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Italian Section of the Combustion Institute

Structure and Dynamics of Hexagonal Cells in H_2/CO_2 Flames

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Motivation

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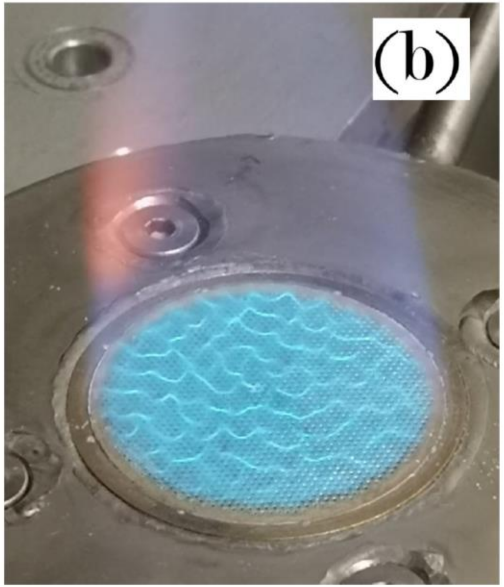
- Hydrogen is an important fuel for a sustainable energy landscape
- It can be produced from biomass where mixtures of H_2 and CO_2 are created
- Instead of separating CO_2 it can be burned together with H_2
- However, addition of CO_2 lowers the Lewis number of the mixture, making even rich hydrogen flames thermodiffusively unstable
- In a recent experimental work, cellular structures of H_2/CO_2 flames were studied on a heat-flux burner
- These types of cellular structures were investigated before in the literature, but no numerical studies are available

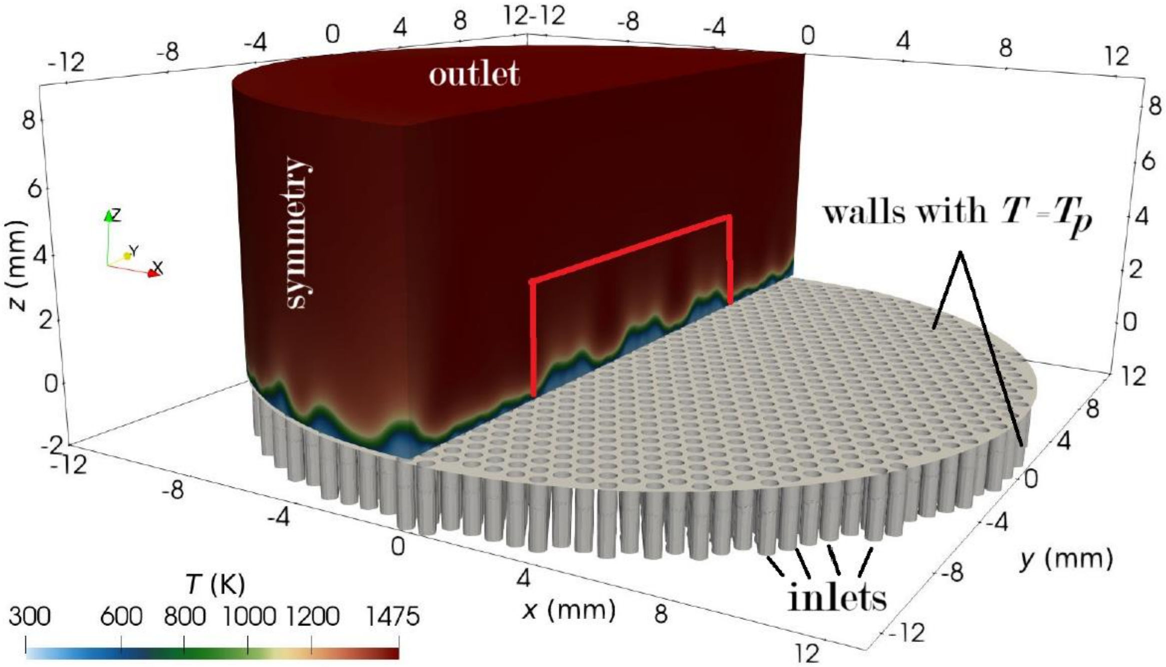
Experimental setup

- Heat-flux burner with a burner plate with diameter 30 mm
- Consists of 1519 holes with diameter 0.5 mm
- Plate is actively temperature controlled and can be heated up to 473 K
- OH chemiluminescence measurement



