APS Advancing Physics

76th Annual Meeting of the Division of Fluid Dynamics

Correlating hydrodynamic and acoustic fields in a turbulent combustor through community-based dimensionality reduction of vortical networks

November 21, 2023

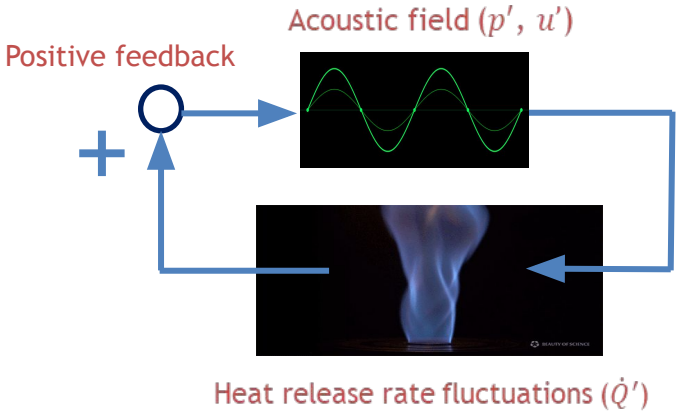
Ankit Sahay[1,2], **Murali Gopalakrishnan Meena**[3], R. I. Sujith[1,2]

[1]Centre of Excellence for Critical Transitions in Complex Systems, IIT Madras, India
[2]Department of Aerospace Engineering, IIT Madras, India
[3]Oak Ridge National Laboratory, USA

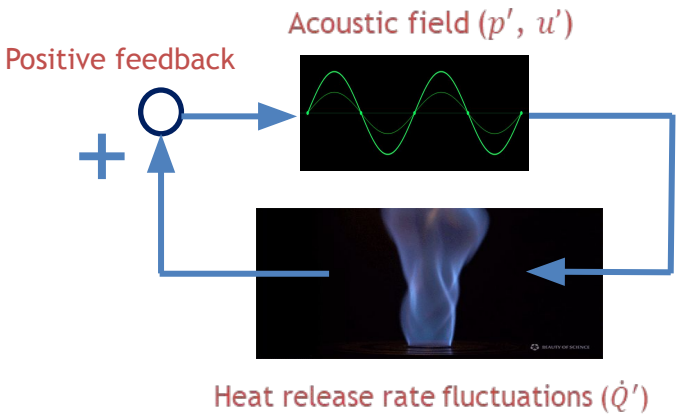
Acknowledgement:

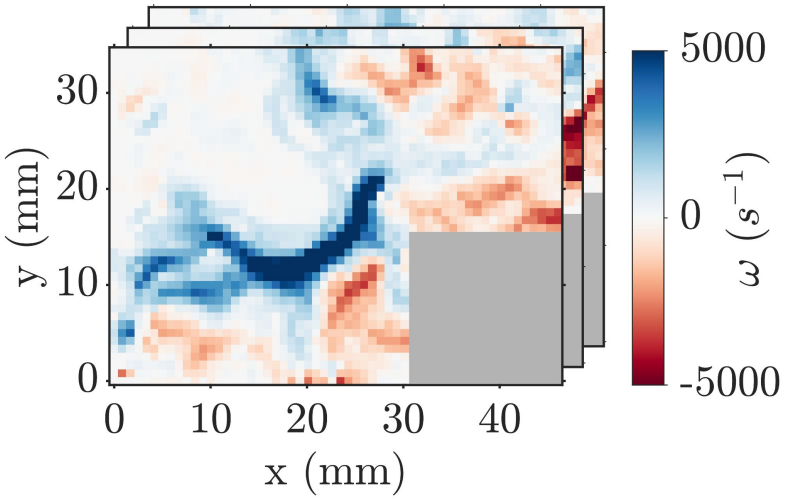
Office of Naval Research Global
Institute of Eminence Initiative, Govt. of India
Office of Science of the US Department of Energy

Positive feedback between acoustic pressure and heat release rate oscillations

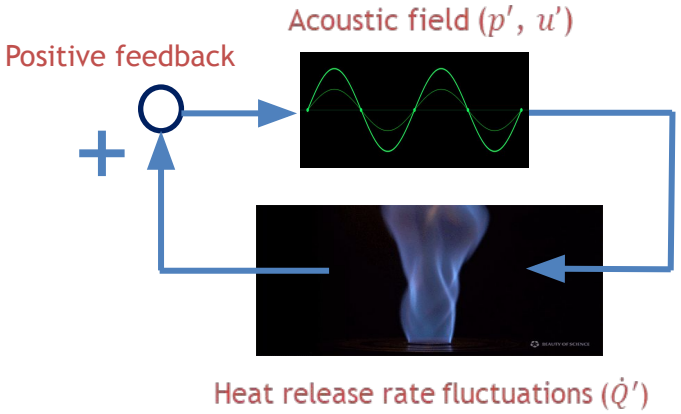


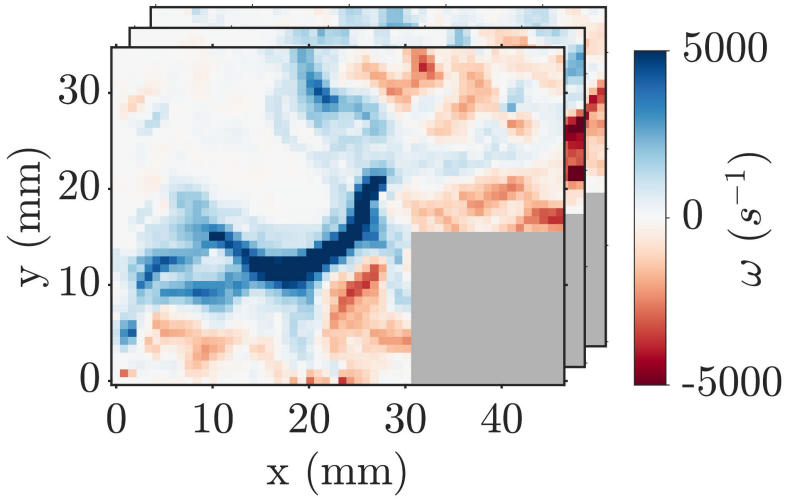
Vortical structures drive thermoacoustic instability in many combustors

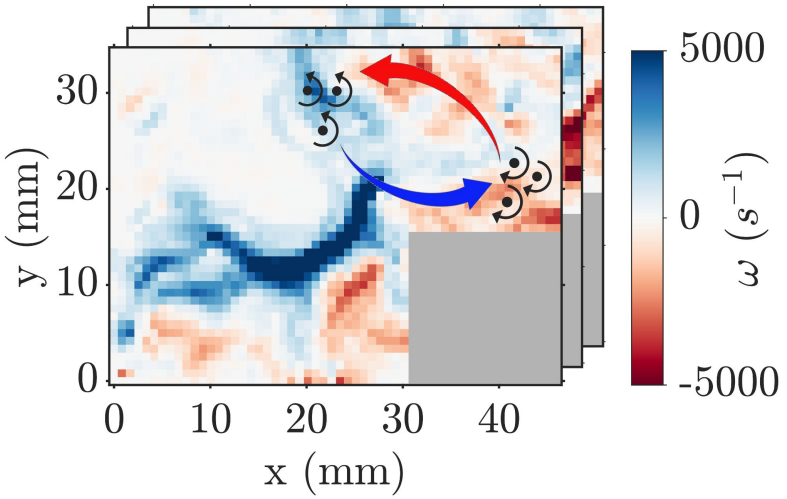




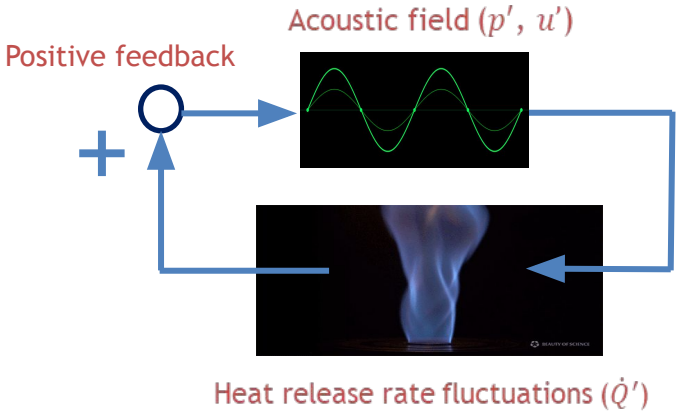
Understand the relation between vortical interactions and acoustic pressure oscillations

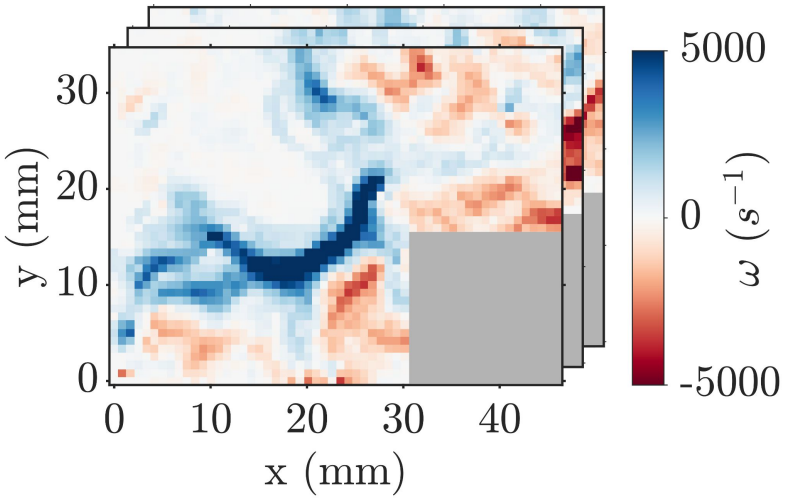


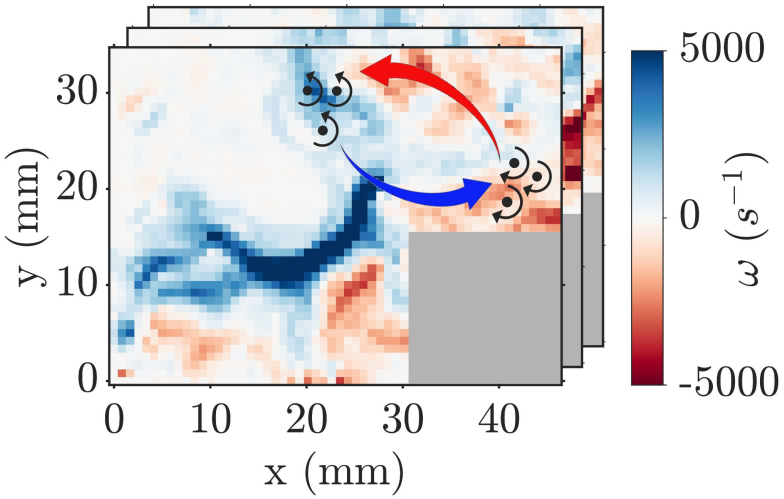




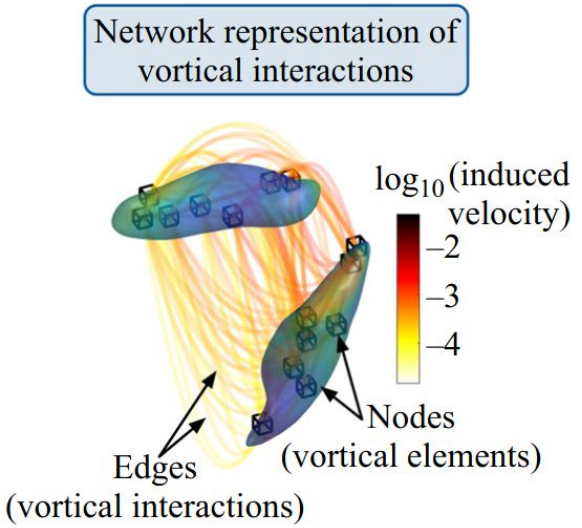
Complex networks provide a convenient framework to work with a large number of interactions



