COMSOL CONFERENCE 2014 CAMBRIDGE

3D Acoustic Streaming Field in High-Intensity Discharge Lamps

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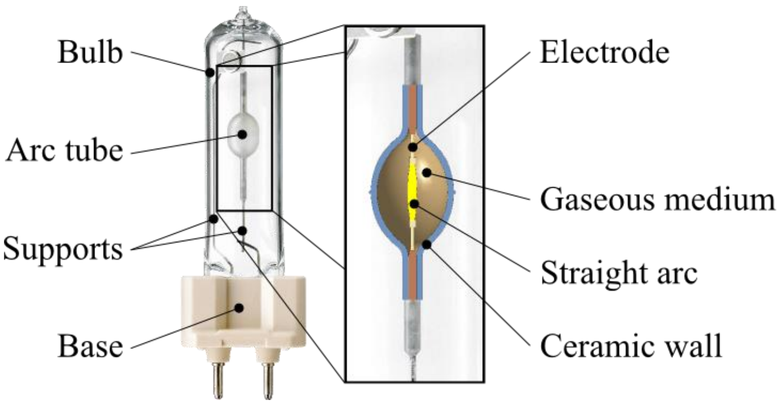
HID Lamps

- High Intensity Discharge (HID) lamp
  - Mercury vapor
  - High-pressure sodium (HPS)
  - Metal halide (MH)
- Lighting applications
  - Streets
  - Stadiums
  - Shops
  - Car headlights
  - …

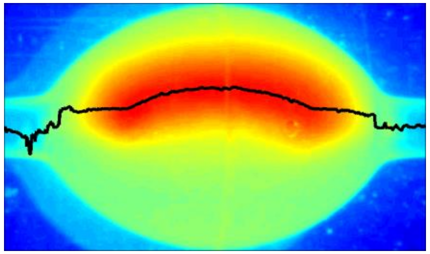
Metal Halide Lamp

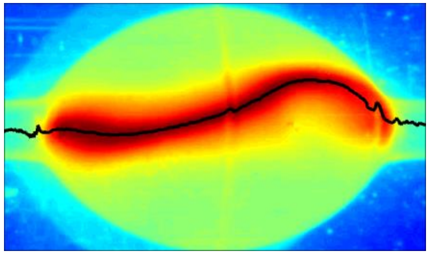
- Bulb, supports, base
- Arc tube
  - Wall: Quartz or ceramics
  - Filling: Mercury, additives (metal halides etc)
  - Pressure: Atmospheric or above
- Electrodes
  - Tungsten
  - Aluminum
- Discharge arc
  - Light source
  - Temperature 5,000 – 6,000 K



AC Operation

- Advantages
  - Avoids demixing of filling
  - Less electrode erosion
  - Cost and energy efficiency (ideal ca. 300 kHz)
- Acoustic resonance (AR) problem
  - Periodic heating excites acoustic resonances
  - Light flicker
  - Reduction of lamp‘s lifetime
  - Lamp destruction





Acoustic Streaming (AS)

- Mystery: Link of high frequency acoustic resonance (ca 300 kHz) to low frequency light flicker (ca 10 Hz)
- Afshar 2008: AS links acoustic resonances and flicker
- Fluid flow generates noise
- Noise generates fluid flow (AS effect)

- Objective: Stationary 3D FE model for AS
- Aim: Improvement of understandig of light flicker
- Test case: Philips 35 W 930 Elite