Numerical setup

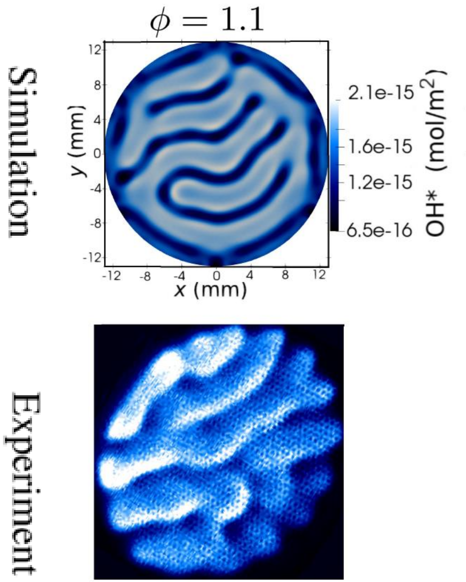
- The numerical setup follows the experiment
- Slightly lower diameter (26 mm)
- 9 mm gas phase considered above the burner plate
- All holes are fully resolved with channels of length 2 mm
- Flame resolved with 15-40 cells
- In-house code EBI-DNS
- Detailed molecular diffusion
- DRM19 reaction mechanism



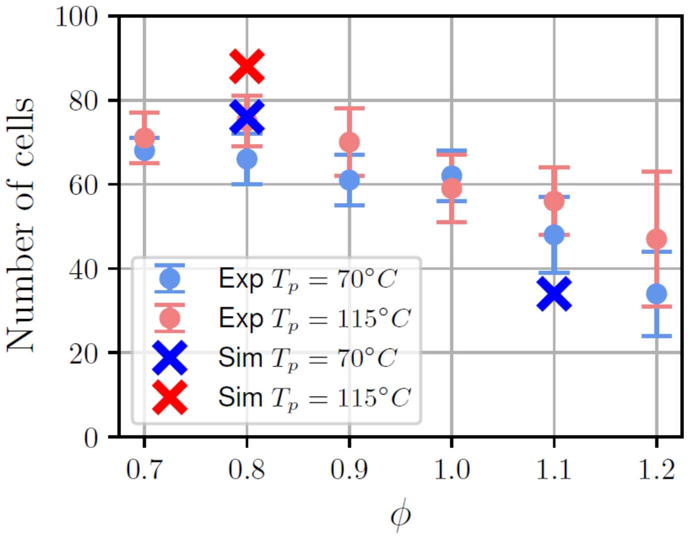
gas enters at 30°C

Validation

- Comparison of cell structure



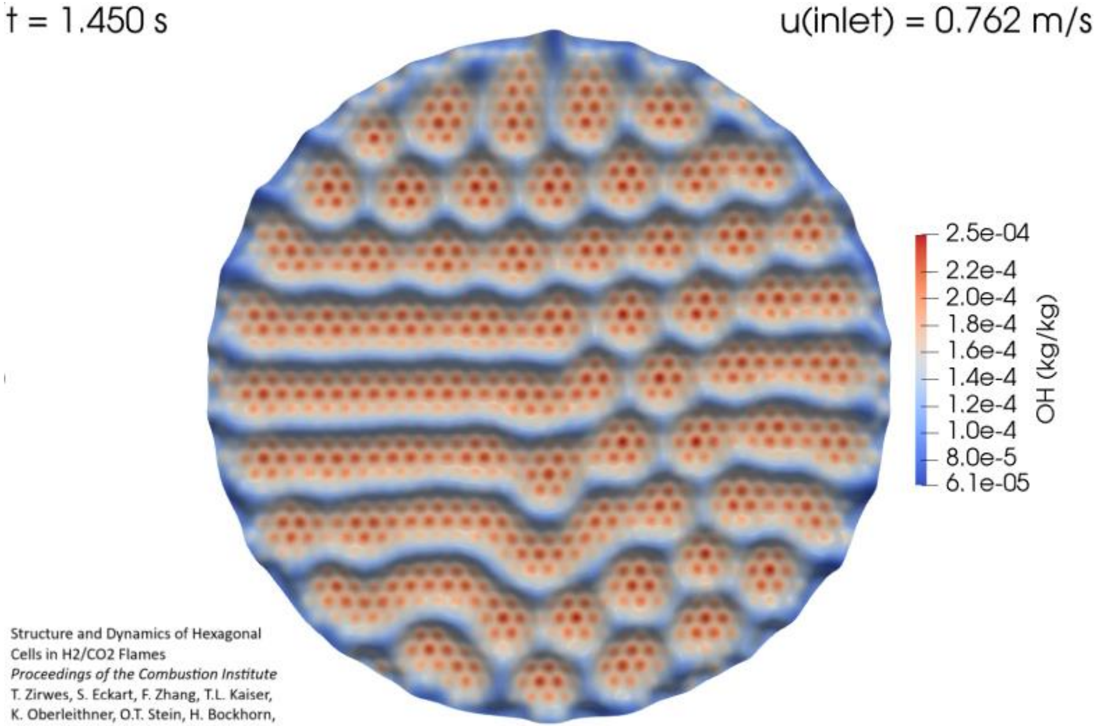
- Comparison of cell number



Effect of mass flow rate

Increasing mass flow rate at constant plate temperature