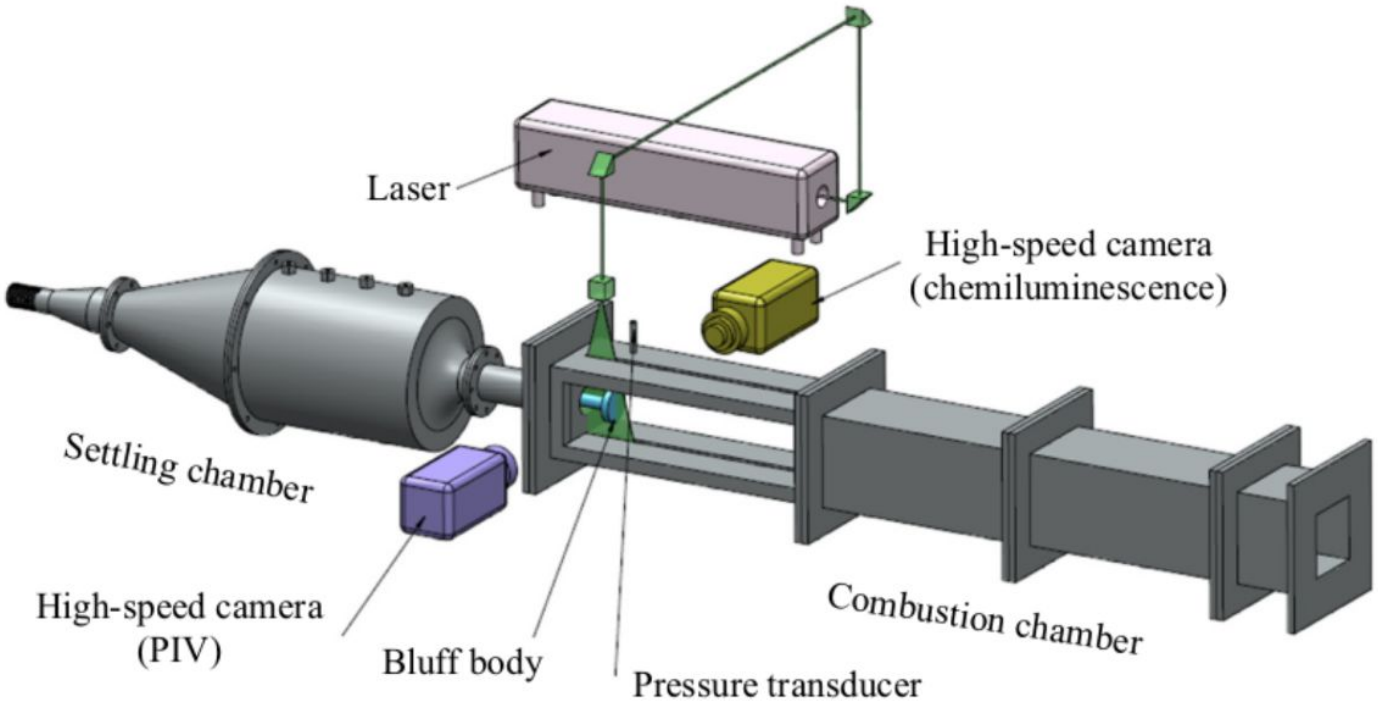




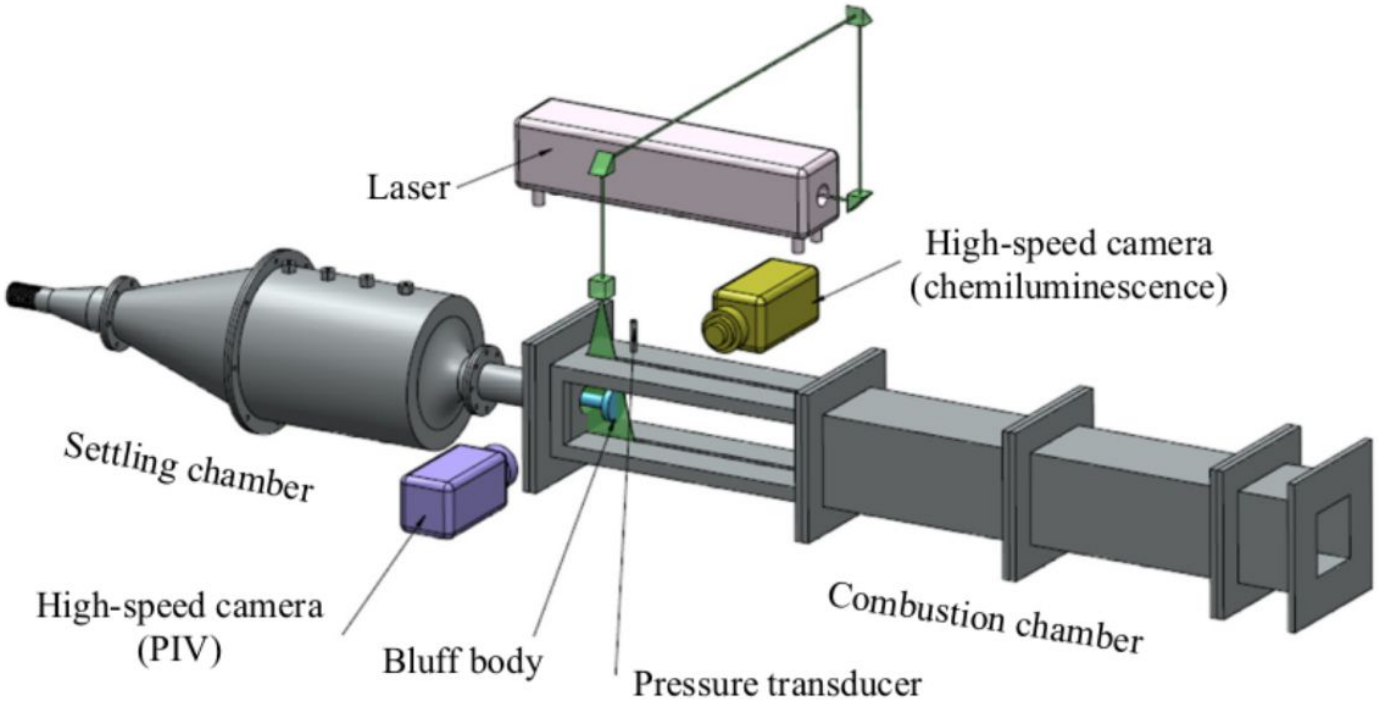
$$45 \times 60 \text{ cells}$$
$$\approx 1.5 \text{ million interactions}$$

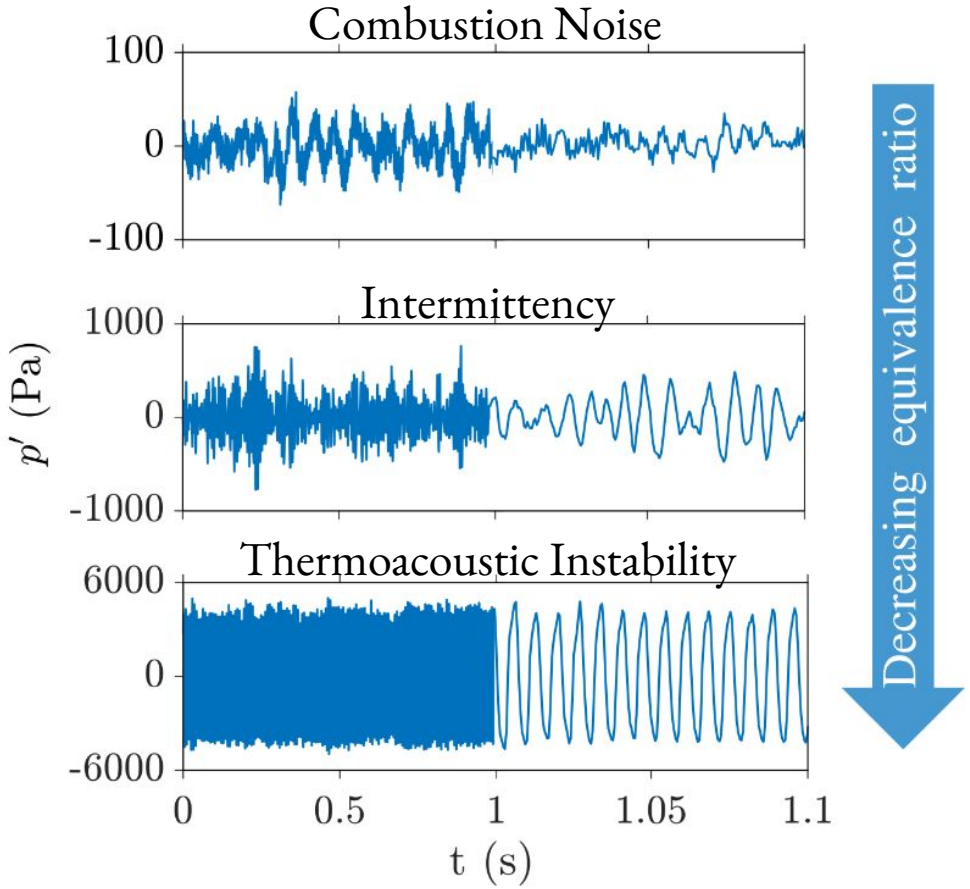


Bluff-body stabilized turbulent combustor

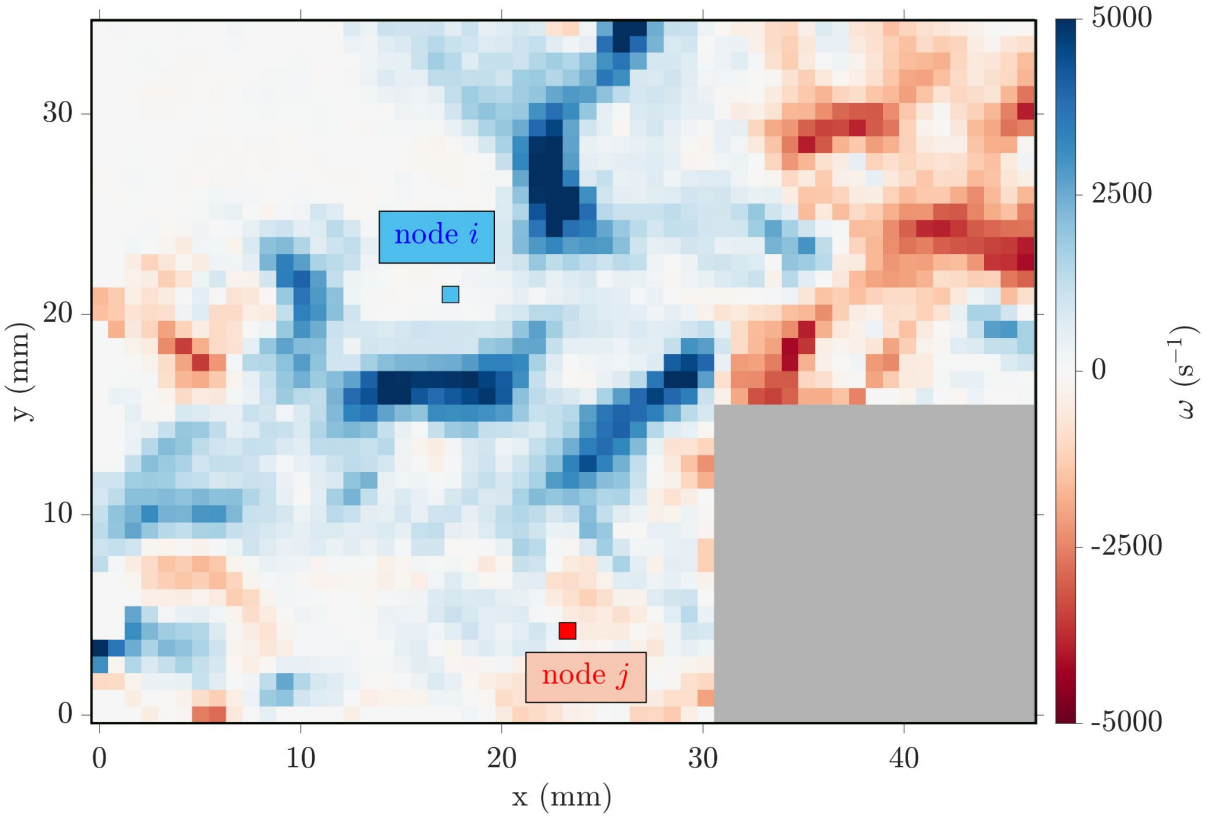


Bluff-body stabilized turbulent combustor - states of combustion noise, intermittency, and thermoacoustic instability

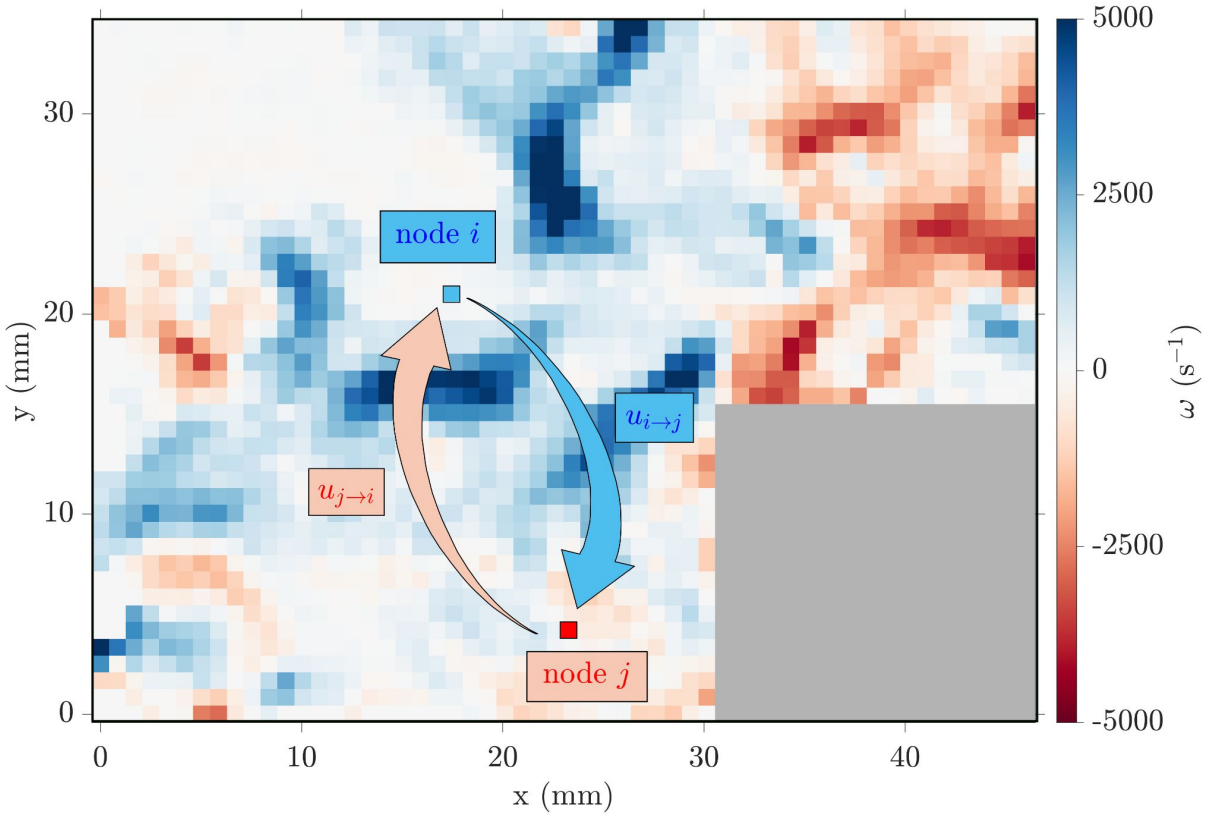




Cells of PIV computation domain - nodes of a complex network

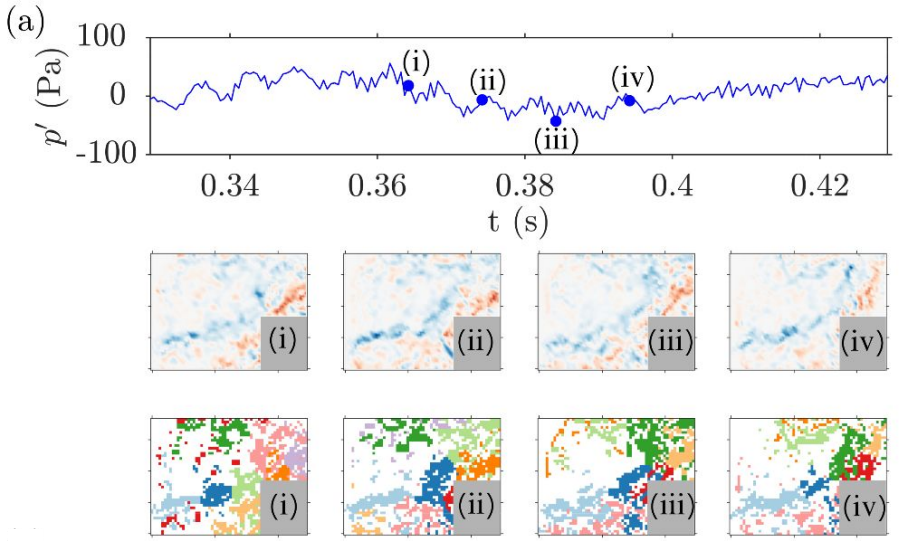


Induced velocity calculated from Biot-Savart law - directed links of a weighted complex network

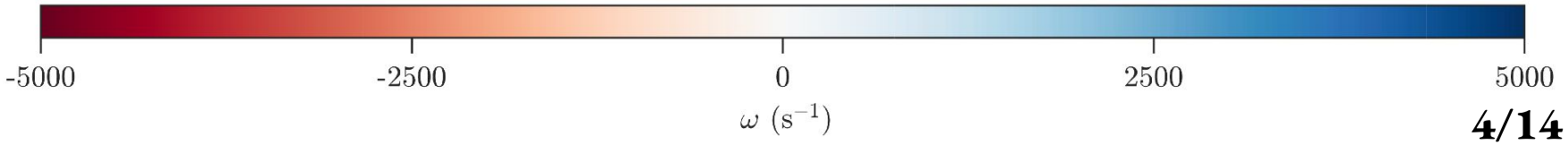


$$u_{i\to j} = \frac{1}{2\pi} \int_{S_i} \frac{\omega_i\left(\boldsymbol{r}', t\right) \times \left(\boldsymbol{r}_j - \boldsymbol{r}_i'\right)}{\left\|\boldsymbol{r}_j - \boldsymbol{r}_i'\right\|_2^2} \, \mathrm{d}S_i$$

