{-1}$ for C-ECE (near midplane).
    - GENE simulation: $\widetilde{T_e}$ with m=0 + m=1, antinode on midplane.
  - Predominantly outward-propagating on TPCI; Propagation direction depends on location on C-ECE.

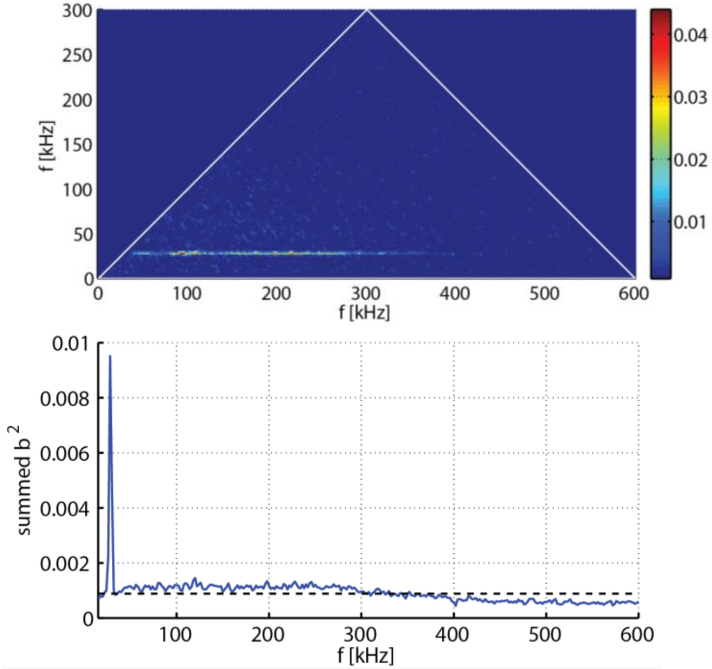


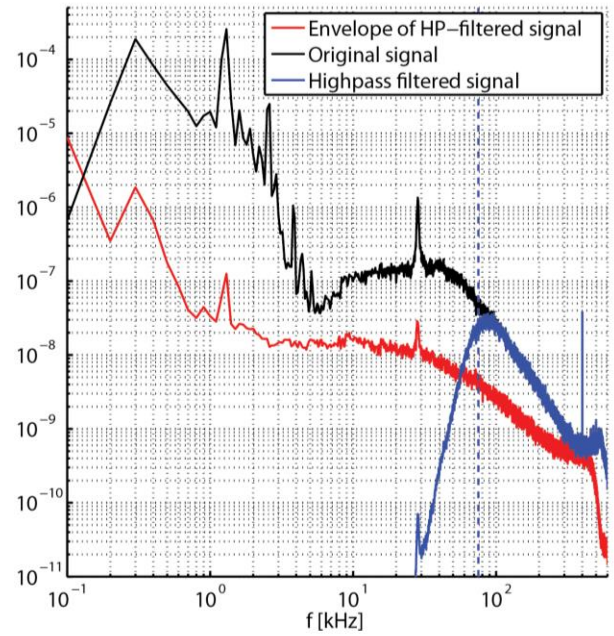
Plasma is invariably optically thin (τ<0.5):

ECE measurement is unknown mix of T_e and n_e fluctuations

GAM-turbulence interactions

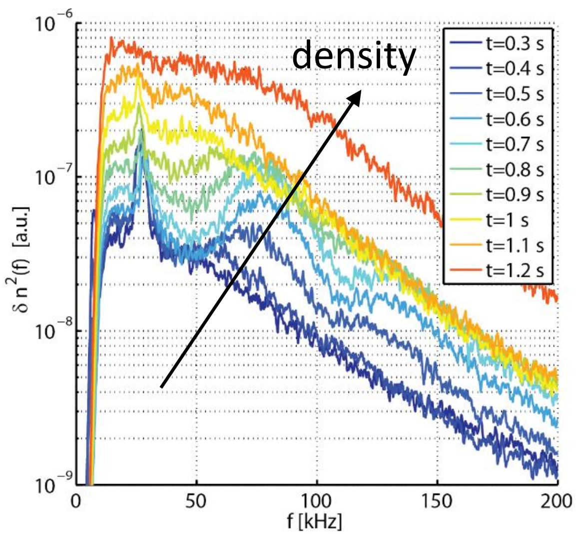
- GAM as a branch of zonal flow, is driven by nonlinear interactions of turbulence, and modulates turbulence.
- Bicoherence and envelope analysis proves nonlinear coupling between GAM and turbulence.