- Temperature iso-surface T = 900 K colored by OH mass fraction
- Plate temperature 115°C
- Equivalence ratio 0.8
- H_2/CO_2 = 35/65
- Transition from band-like to hexagonal structures
- Once the hexahedral cells are formed, their size stay nearly the same but they become more pronounced



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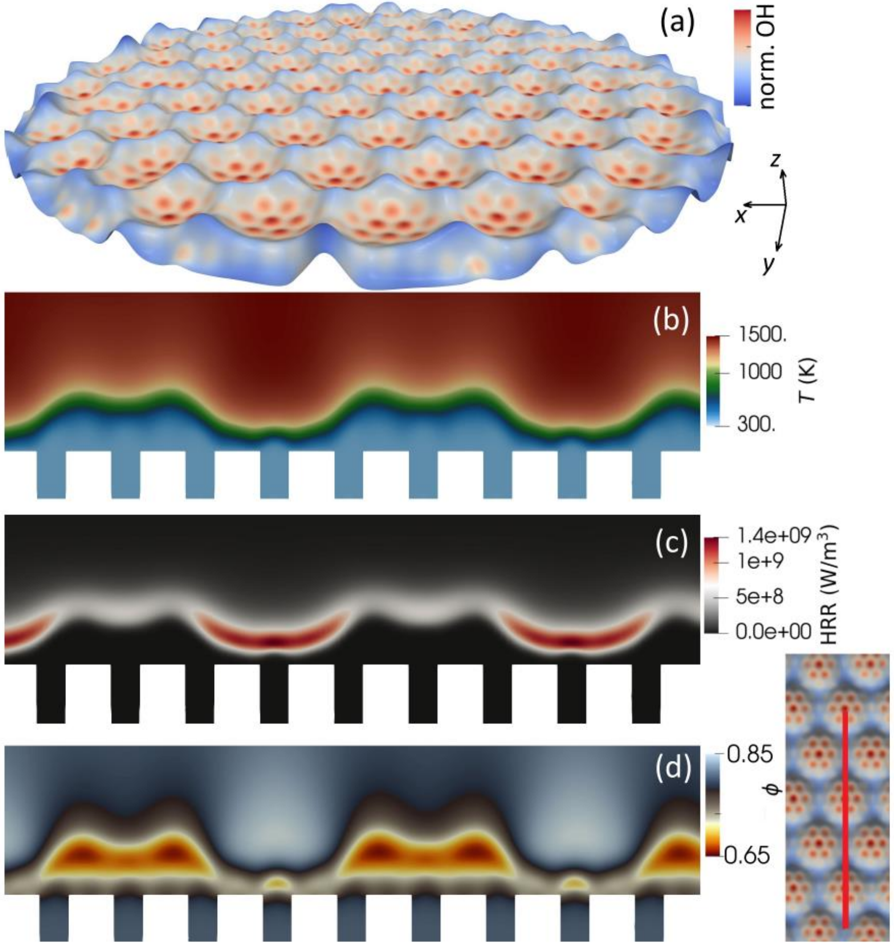
Structure of hexagonal cells

- Typical structure of thermo-diffusively unstable flame
- Flame lifted furthest at negatively curved flame segments
- Likewise, flame burns closest to plate at positively curved flame segments
- (results shown for steady-state simulation)