Vortical communities during different dynamical states

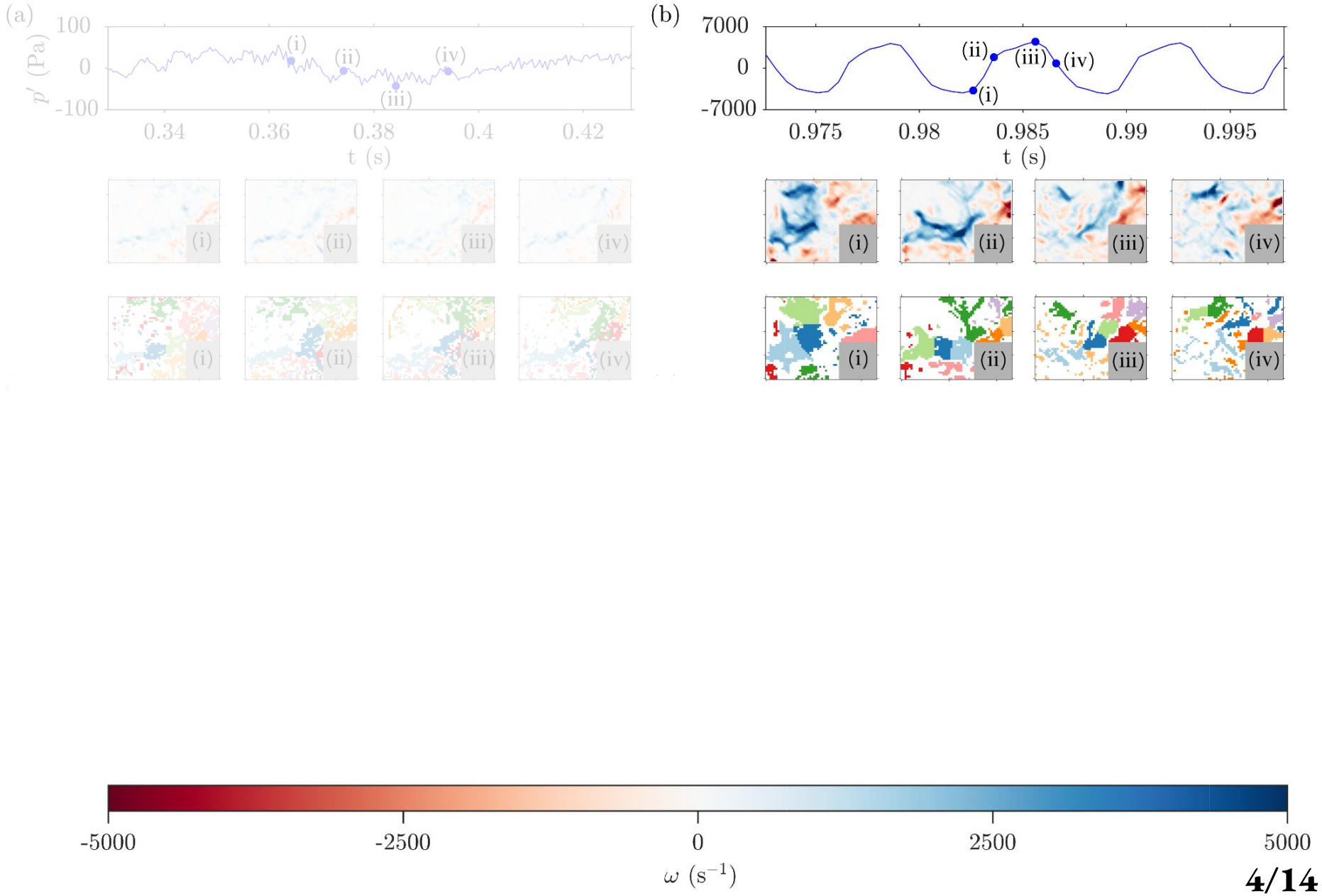


Combustion noise



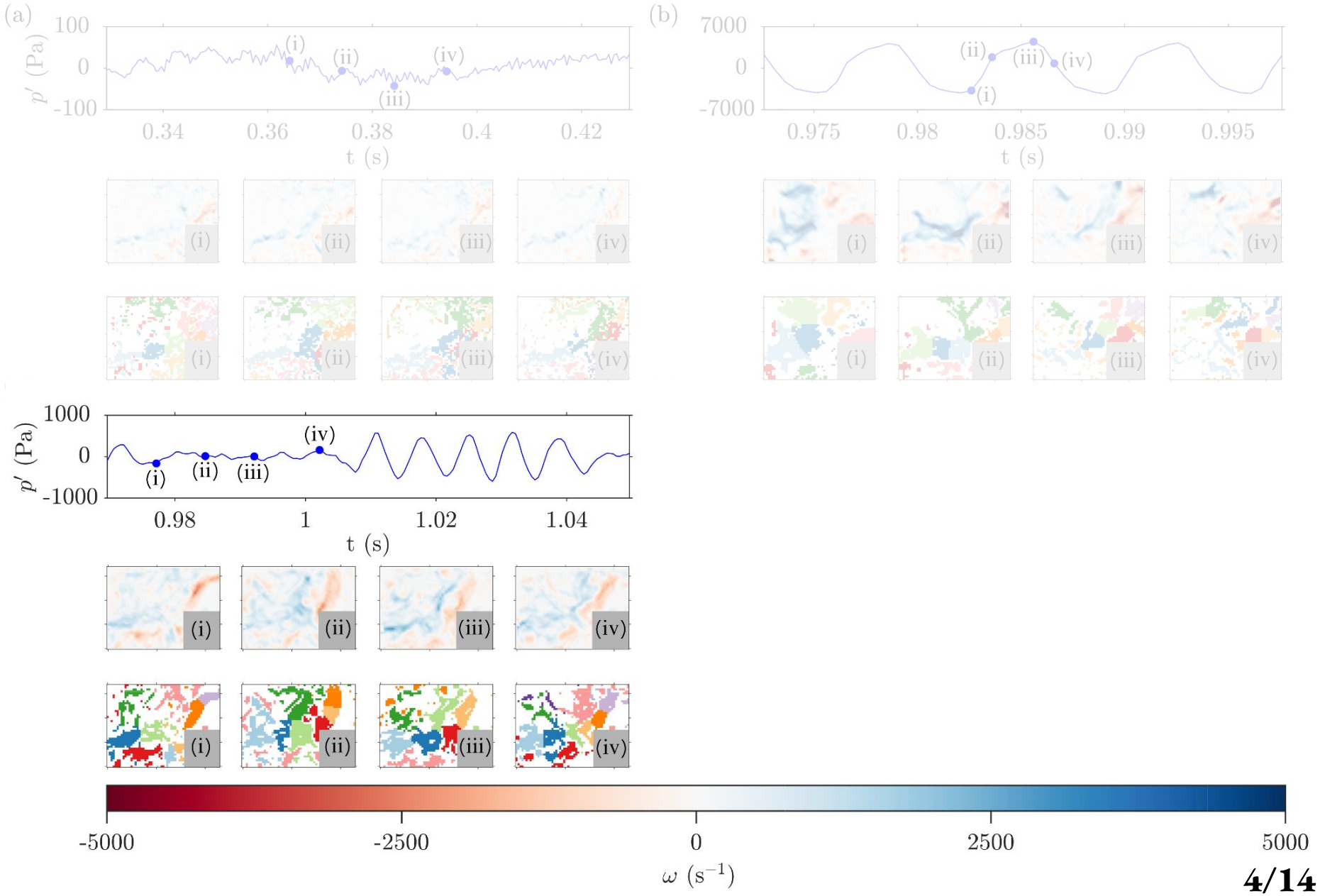
Vortical communities during different dynamical states

Thermoacoustic instability



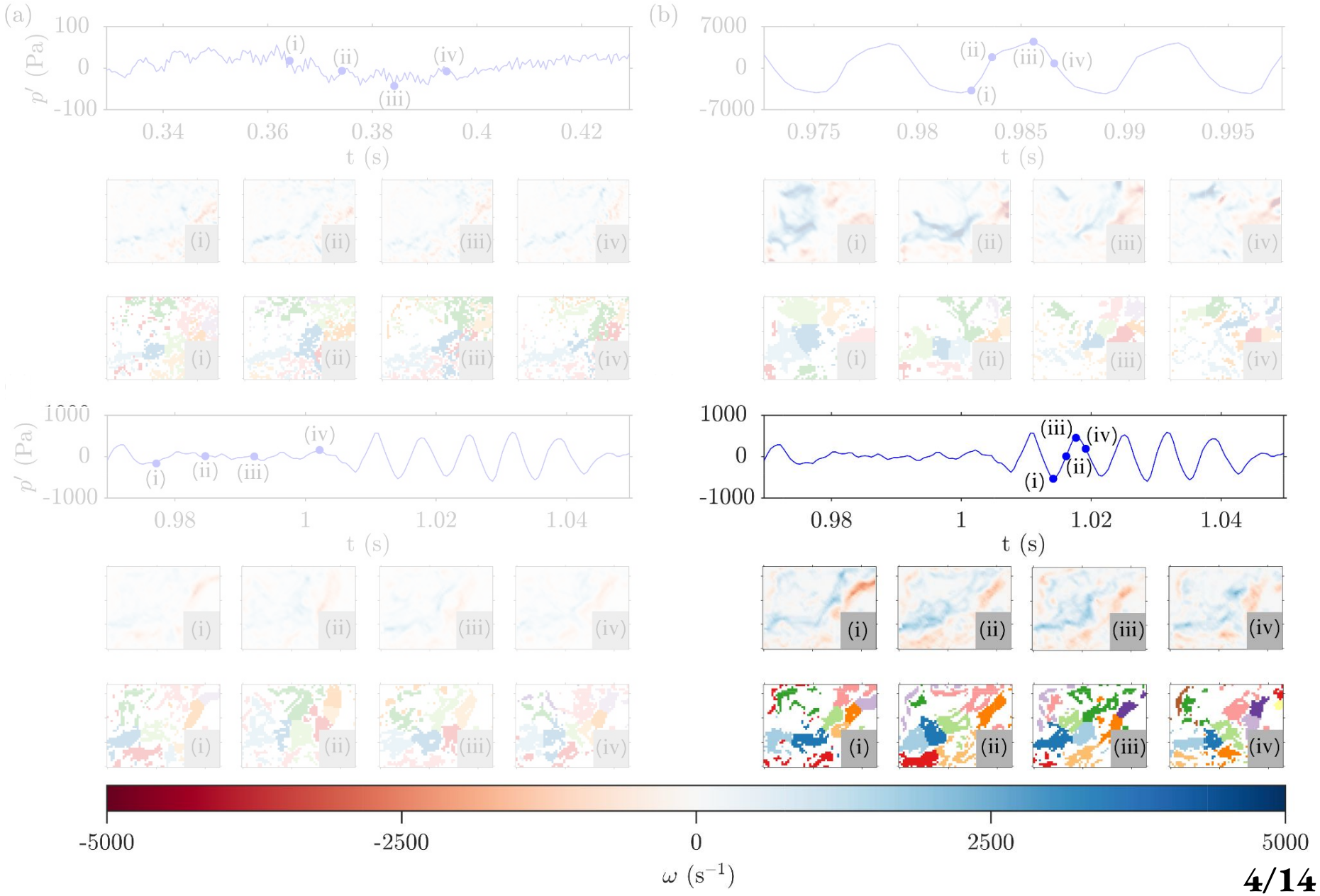
Vortical communities during different dynamical states

Aperiodic epoch of intermittency

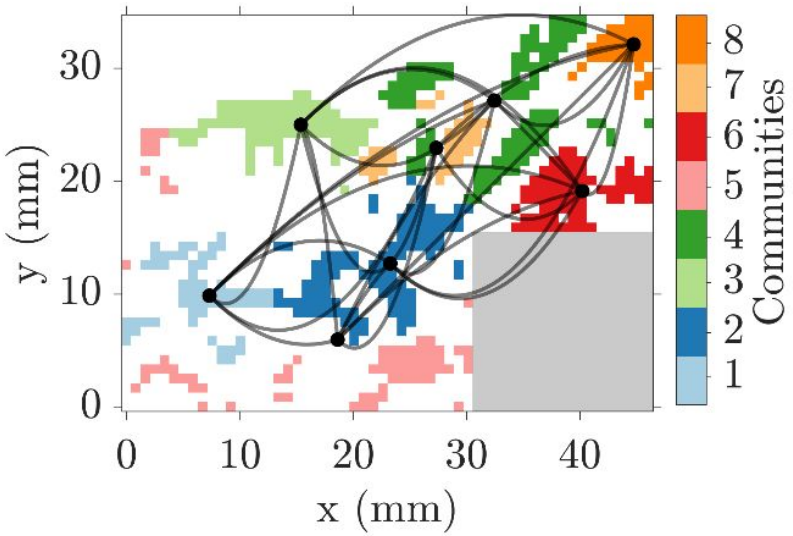


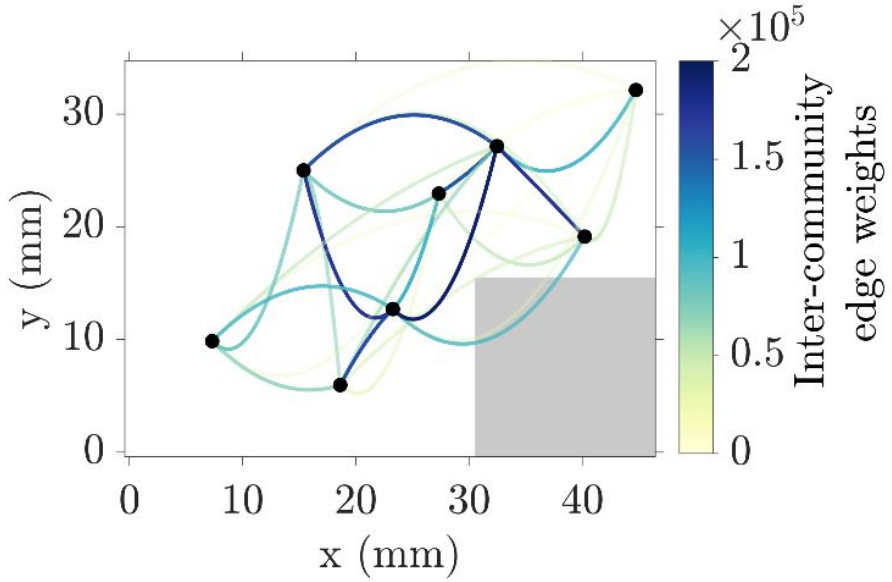
Vortical communities during different dynamical states

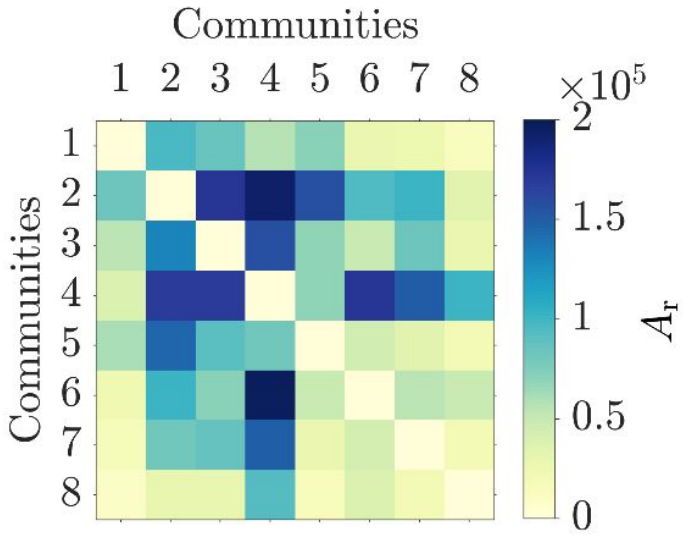
Periodic epoch of intermittency



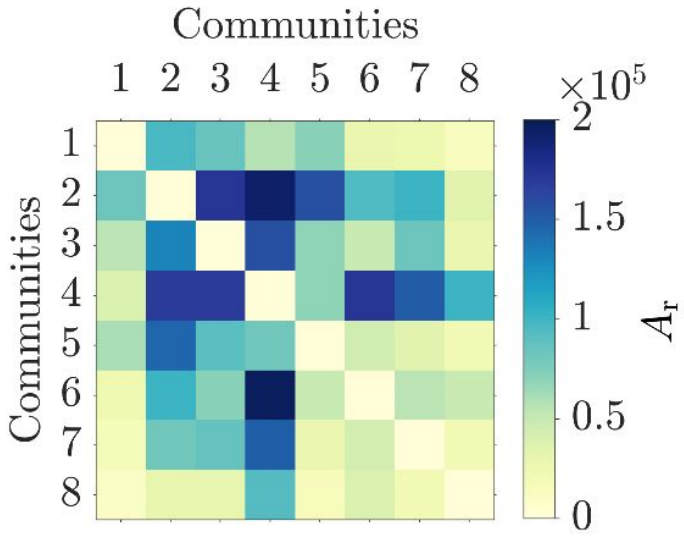
At each time instant, communities are condensed through their weighted centroids to form inter-community reduced networks