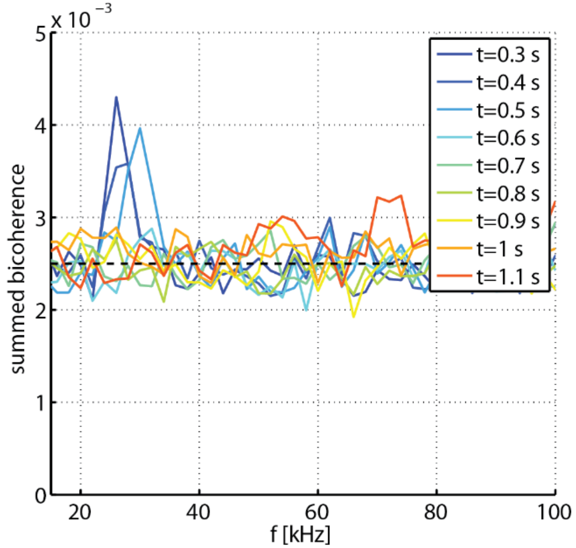




Drive and damping: dependence on n

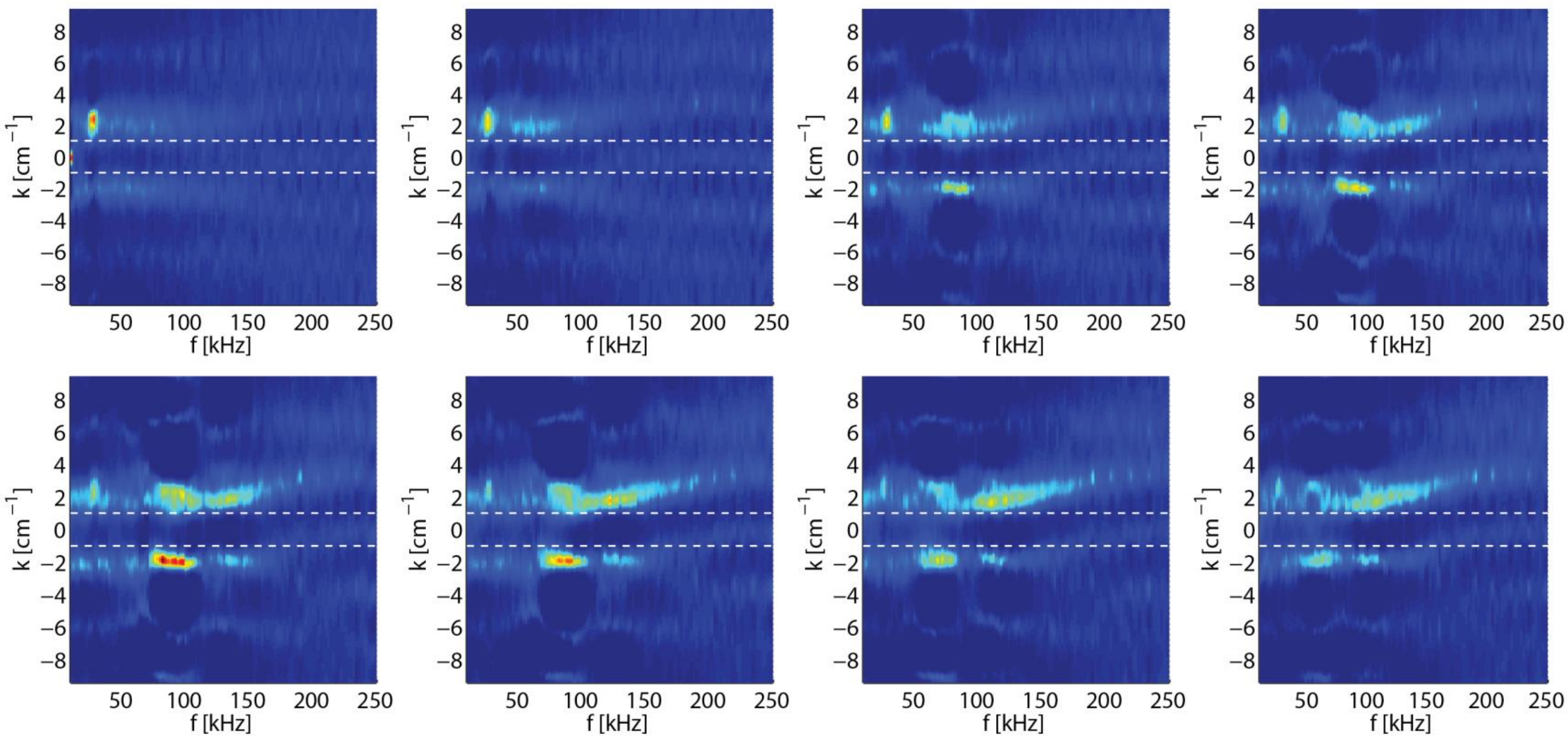
- Ohmic density ramp-up: increase in background turbulence but GAM ~constant
- A quasi-coherent mode (QCM) at $70-110$ kHz is visible from 0.5 to 0.9 s.
- Bicoherence is above noise level only from 0.3-0.6 s