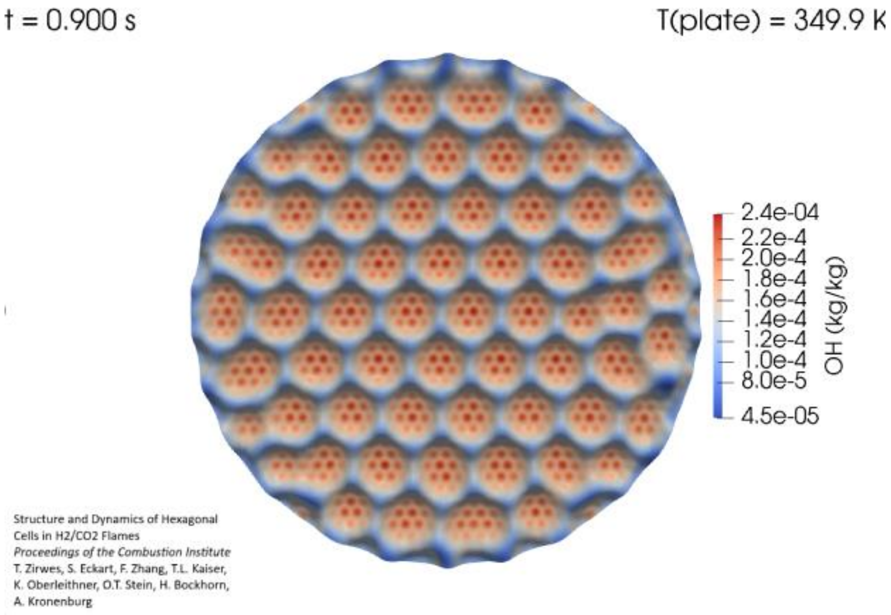


$$\dot{m}_{\text{bulk}} = 0.46\,\text{kg/m}^2/\text{s}$$

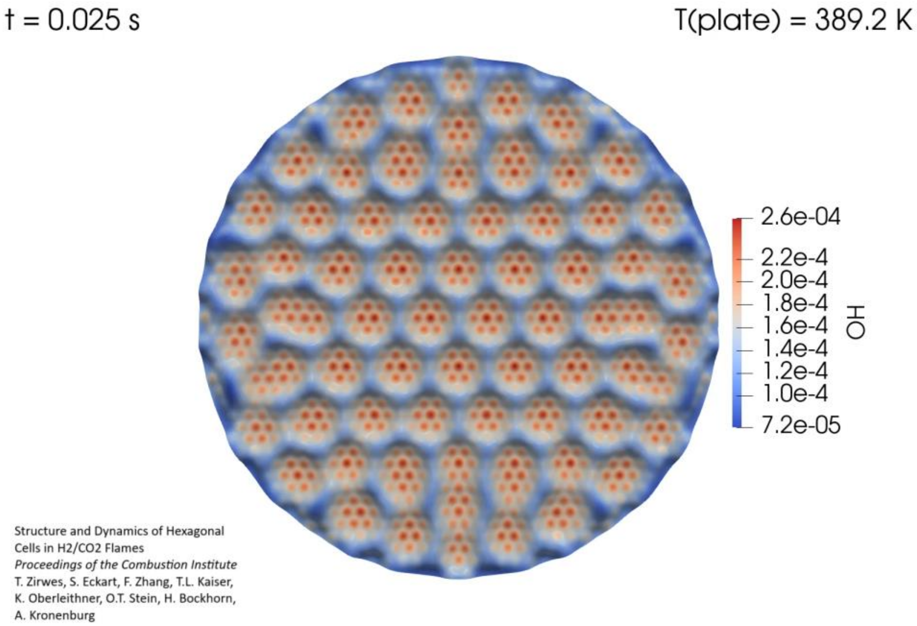
Effect of pre-heating

Effect of pre-heating

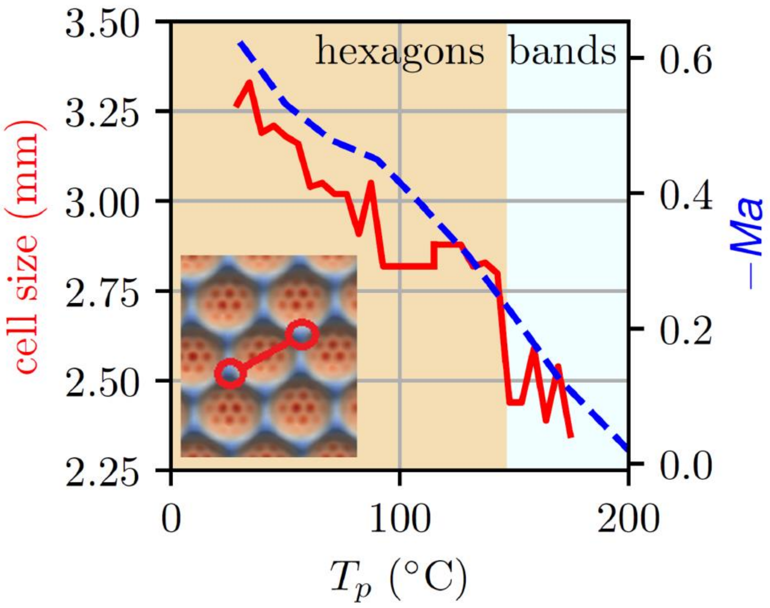
Cooling



Heating



- As the burner plate is cooled at constant mass flow rate, the size of the hexahedral cells increases
- As the burner plate is heated (the gas is pre-heated), the cells shrink and then transition to the band-like structures
- Eventually, the flame becomes flat
- This can be correlated with the temperature dependent Markstein numbers obtained from 1D counterflow flames

