Turbulent Combustion of Ammonia at USYD

A.R.W Macfarlane, M.J. Dunn, A.R. Masri
School of Aerospace, Mechanical and Mechatronic Engineering
The University of Sydney

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NZI at USYD

The Net Zero Initiative

THEME

Zero Emissions Energy & Industry

PILLARS

Renewable Energy including solar and wind
Energy Hybridisation
Powerfuels including hydrogen and ammonia
Greenhouse Gas Conversion and Utilisation
Alternative Energy

THEME

Climate Change Risk

PILLARS

Projects in the face of climate change
Net Zero Agriculture
Water security
Net Zero Health

THEME

Greenhouse Gas Removals

PILLARS

Direct Air Capture
Nature-based Carbon Removal including coastal carbon capture

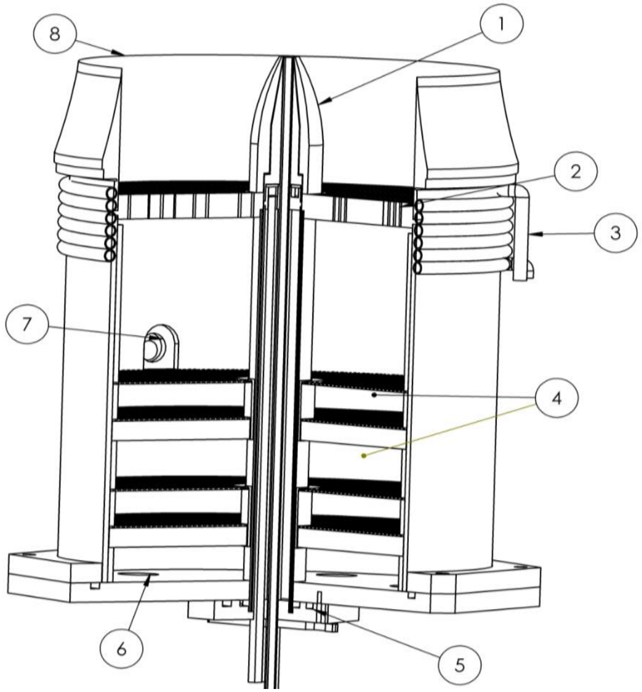
THEME

Demand Reduction

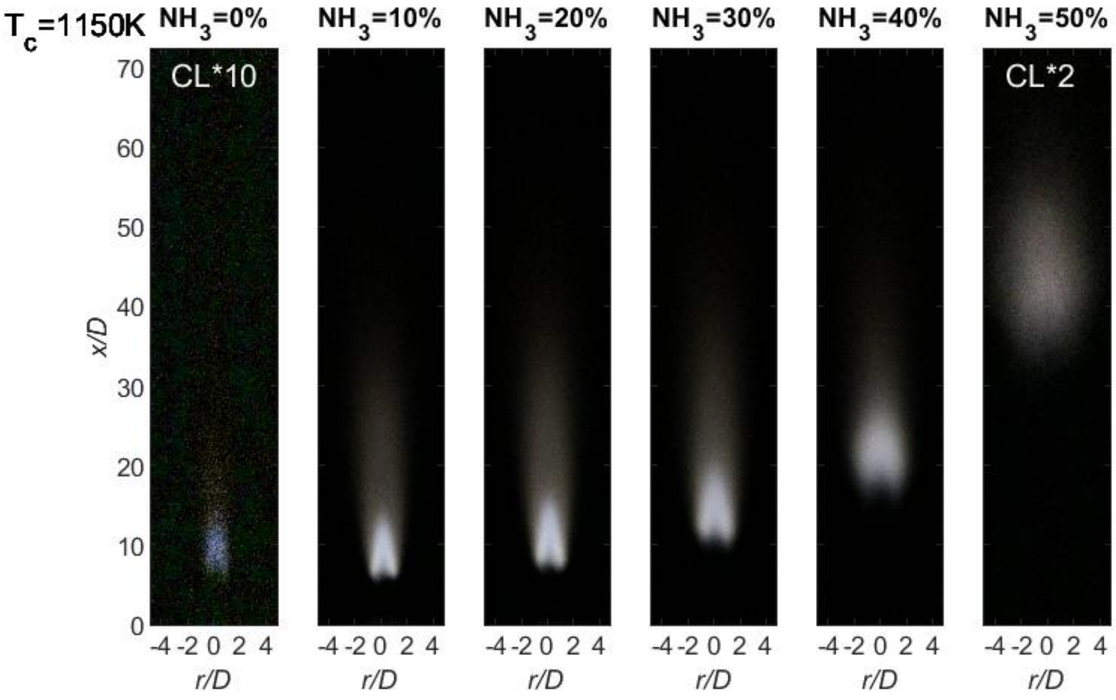
PILLARS

Smart Net-Zero Energy Buildings
Critical Minerals
Electrification
Transport including land and aviation
Circular Economy