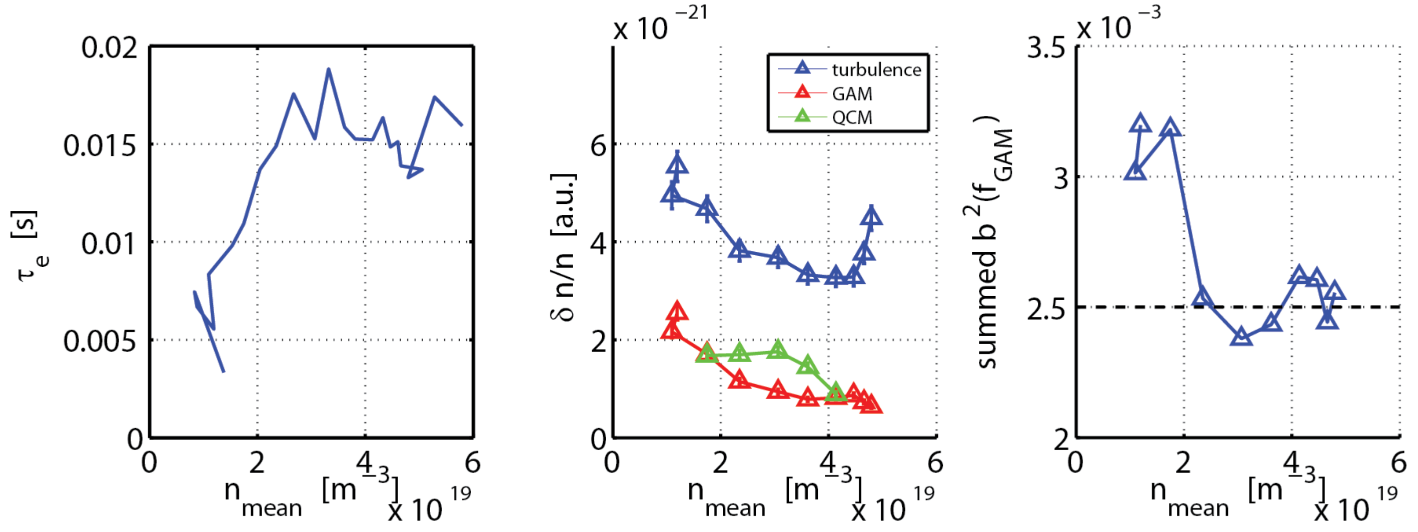
Drive and damping: dependence on n

- The quasi-coherent mode has opposite propagating direction to the GAM



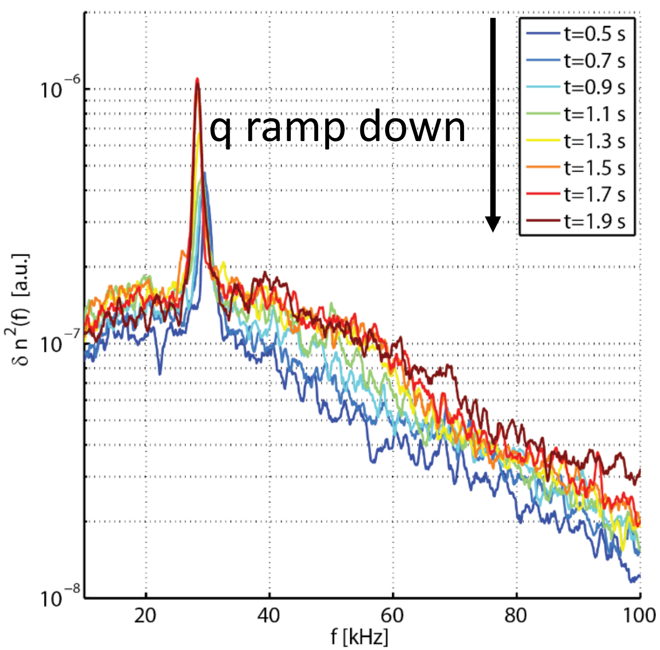
Drive and damping: dependence on n

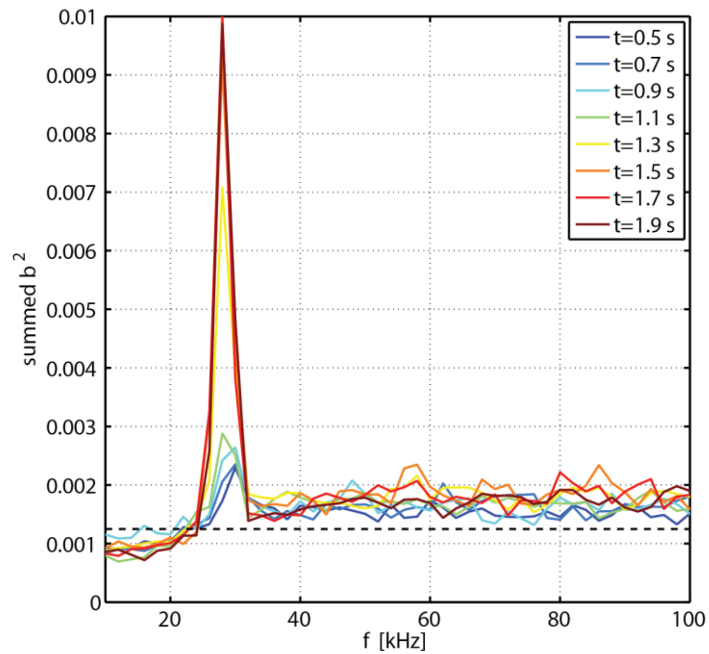
- Relative fluctuation level: turbulence has modest excursion (LOC-SOC evolution), the transition time is about when bicoherence falls to noise level.
- QCM arises before the LOC-SOC transition, disappears before the phase when $\delta n/n$ increases with n.



Drive and damping: dependence on q

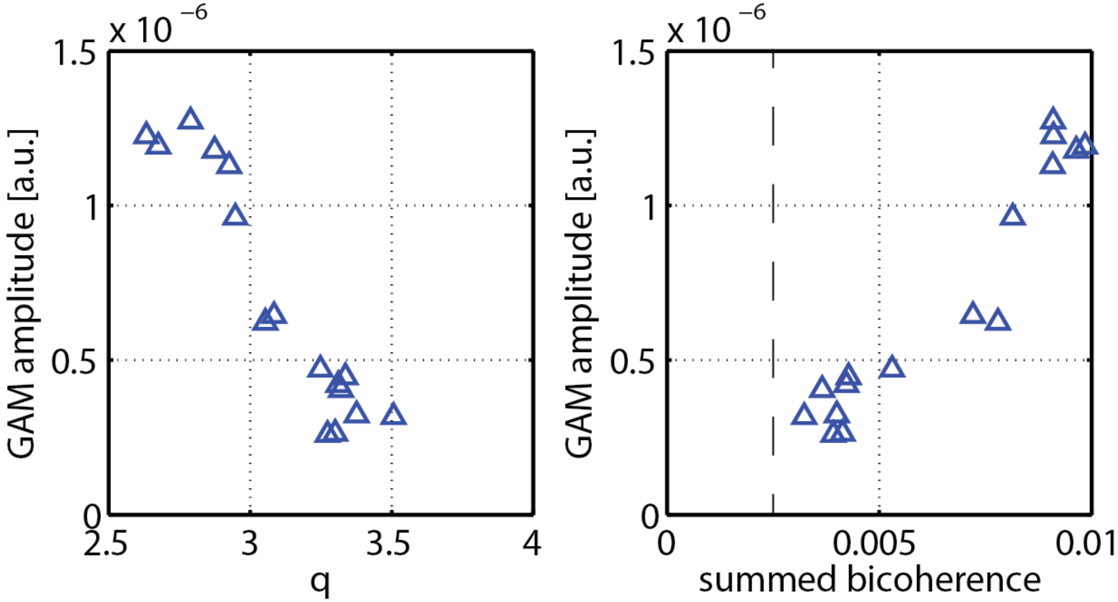
- In some q scan shot, GAM remains an eigenmode.
- q ramp down, GAM becomes stronger.





Drive and damping: dependence on q

- GAM amplitude increases when q is ramping down, opposite to increased Landau damping
- Summed-bicoherence at GAM frequency increases, suggests a trend of stronger drive from turbulence.



Summary

- Initial study on TCV has revealed GAM in density, magnetic-field, flow and ECE radiative temperature fields
- First multi-probe analysis of magnetic component has clearly confirmed axisymmetry
- Frequency, 3D wave number, radial profile have all been measured
- Bicoherence and envelope analysis proves GAM-turbulence nonlinear coupling

Outlook

- Dedicated parameter and location scans with multiple diagnostics
- Better diagnostics:
  - Fully commissioned TPCI,
  - C-ECE using movable antenna
  - Toroidal Mirnov coil array on and off axis
- Additional gyrokinetic modelling runs (parametric studies) + synthetic diagnostics