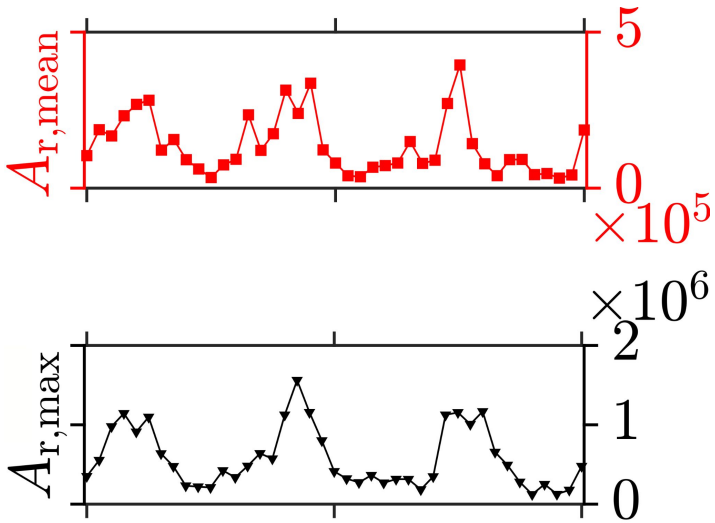






Network measures considered - mean and maximum of the reduced adjacency matrix

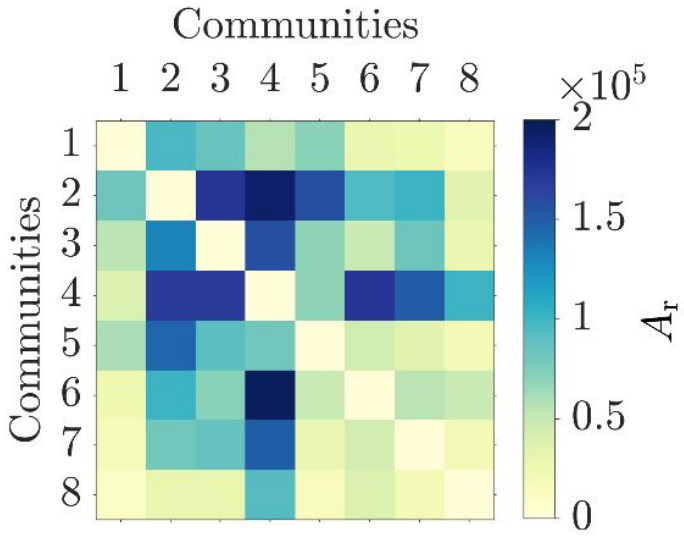


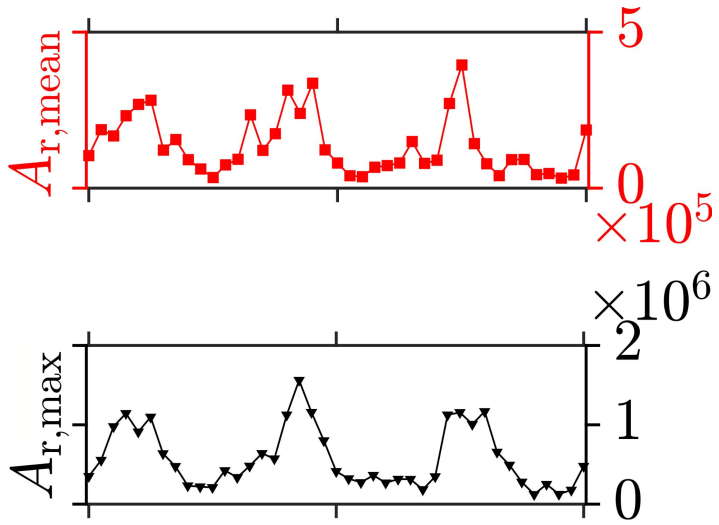


Average of all inter-community interactions

Maximum of all inter-community interactions

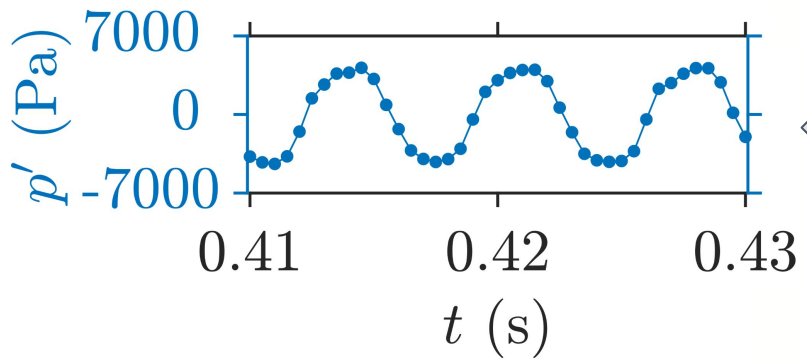
Evaluate correlation between temporal evolution of network measures and acoustic pressure fluctuations

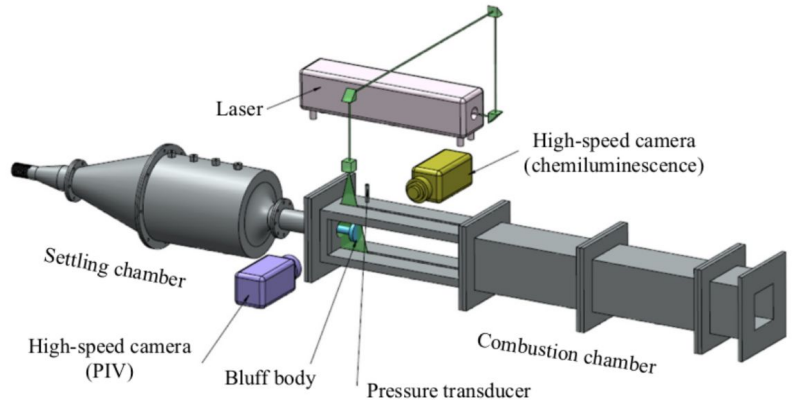




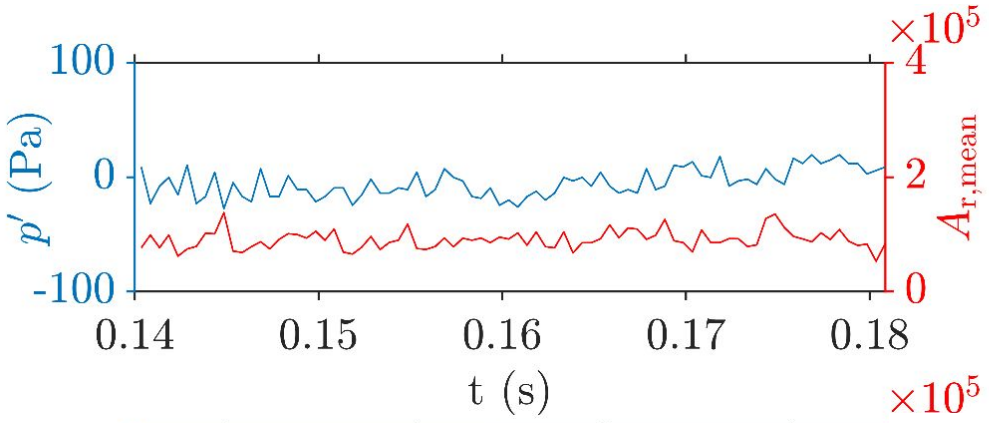
Average of all inter-community interactions

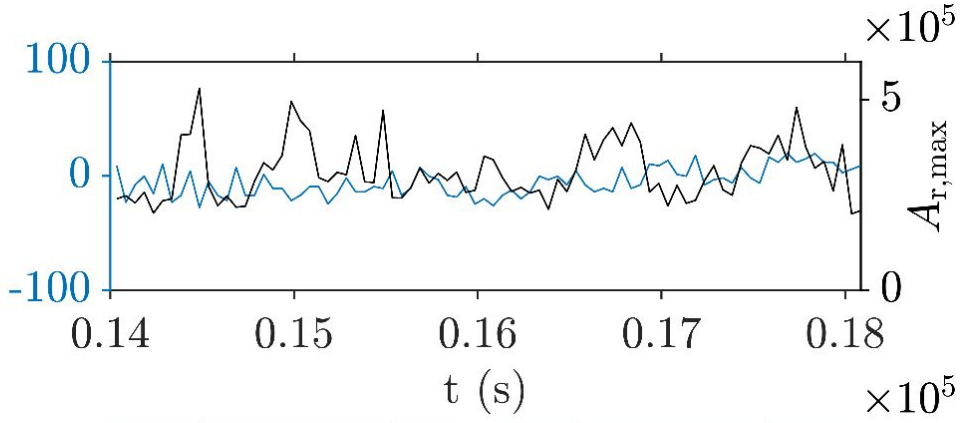
Maximum of all inter-community interactions



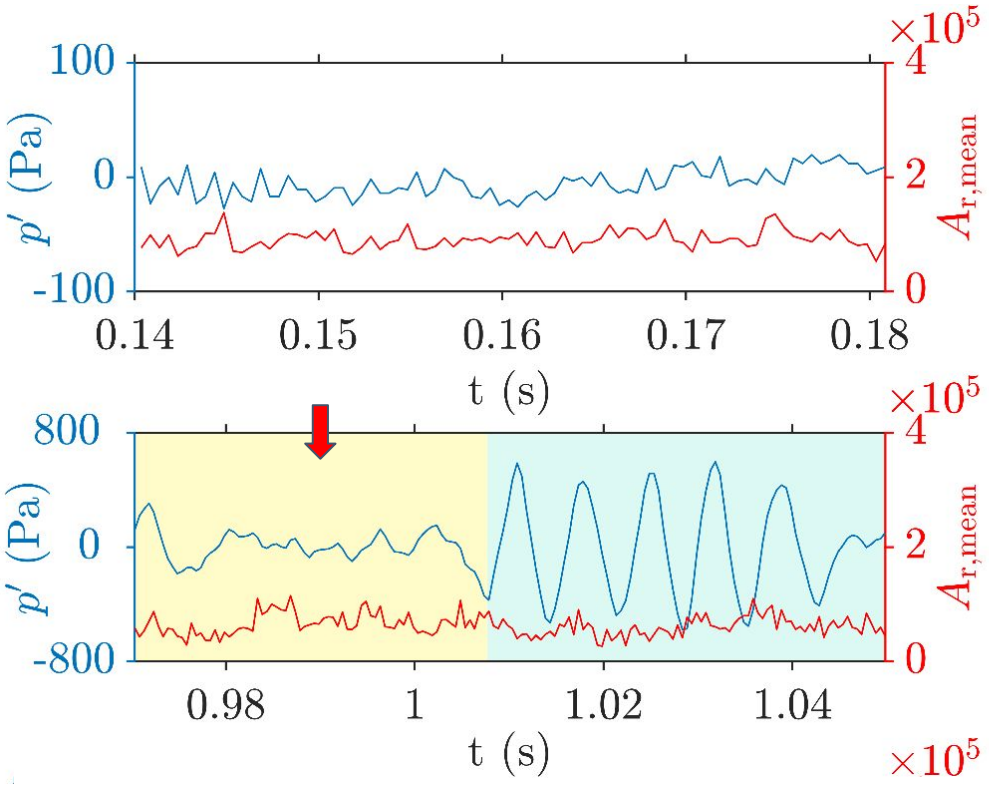


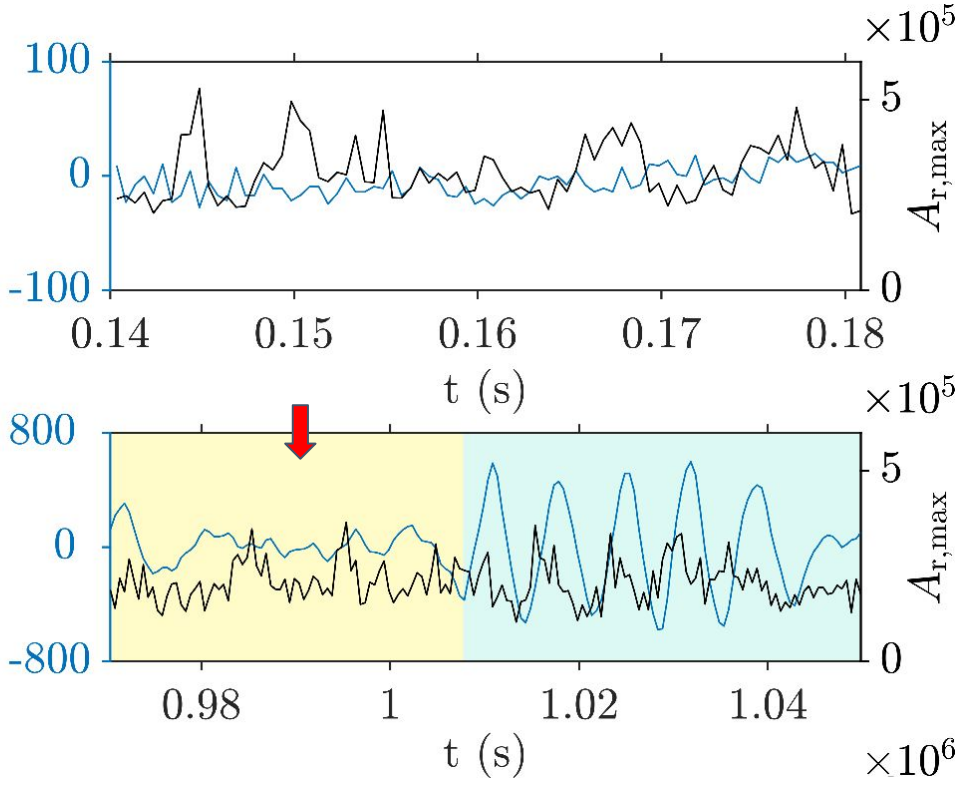
Combustion noise - aperiodic dynamics of networks measures