Turbulent Autoigniting NH_3 flames



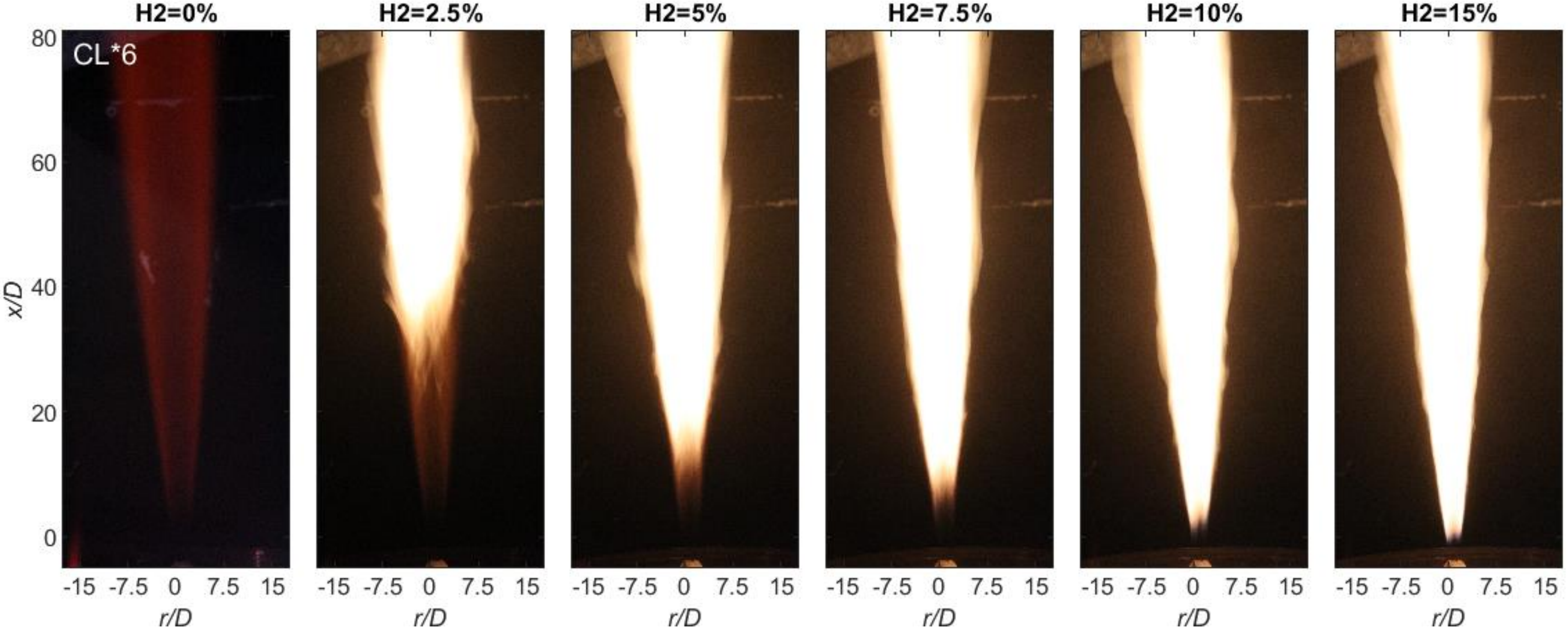
Vary % NH_3



H_2/NH_3:Air =1:2, U_{jet}=100 m/s, T_c = 1150 K