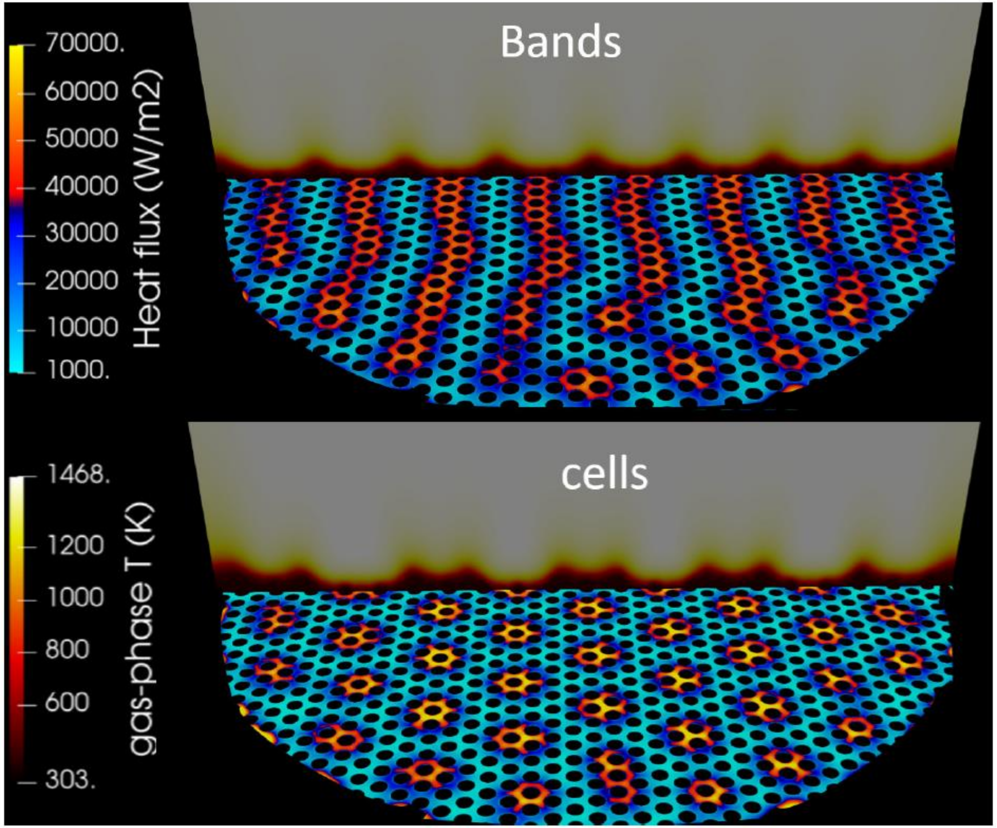


$$Ma = -\frac{\partial s / s_L^0}{\partial Ka},$$

Heat losses

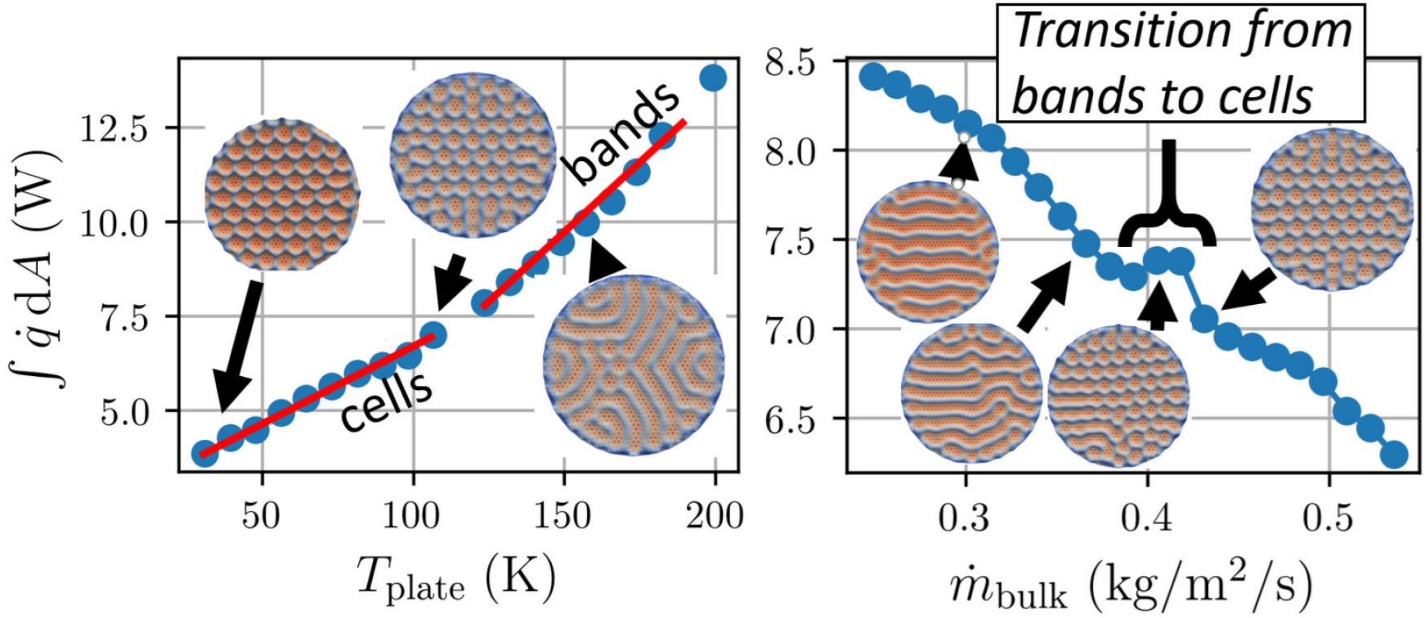
Heat losses to the burner plate

- Heat flux to the burner plate
- For band-like structures, the area with high heat losses is larger
- But for the hexahedral cells, more intense heat loss is observed



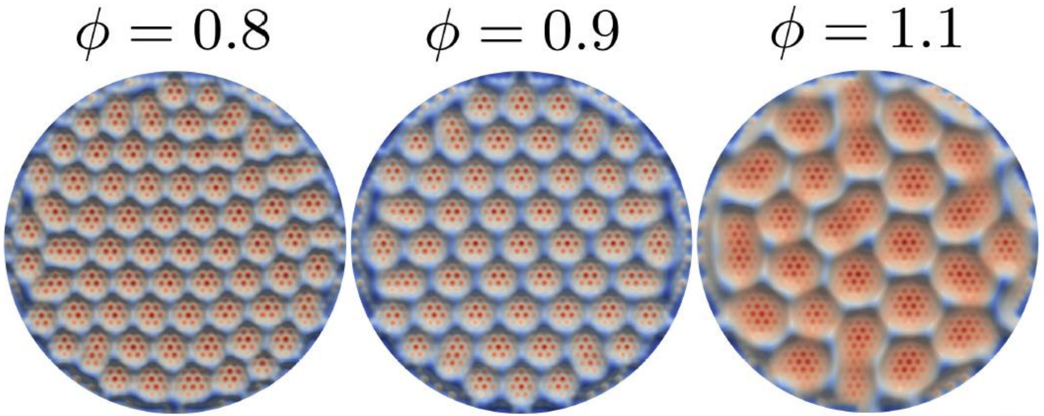
Heat losses to the burner plate

- The transition from bands to cells can be observed in the total heat loss to the plate:



Influence of equivalence ratio

- Strong influence of equivalence ratio on cell size
- More detailed analysis left for future work



ϕ	$\|Ma\|$	cell size d (mm)	$\|Ma\|/d$ (mm^{-1})
0.8	0.40	3.0	0.13
0.9	0.41	3.7	0.11
1.1	0.44	5.5	0.08

Conclusions

- Cellular structures stabilized on flat-flame burners show typical characteristics of thermodiffusively unstable flames
- Increasing mass flow rate enhances local stretch and local heat release rates, but cell diameters stay nearly the same
- Pre-heating decreases the cell size and eventually leads to a flat, thermodiffusivley stable flame
- Full 3D datasets available online (link in paper)

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Thank you!

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