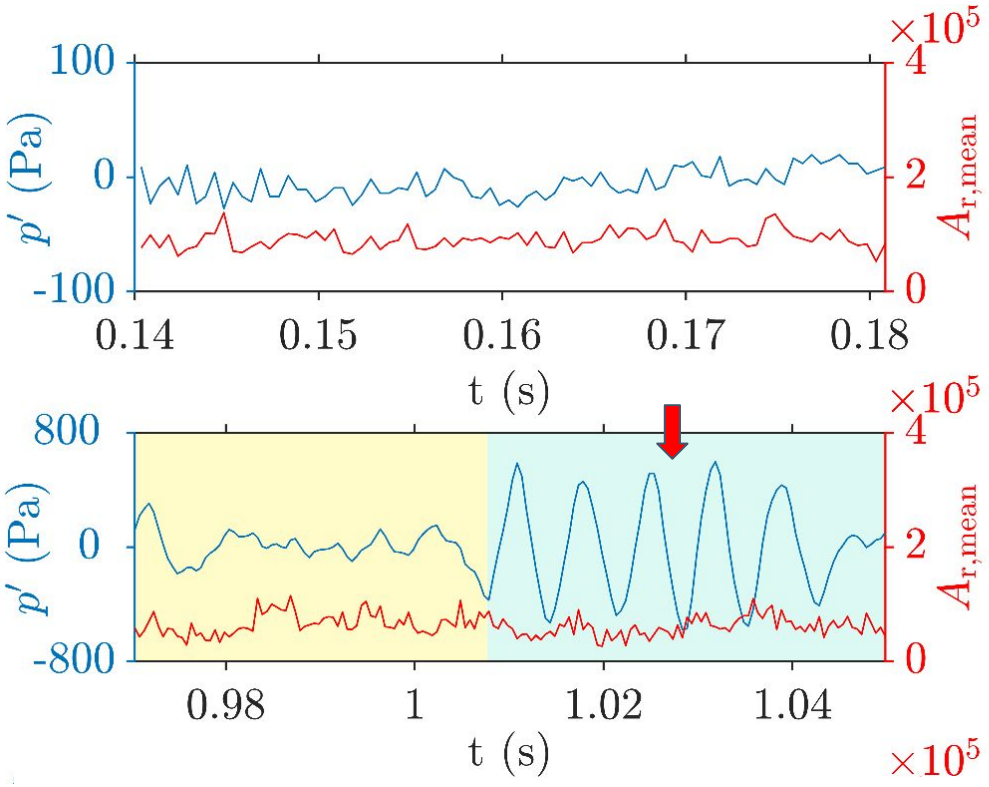


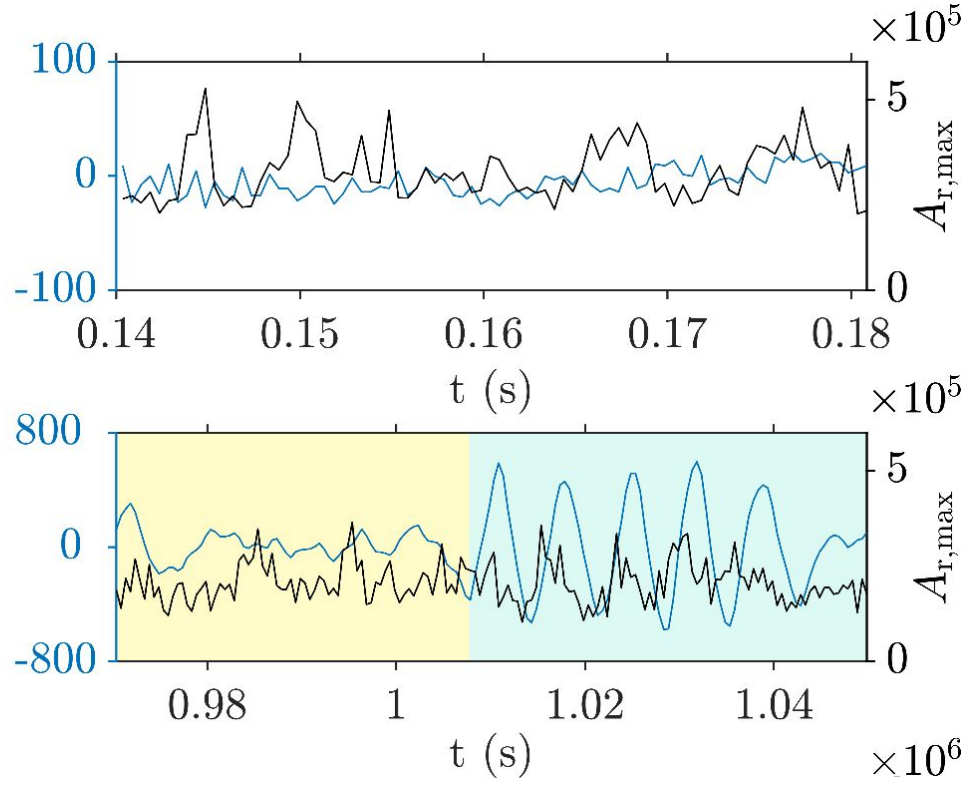
Intermittency - network measures are aperiodic during the aperiodic epoch of intermittency



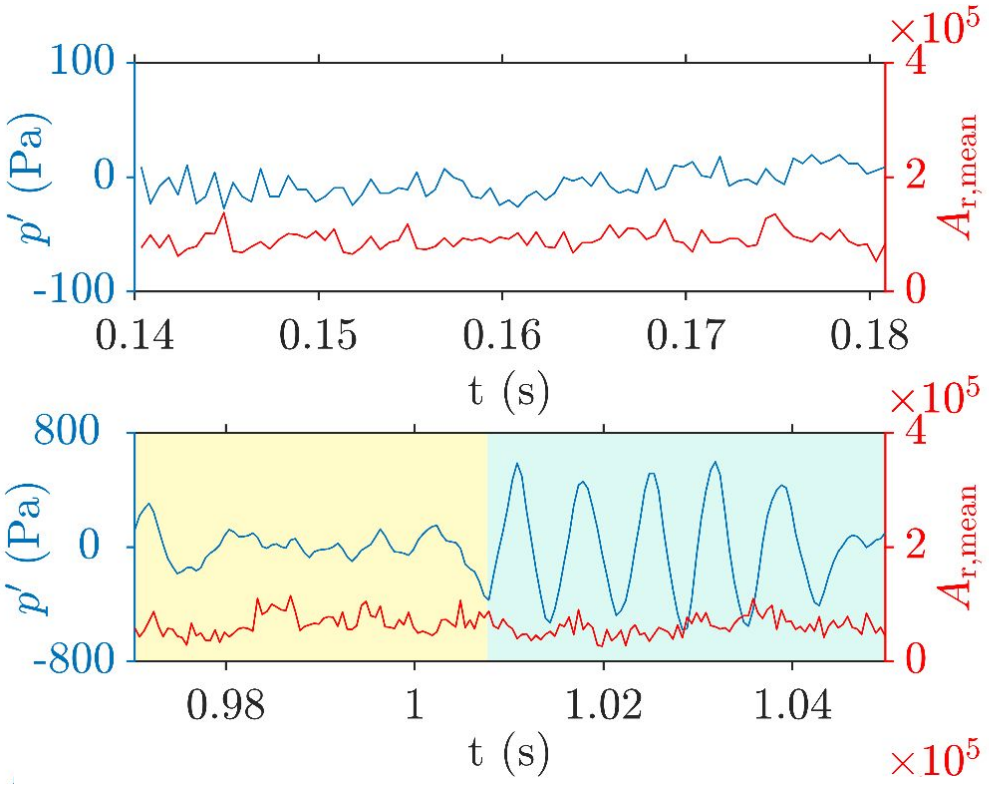


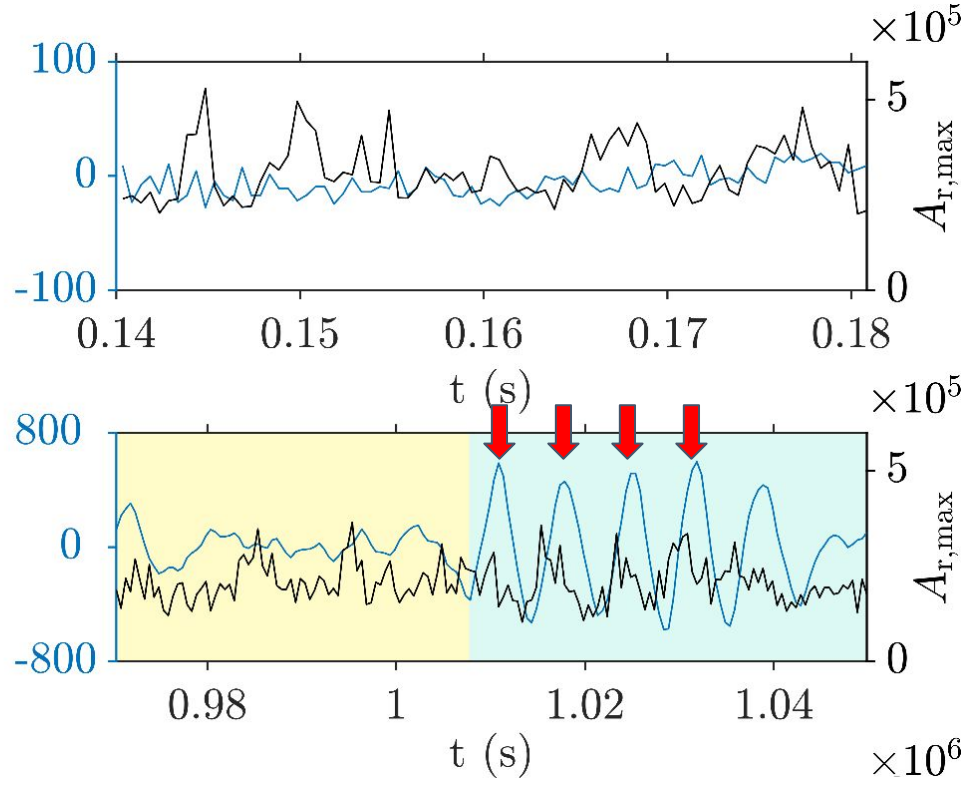
Intermittency - taking average of inter-community interactions smears out the periodic information of the flow field



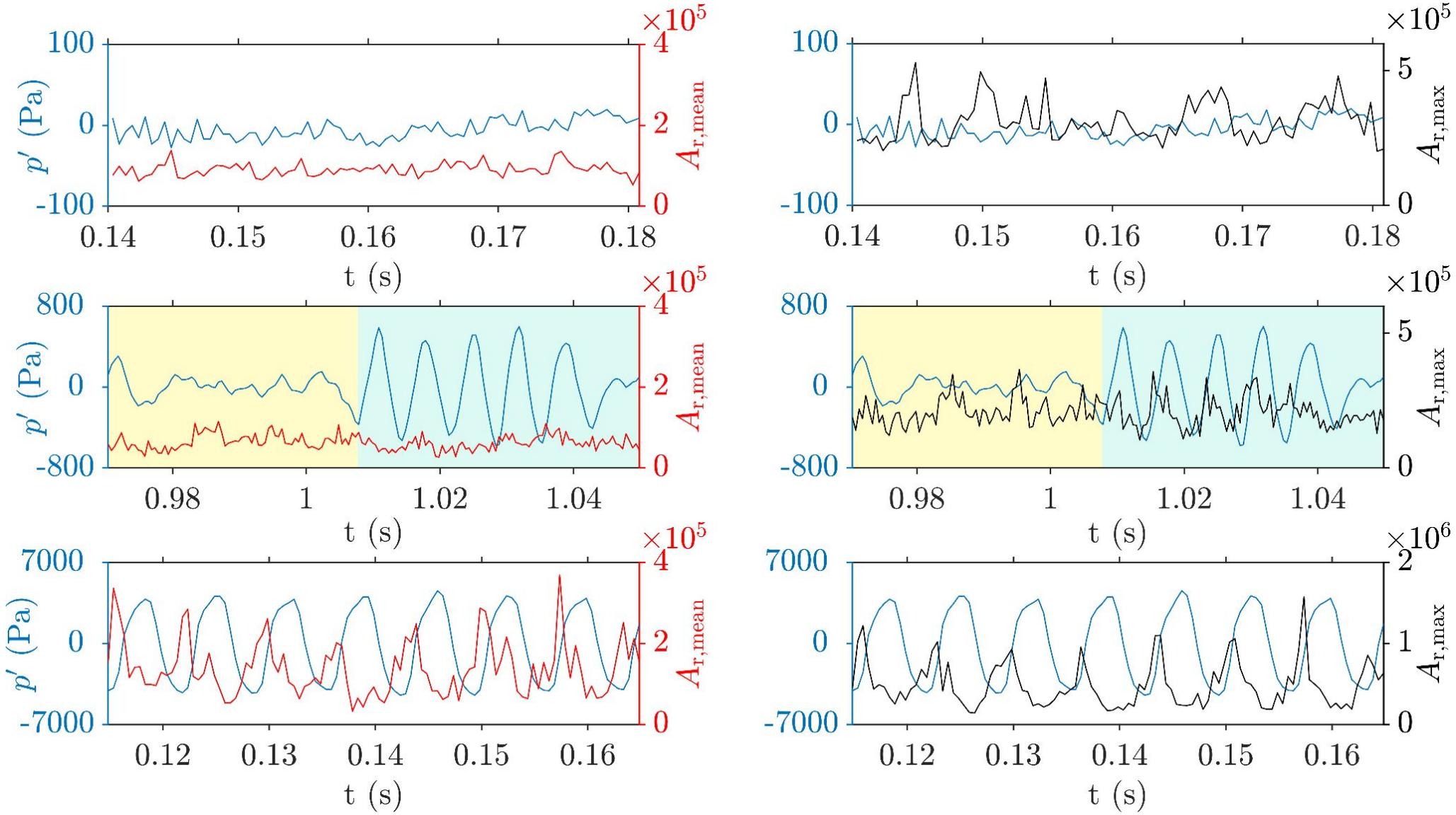


Intermittency - maximum inter-community interactions captures the periodicity of acoustics during the periodic epoch