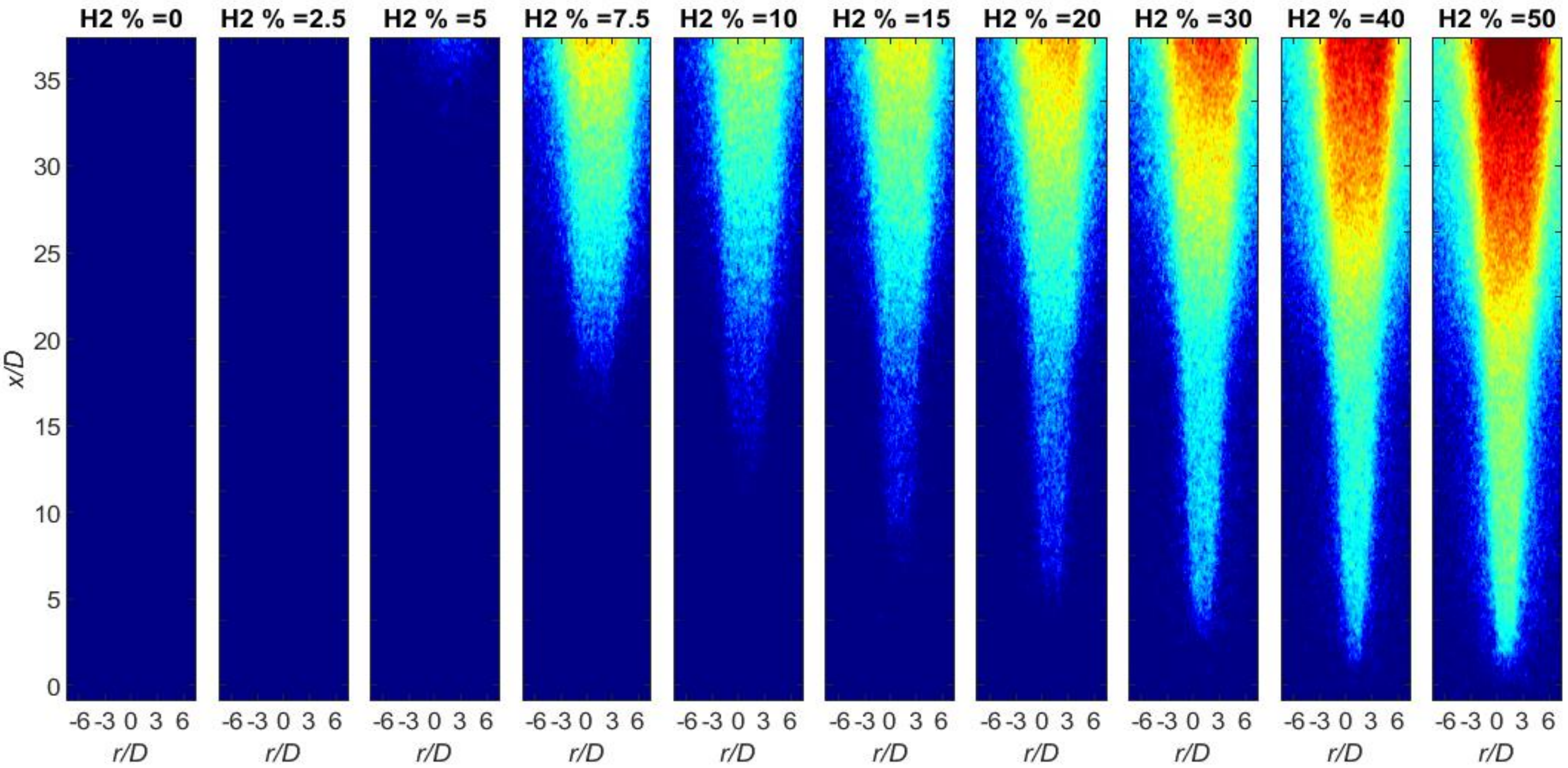
- Well established jet in hot coflow geometry
- Partially premixed NH_3/H_2 flames
- The ratio of NH_3 to H_2 controls fuel reactivity