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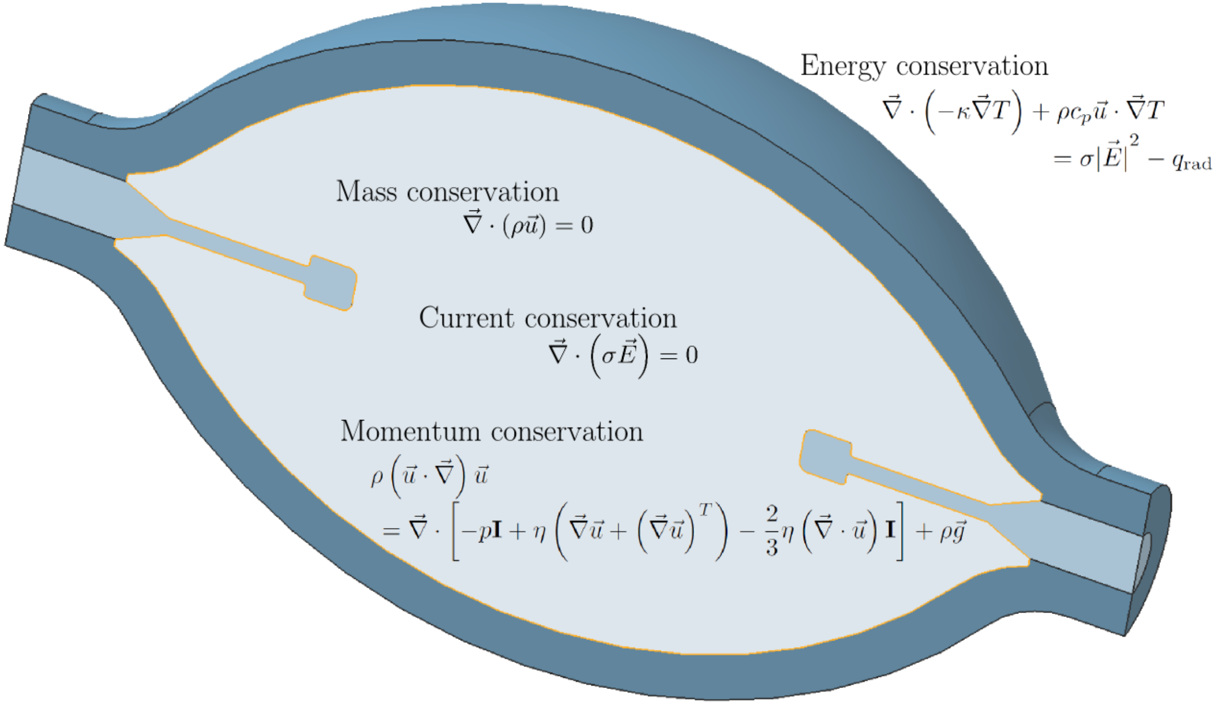
Temperature and Heat Source Distribution



Physical parameters feature complicated temperature dependencies

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Inhomogeneous Helmholtz Equation

Heat source distribution

Acoustic pressure

$$\vec{\nabla}\left(\frac{1}{\rho}\vec{\nabla}p\right)+\frac{\omega^2}{\rho c^2}p=\mathrm{i}\omega\frac{\gamma-1}{\rho c^2}\mathcal{H}$$

Ideal gas law

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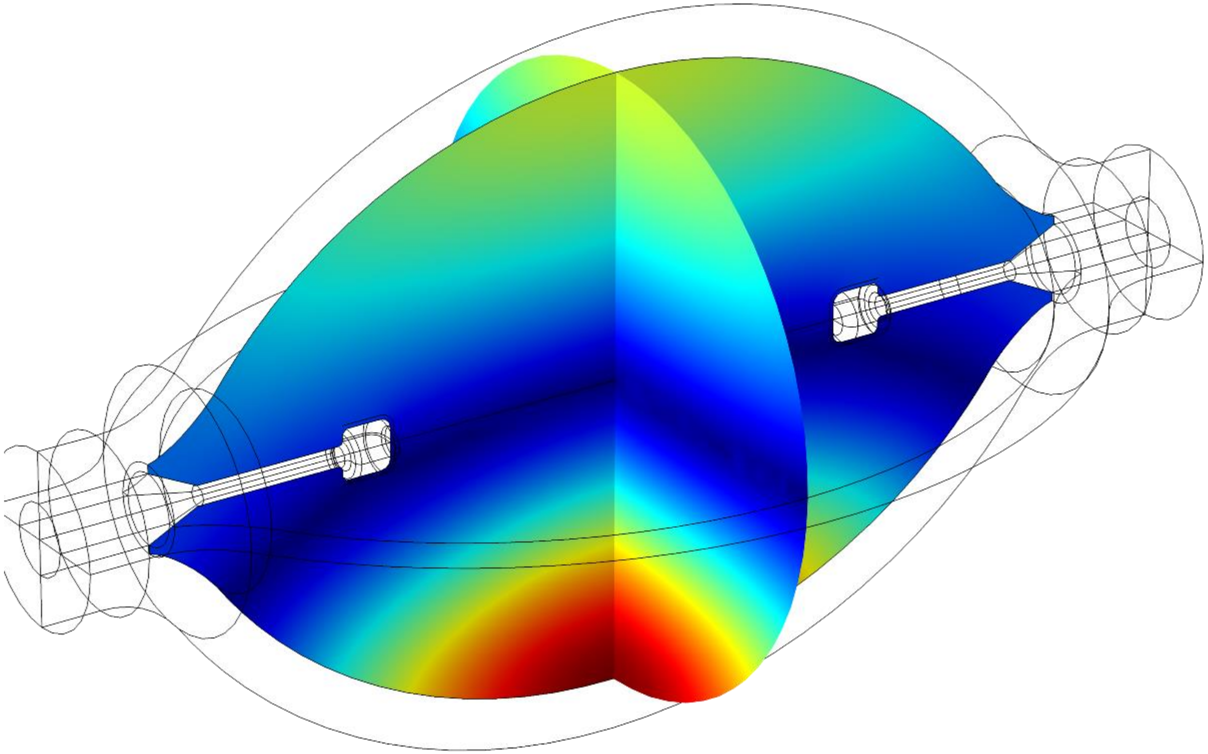
Eigenmode