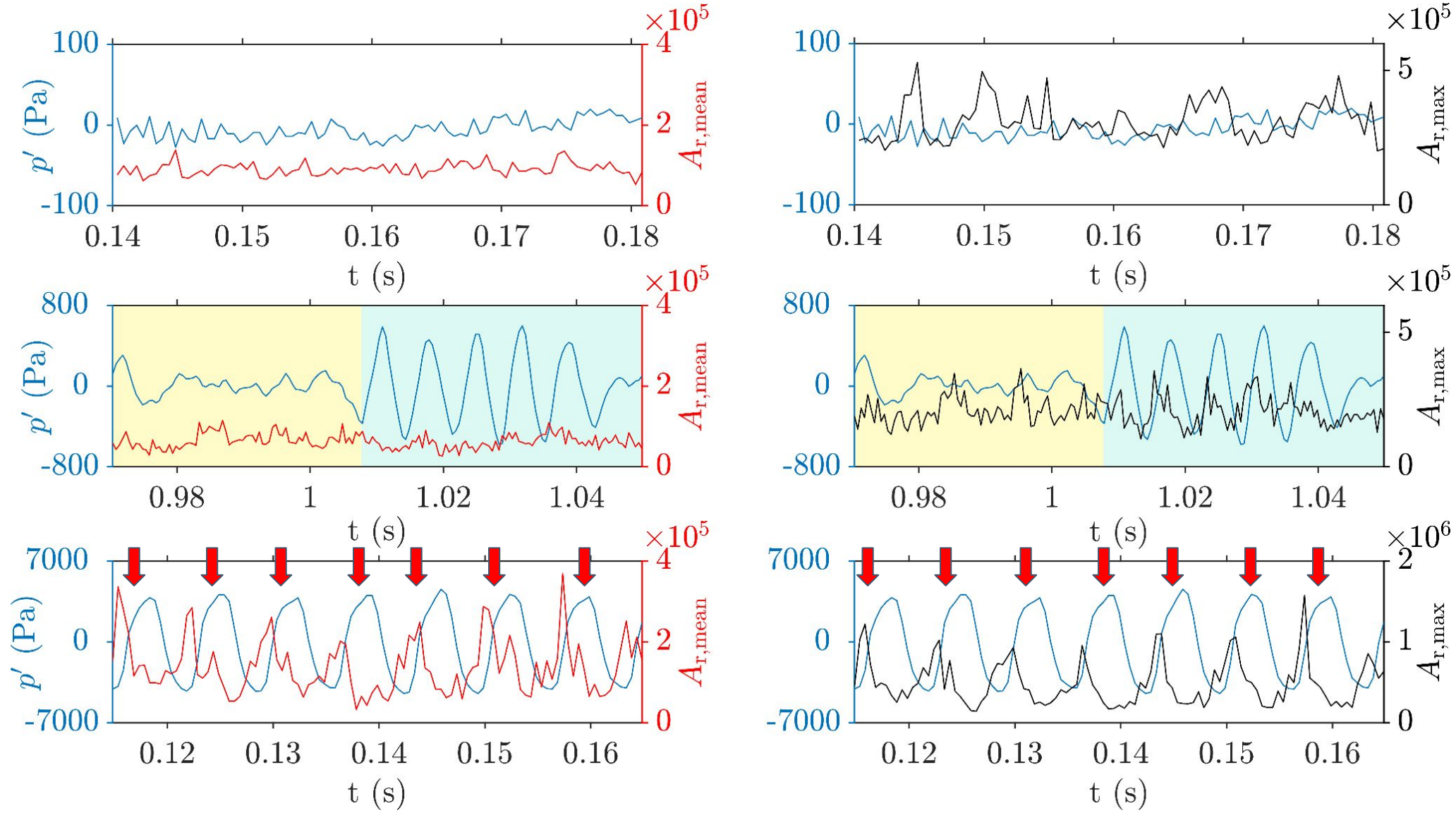




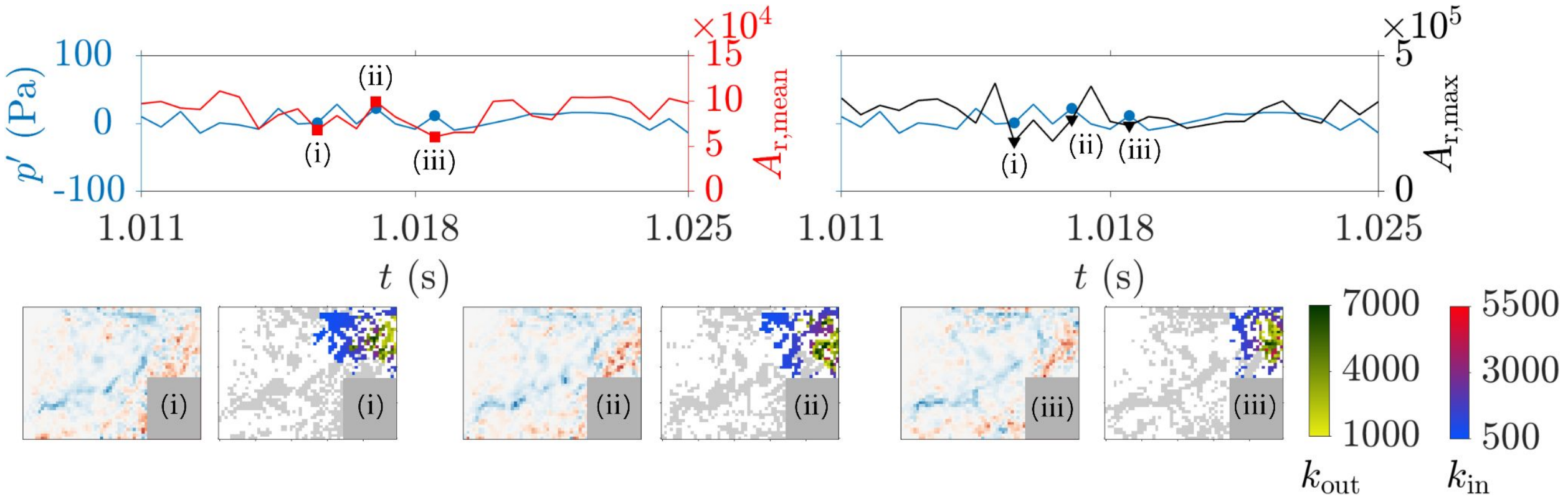
Thermoacoustic instability - network measures are periodic



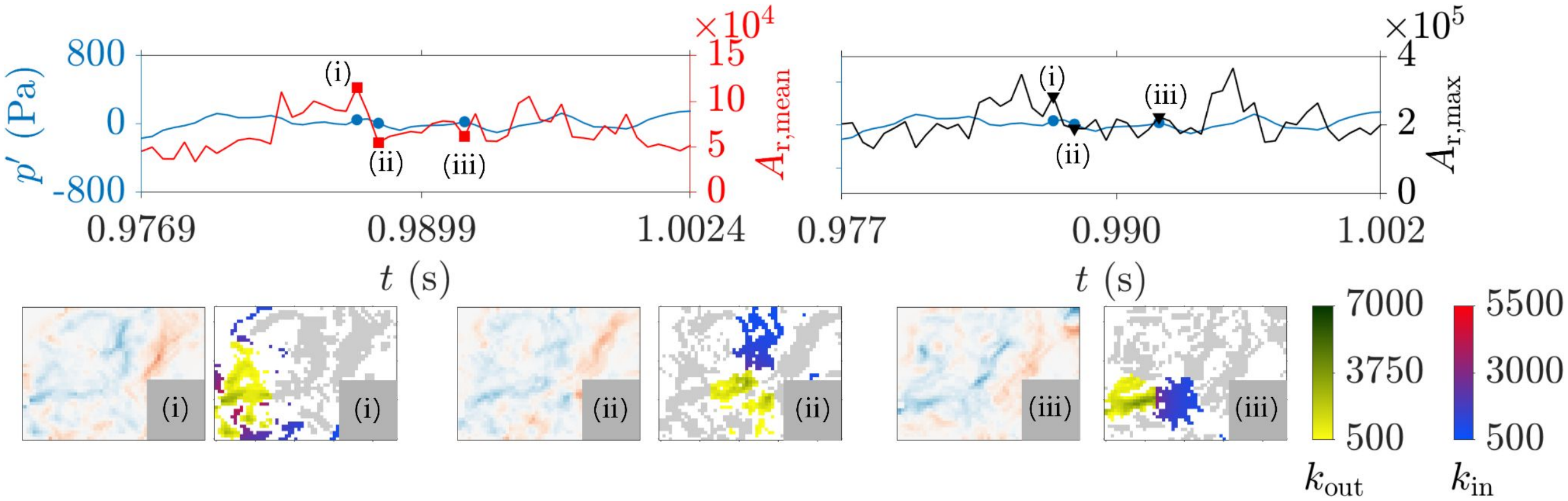
Thermoacoustic instability - significant delayed correlation between acoustics and network measures



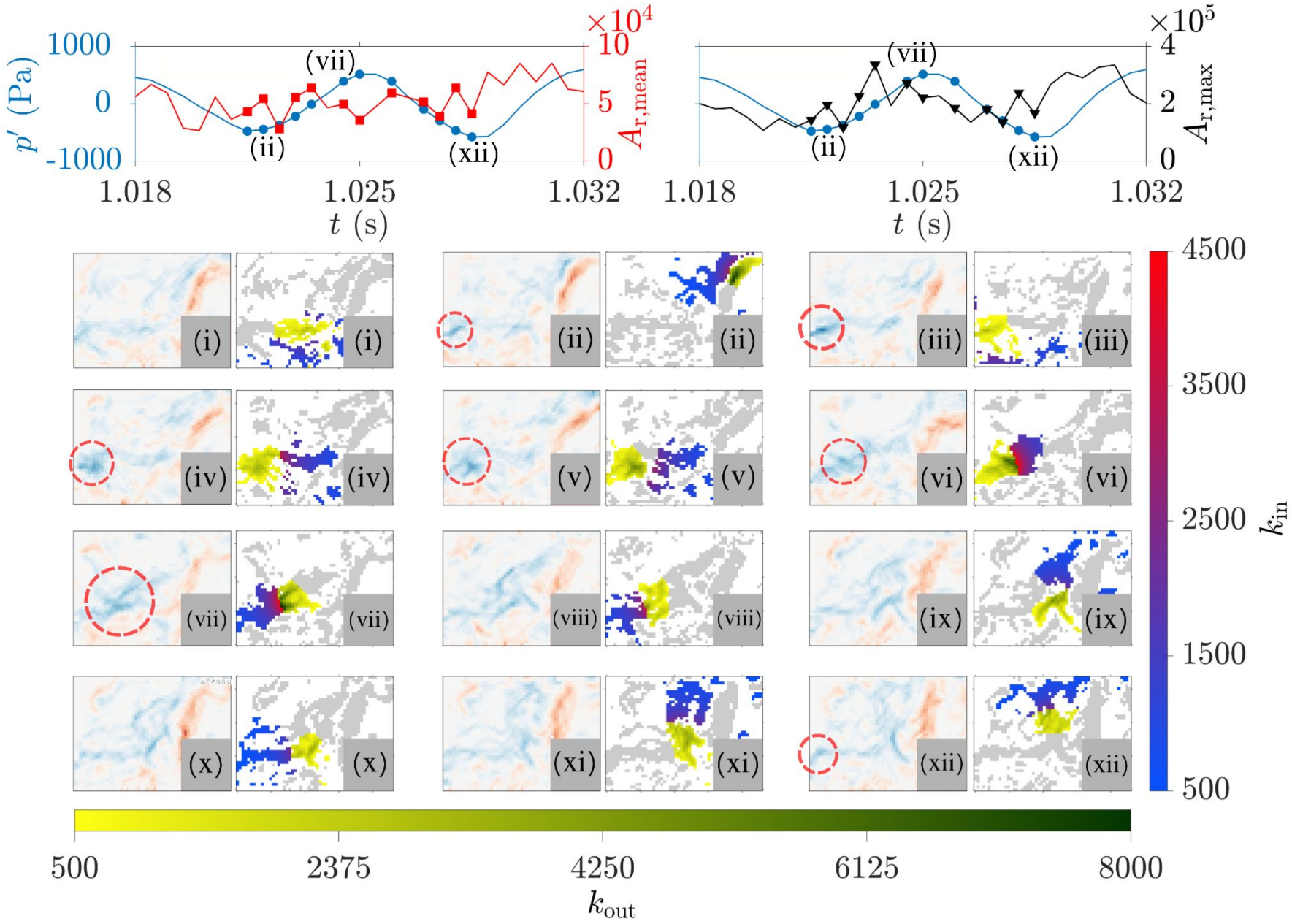
Combustion noise - significant vortex shedding from the upstream tip of bluff body



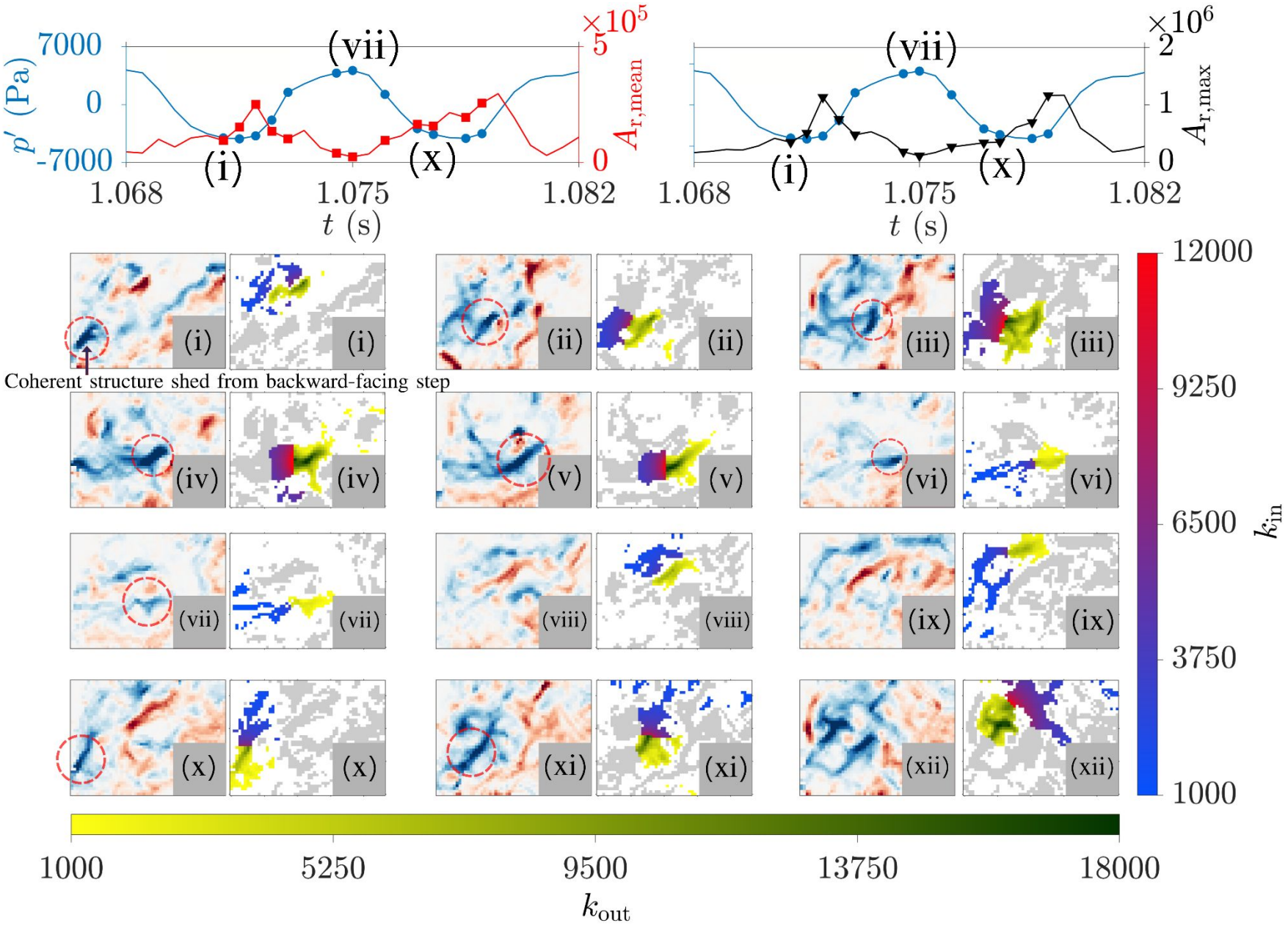
Aperiodic epoch of intermittency - aperiodic temporal variation of network measures



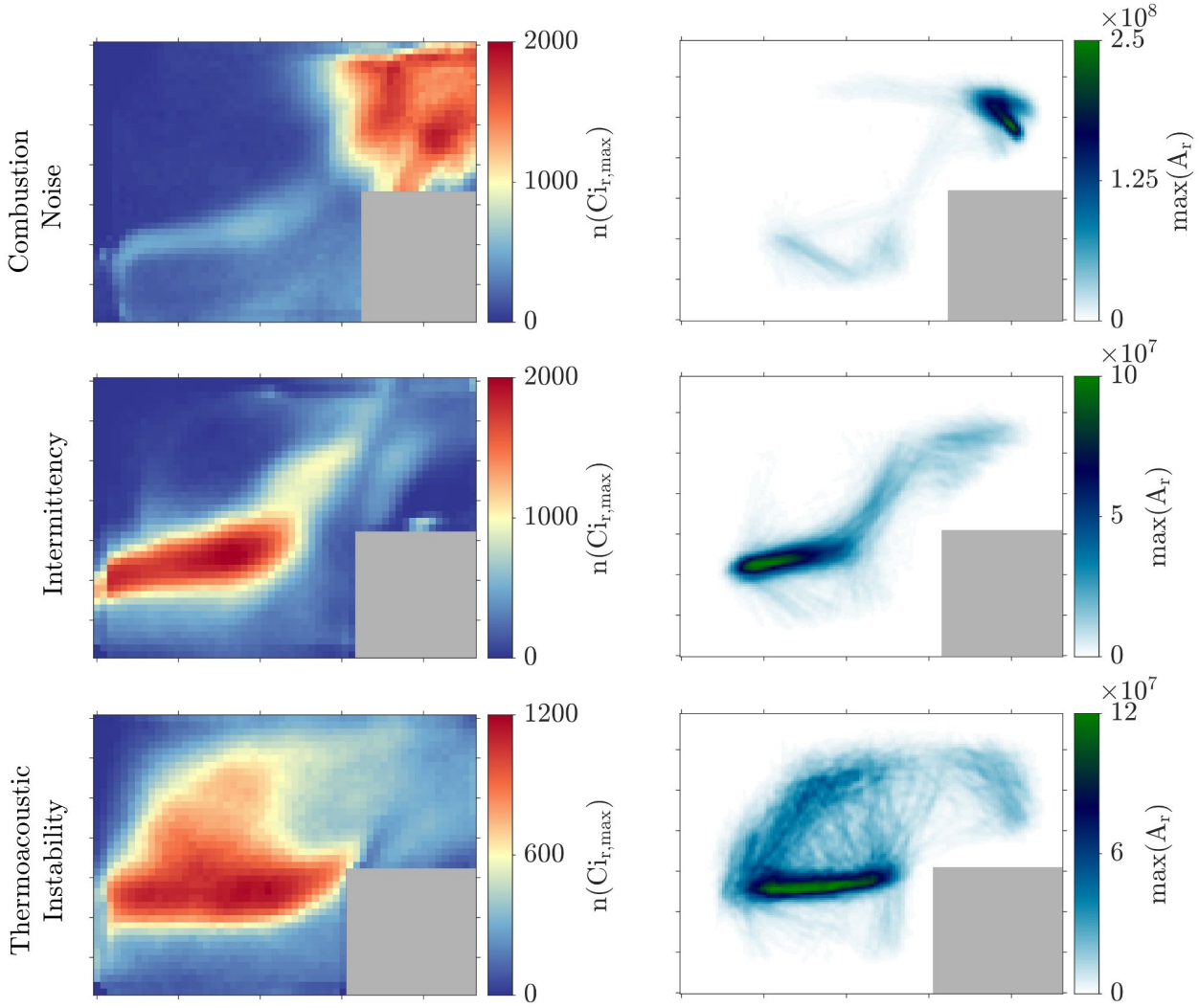
Periodic epoch of intermittency - periodic emergence of vortices



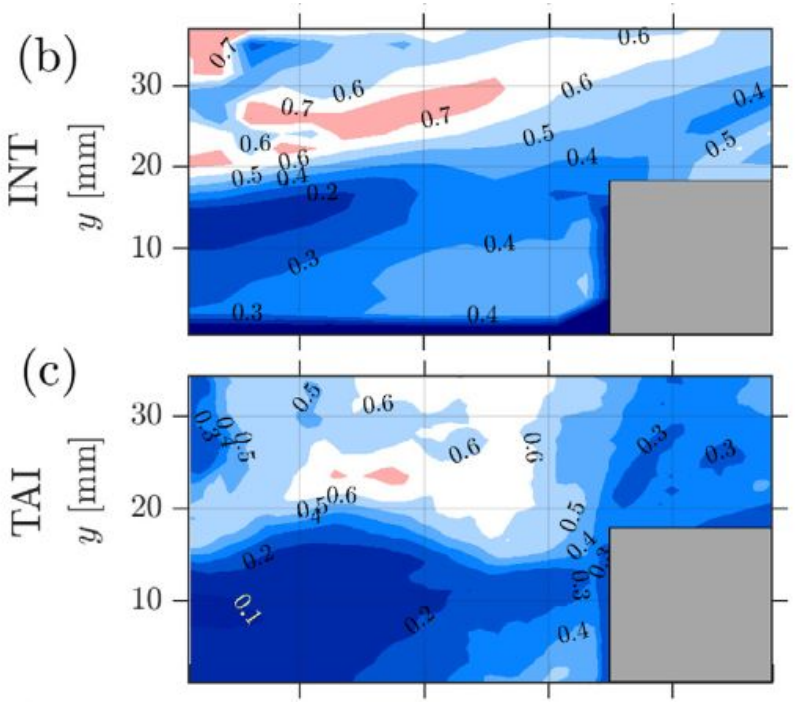
Thermoacoustic instability - periodic dynamics of network measures



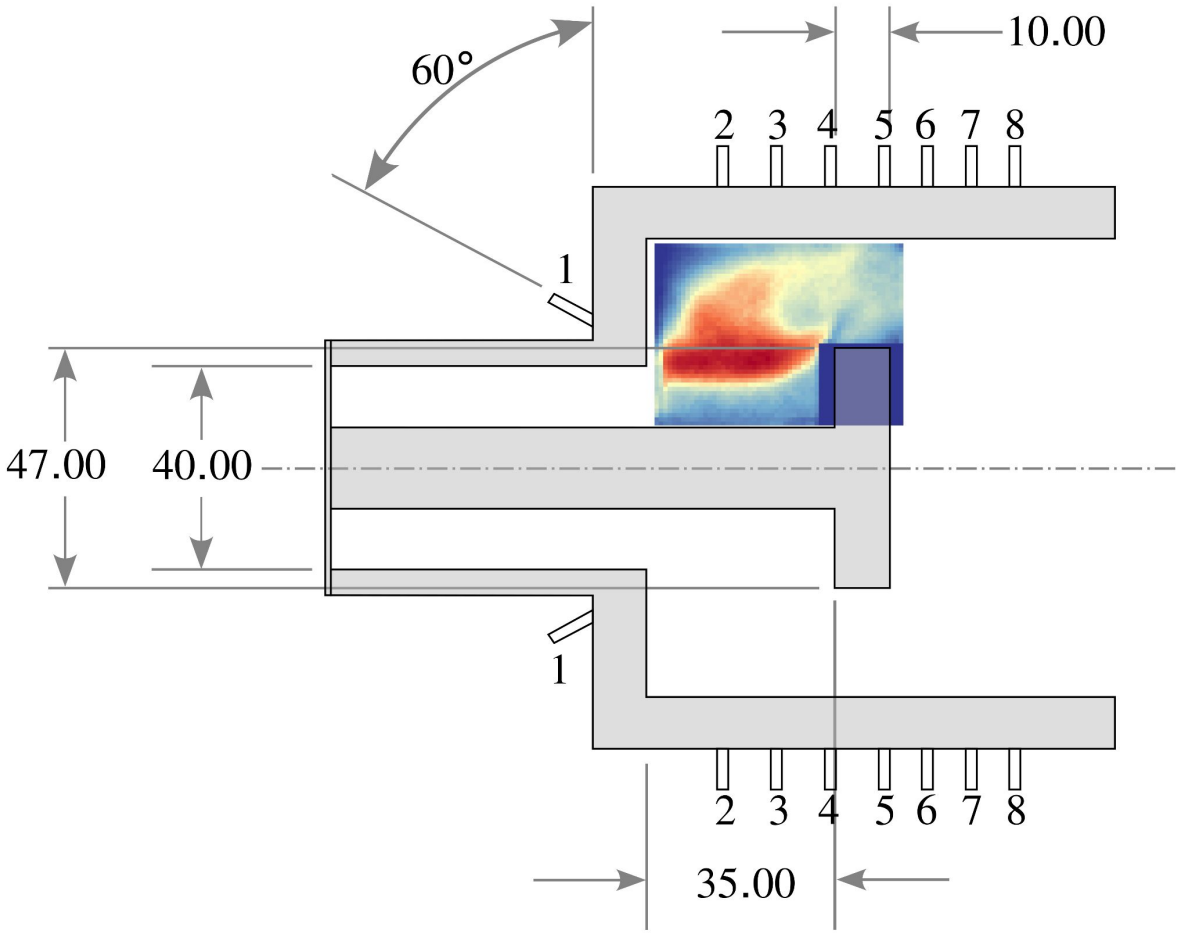
Critical regions - probability distribution of communities with largest inter-community interactions

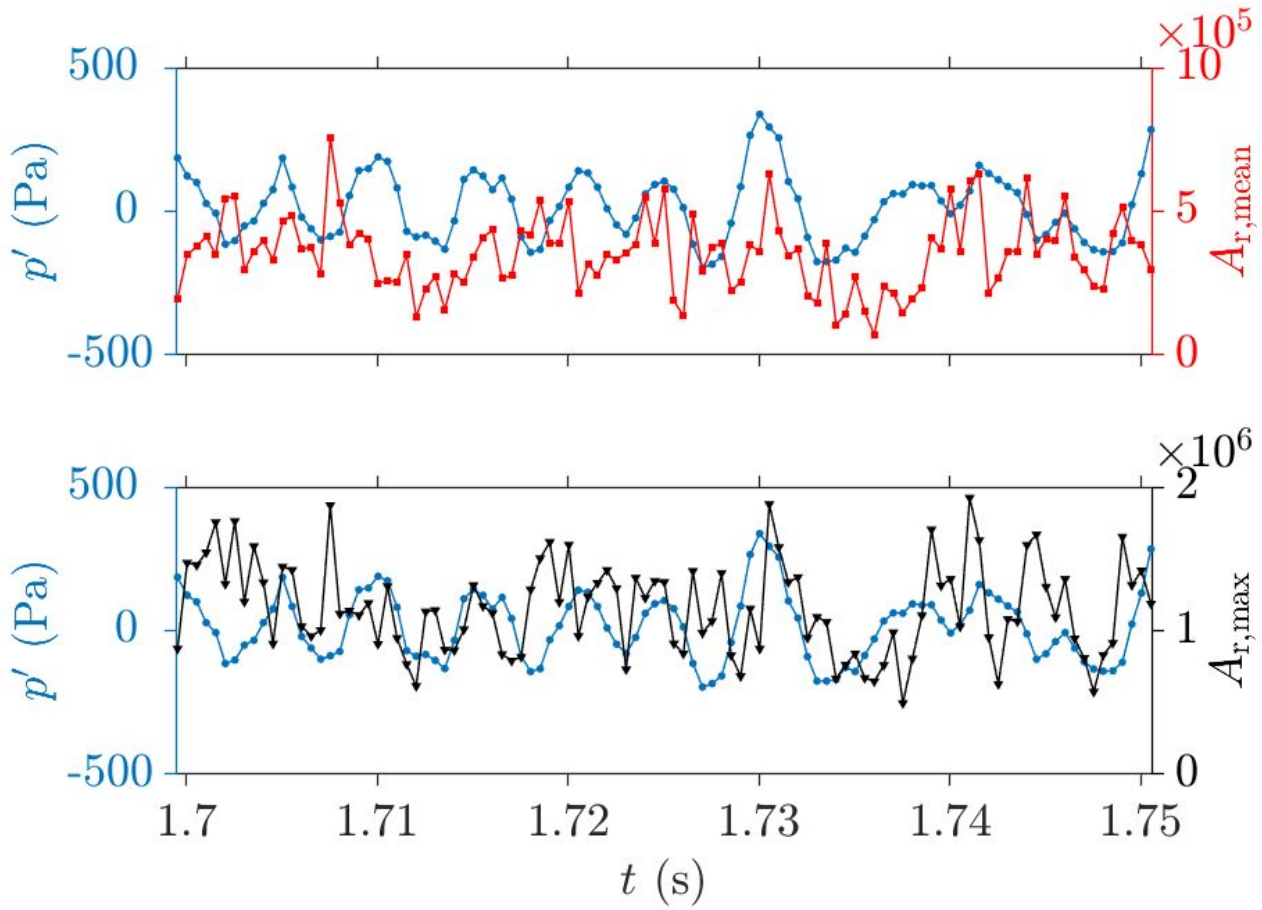


Hurst exponent (Roy et al., Combust. Flame, 2021)

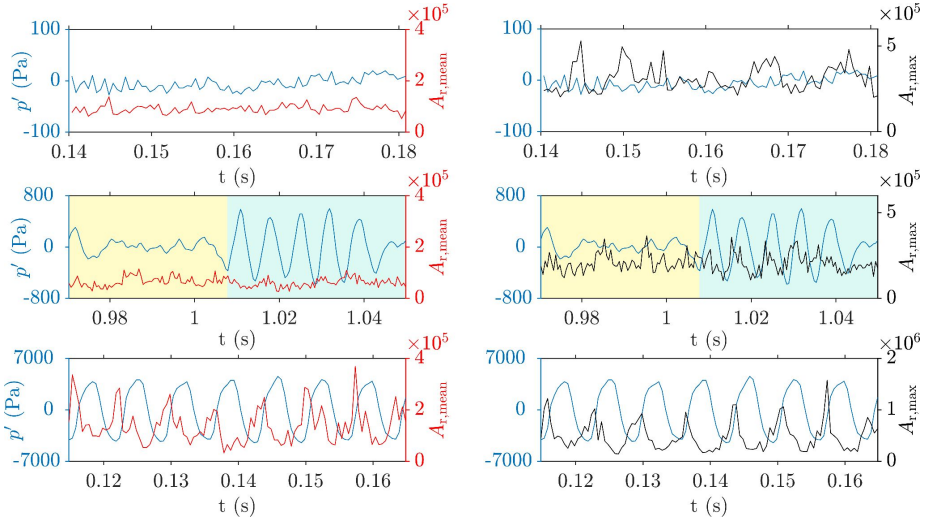


Smart passive control - mitigation of thermoacoustic instability via air microjets



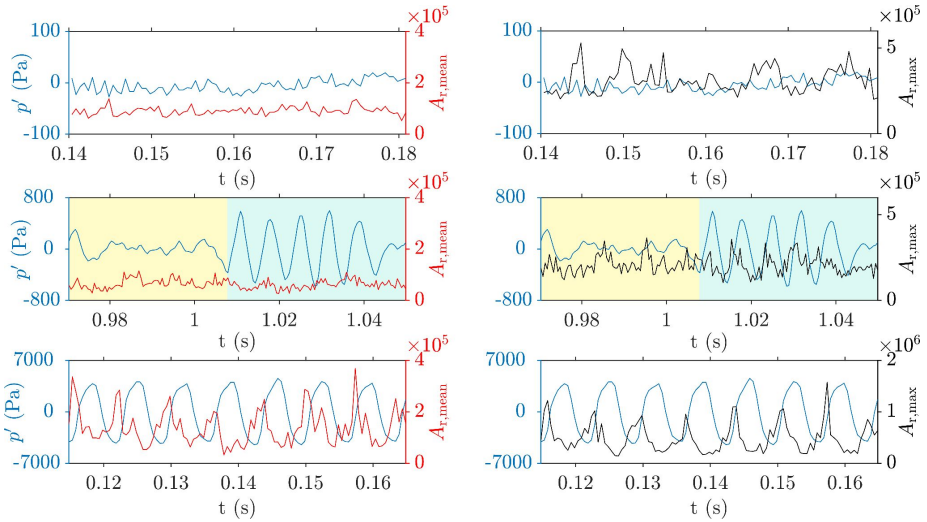


Summary

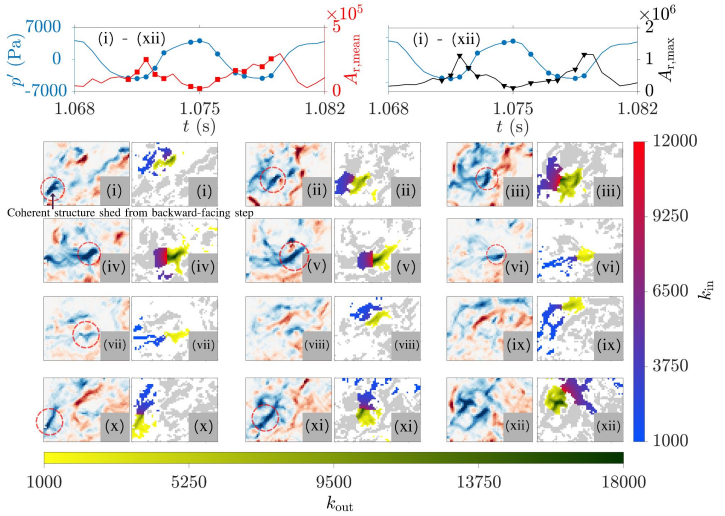


Interplay between vortical interactions and acoustics quantified via vortical network measures