Eigenfrequency: 47.4 kHz

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Acoustic Streaming

- Navier-Stokes equation with external force density

Time average

Sound particle velocity

$$f_l = \frac{\partial \overline{\rho v_k v_l}}{\partial x_k} - \delta_{l3} \rho g$$

Buoyancy

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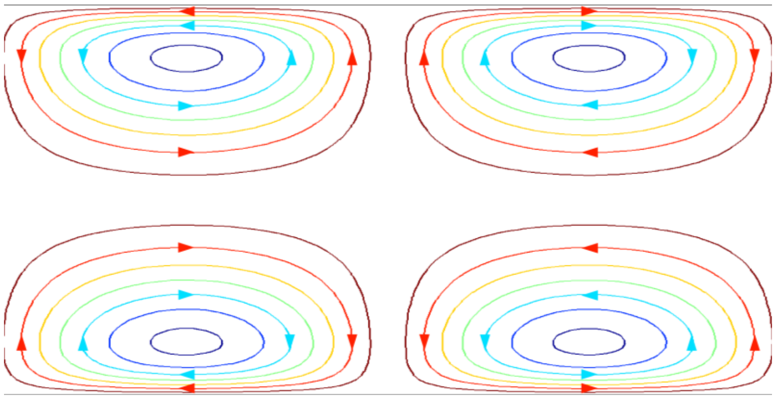
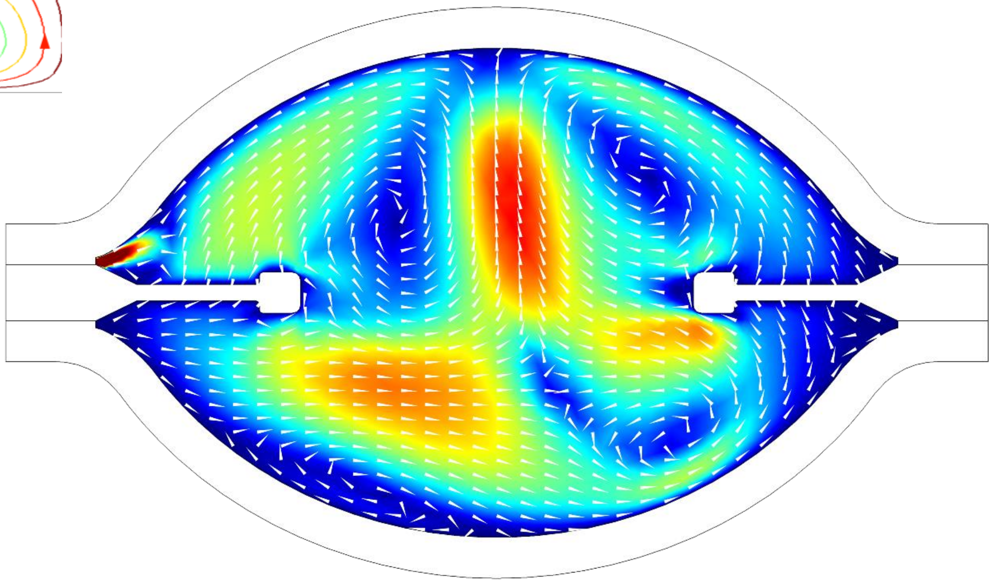
Flow Pattern

Kundt's tube



HID lamp

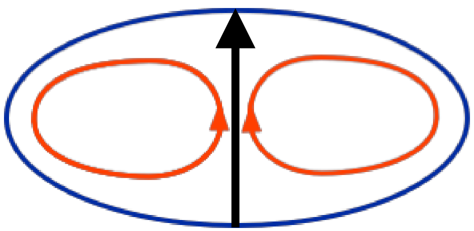


Nonlinear Dynamical System

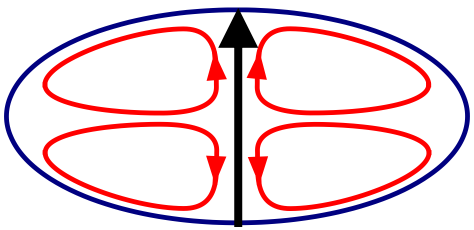
$$f_l = S \frac{\partial \overline{v_k v_l}}{\partial x_k} - \delta_{l3}\, g$$