Summary

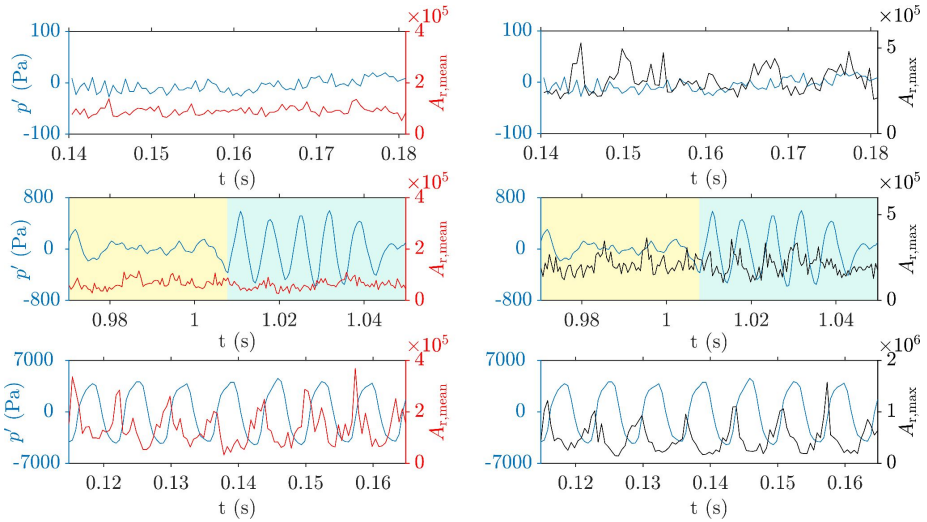


Interplay between vortical interactions and acoustics quantified via vortical network measures

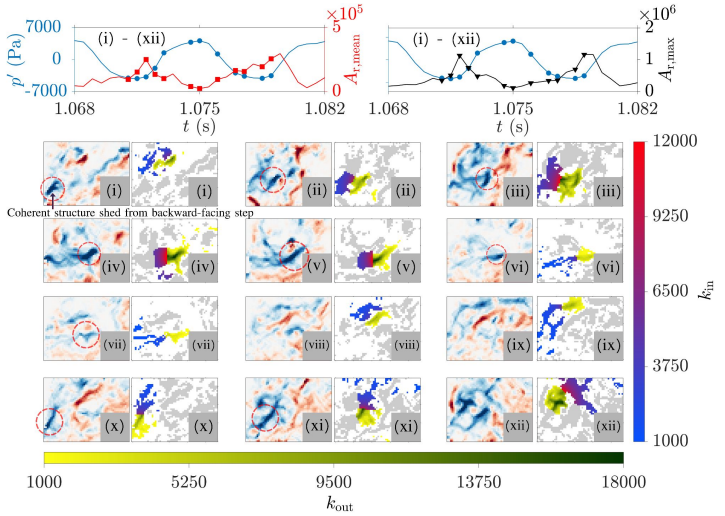


Temporal evolution of influential vortical communities in the reaction field of the combustor

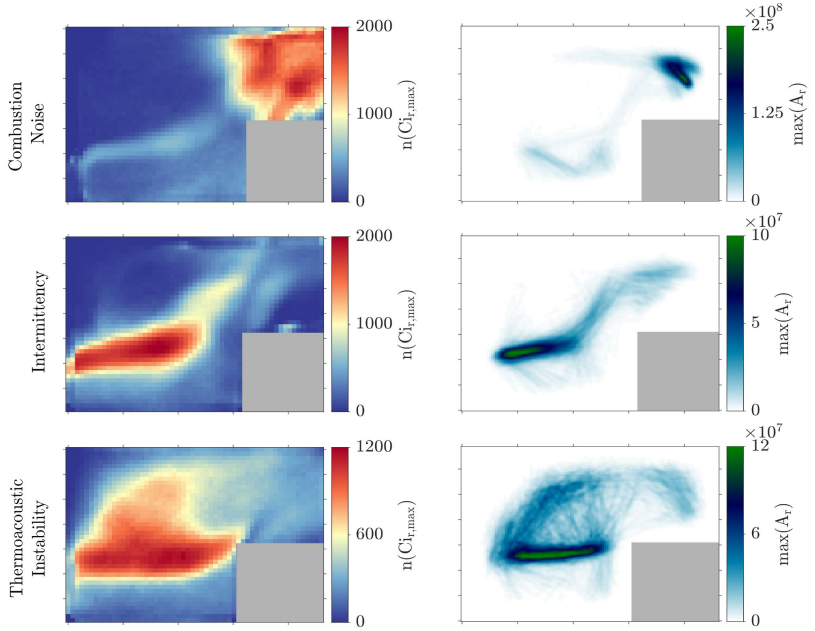
Summary



Interplay between vortical interactions and acoustics quantified via vortical network measures

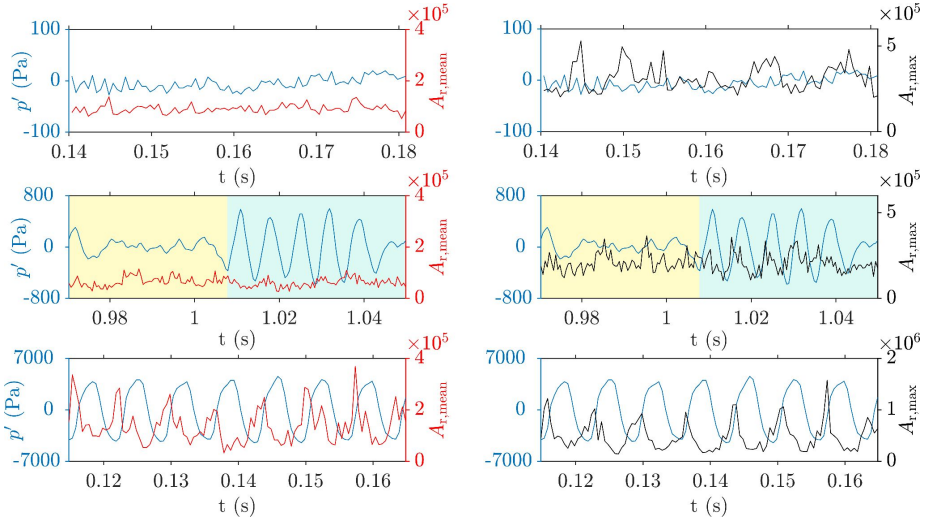


Temporal evolution of influential vortical communities in the reaction field of the combustor

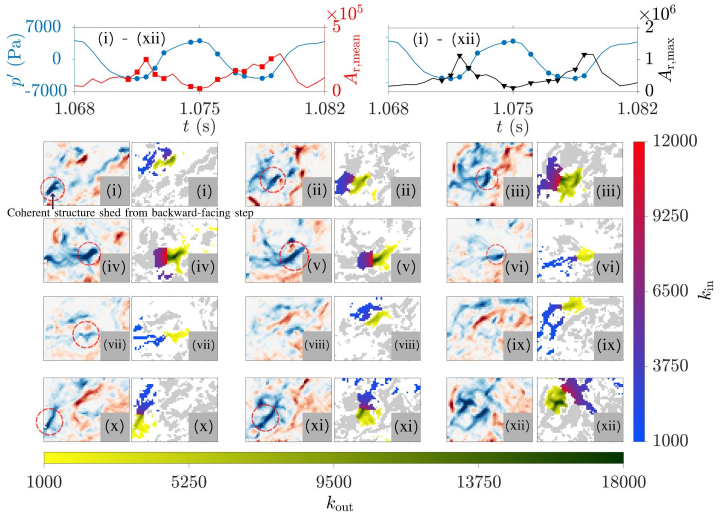


Spatial probability of locating most influential communities during the state of thermoacoustic instability

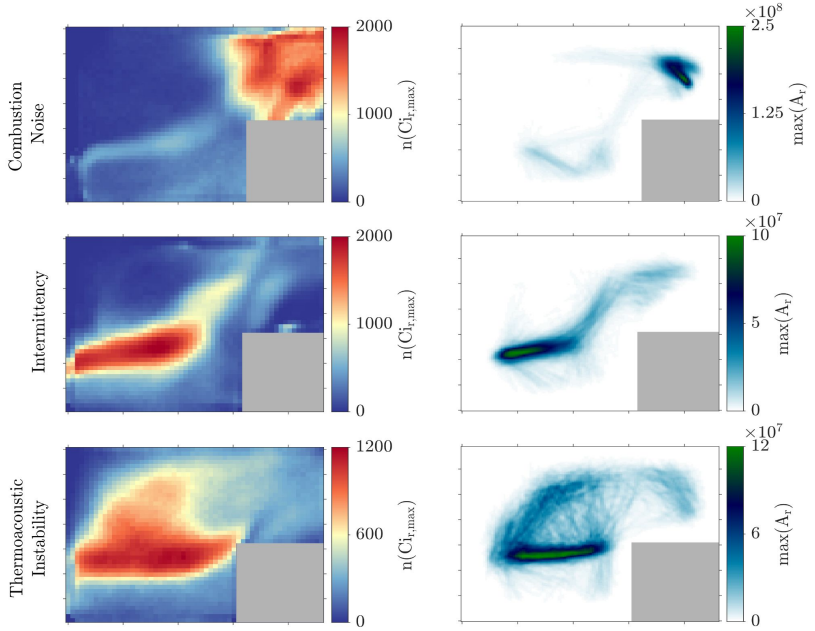
Summary



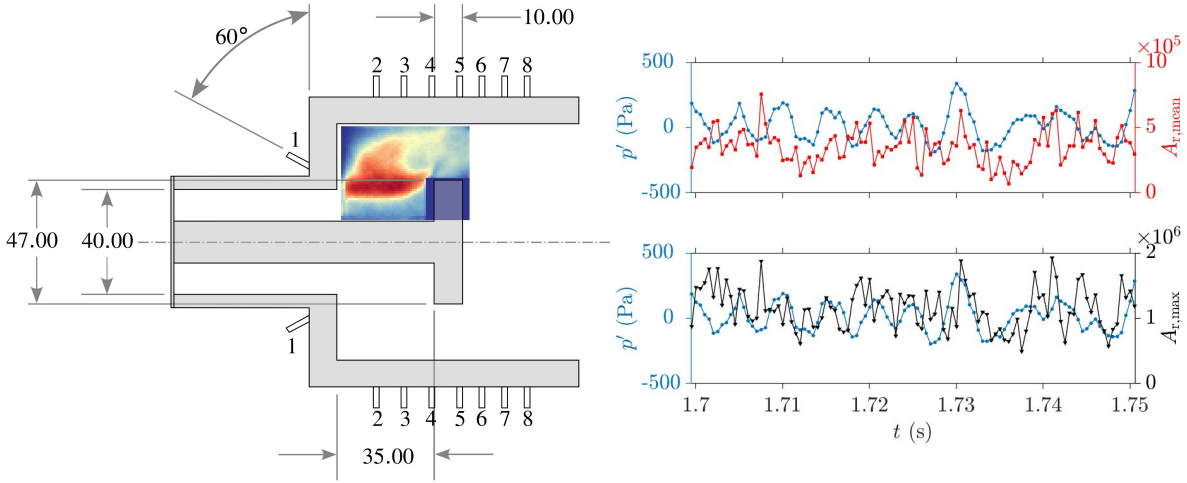
Interplay between vortical interactions and acoustics quantified via vortical network measures



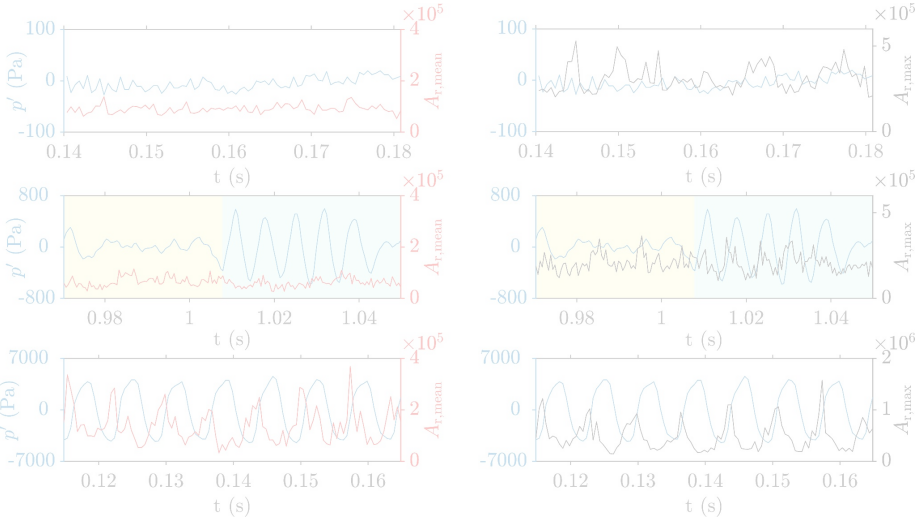
Temporal evolution of influential vortical communities in the reaction field of the combustor



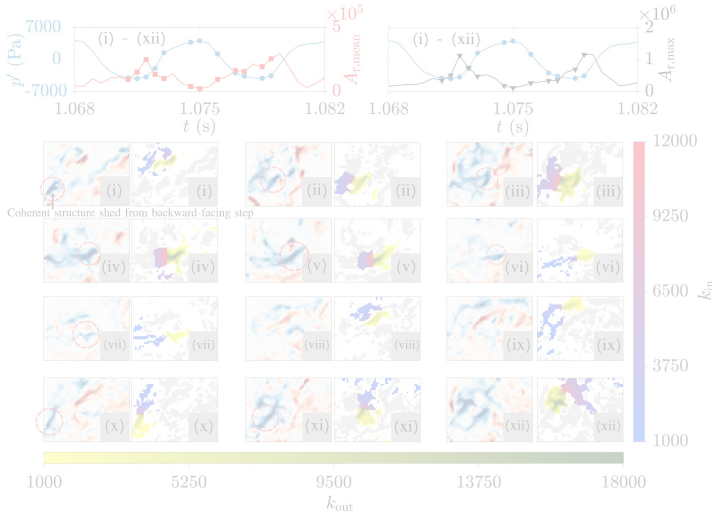
Spatial probability of locating most influential communities during the state of thermoacoustic instability



Summary

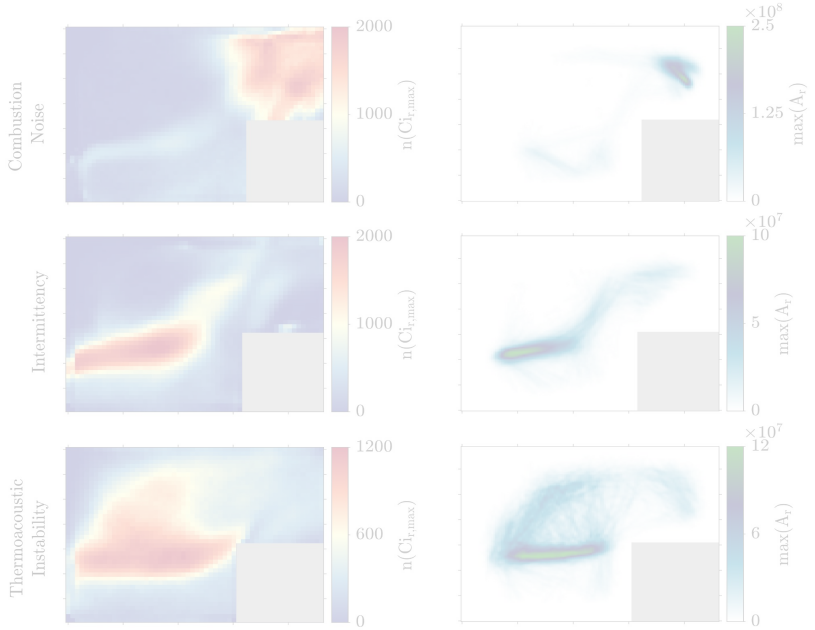


Interplay between vortical interactions and acoustics quantified via vortical network measures



Temporal evolution of influential vortical communities in the reaction field of the combustor

Thank you



Spatial probability of locating most influential communities during the state of thermoacoustic instability