Control parameter

Buoyancy (S = 0)

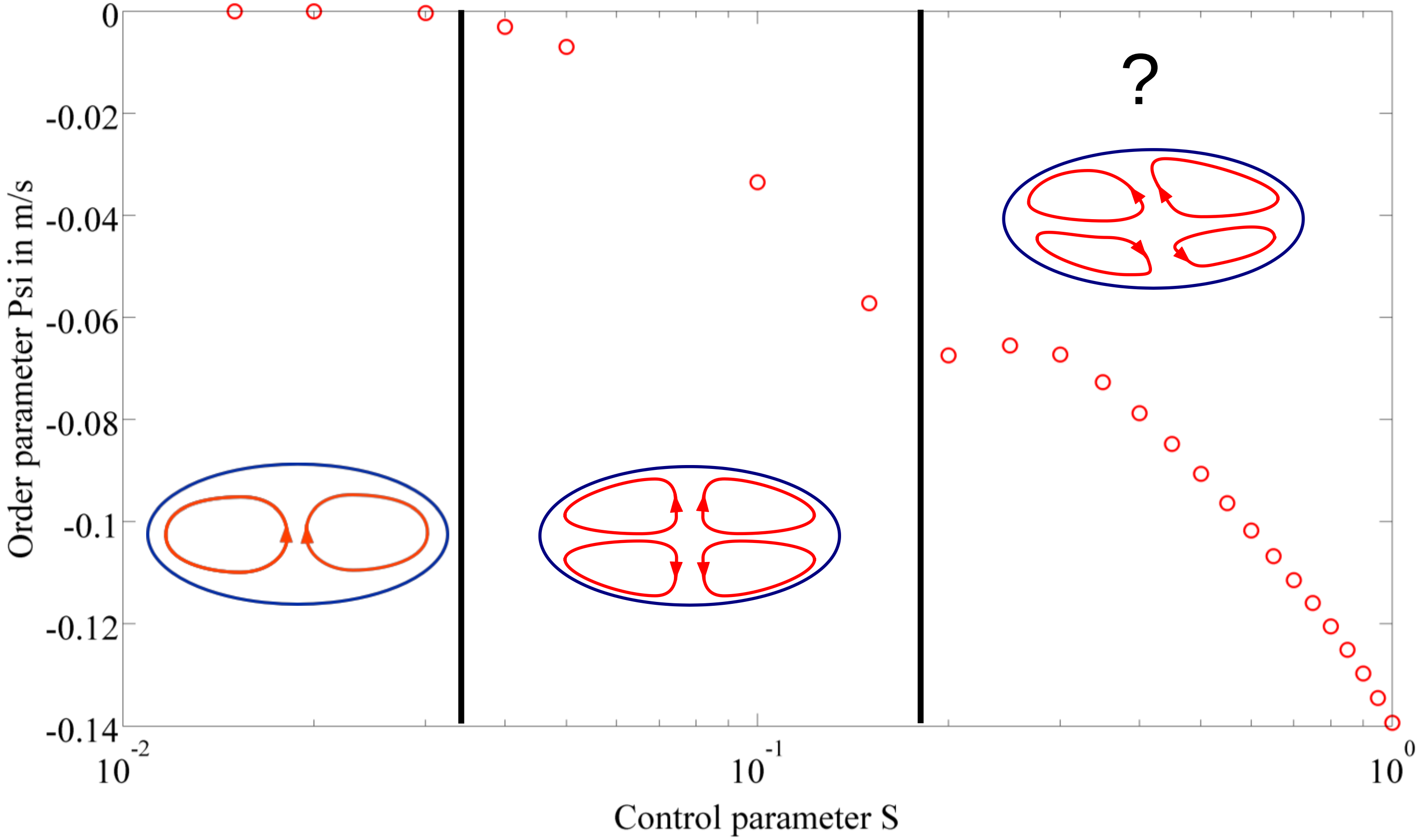


Acoustic Streaming



Order parameter: $$\Psi := \min_{z \in \mathcal{D}} u_z(0, 0, z)$$

Order Parameter for Additional Vortices



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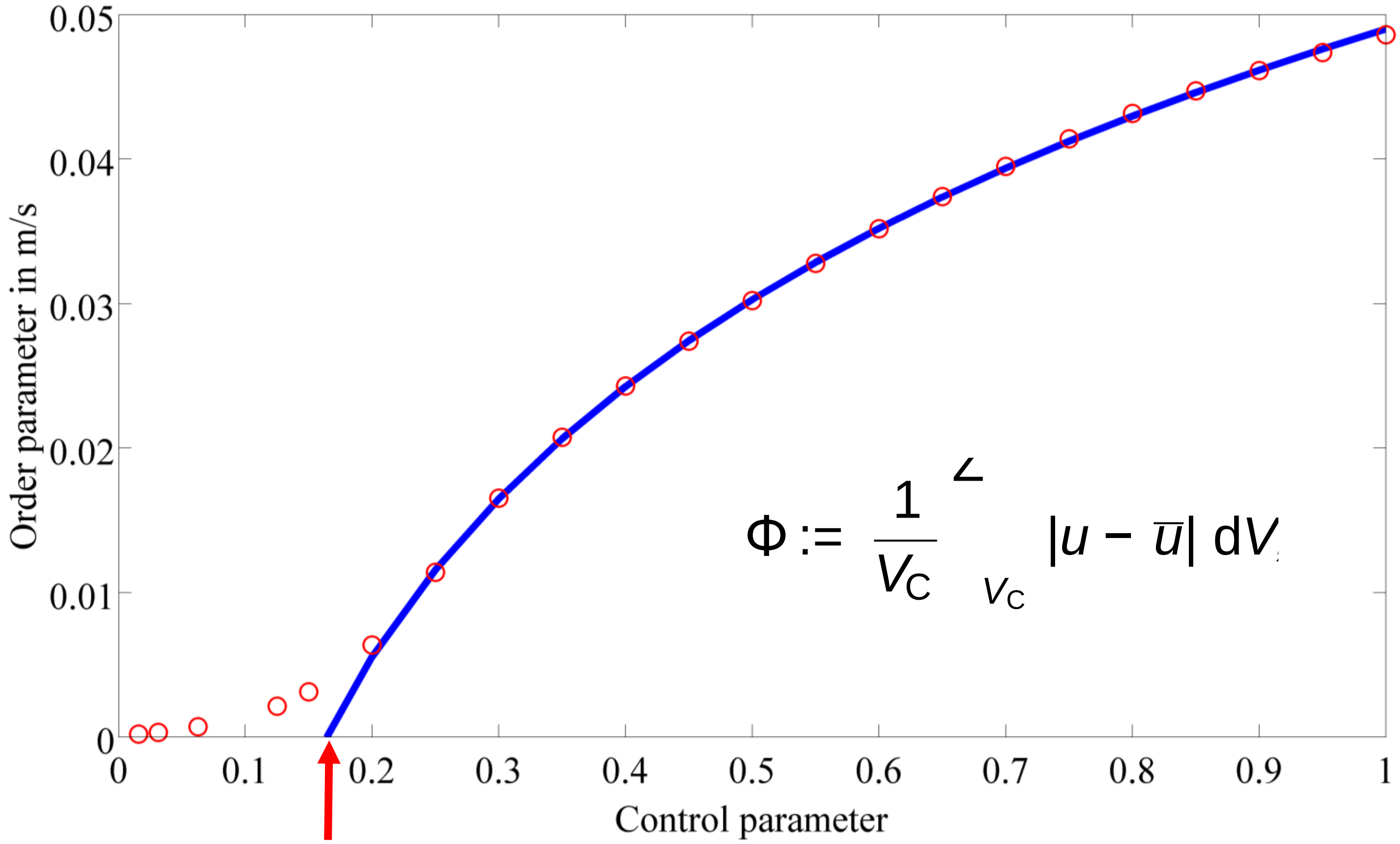
Order Parameter for Mirror Symmetry



$$\Phi := \frac{1}{V_C} \int_{V_C} |u - \overline{u}| \, dV$$

Critical point

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Strategy

- Flicker: Transient process
- FE model: Stationary
- Investigate stability of stationary solutions (linear stability analysis)
- Flicker related to onset of instabilities
- Conjecture: Asymmetric state is unstable
- CPU-time and memory requirements orders of magnitude smaller than in transient model

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Conclusions

- Stationary 3D FE model for calculation of acoustical streaming field in arc tube of HID lamps
- Consistent results obtained for prototype lamp
- Symmetry breaking
- Recursion needed to account for feedback of AS on temperature field
- Arc straightening

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Thank you!

Questions?