NH_3/H_2 Coflow Images, Tc= 1450K



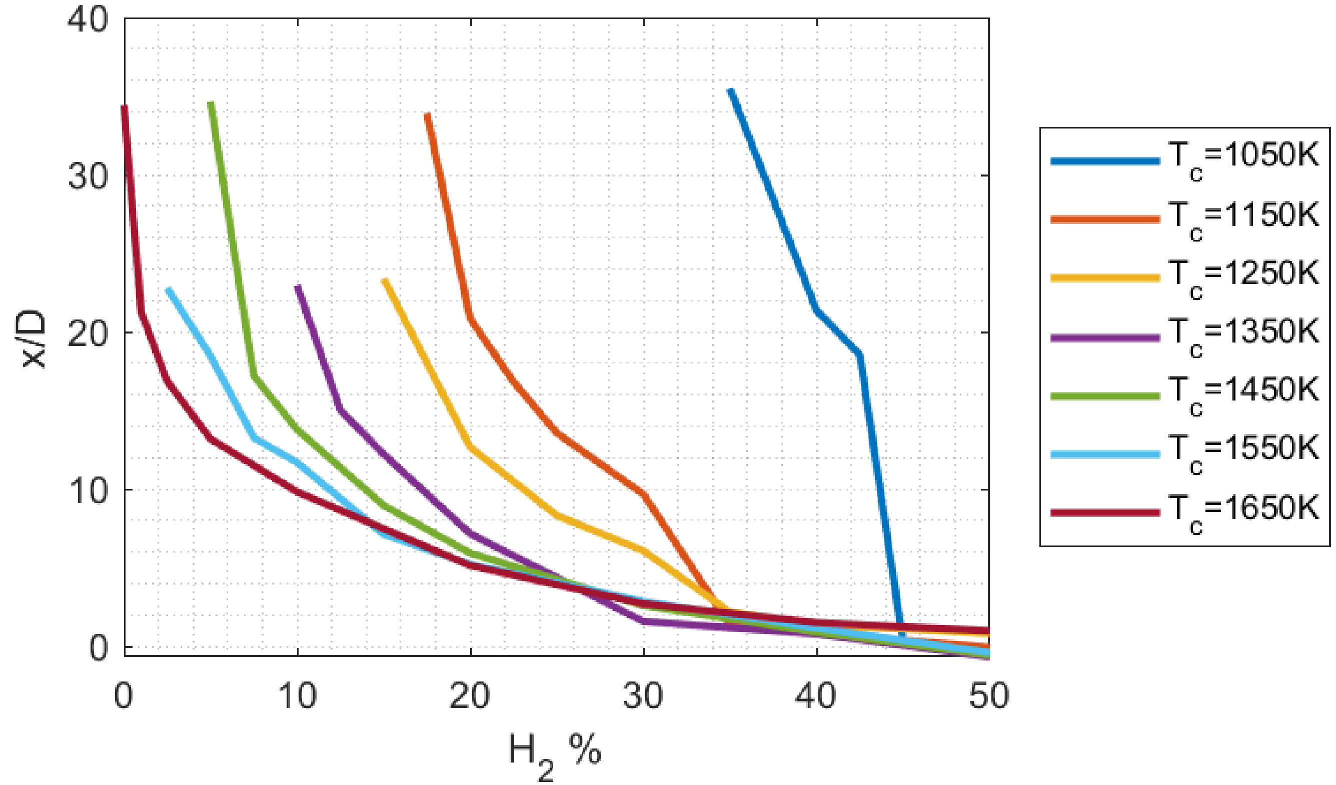
- High coflow temperature of Tc=1450 K to burn NH_3
- For pure NH_3 the flame resembles a distributed regime (MILD)
- Only 2.5% H_2 causes a significant increase in chemiluminescence (NH_2)
- For all flames there is a low intensity region upstream

NH_3/H_2 OH* Images, Tc= 1550K



- The addition of 5-7.5 % H_2 causes a rapid increase in OH*
- **$Re_{NH3/H2:100/0}$= 20 100**
- **$Re_{NH3/H2:50/50}$ =9 900**

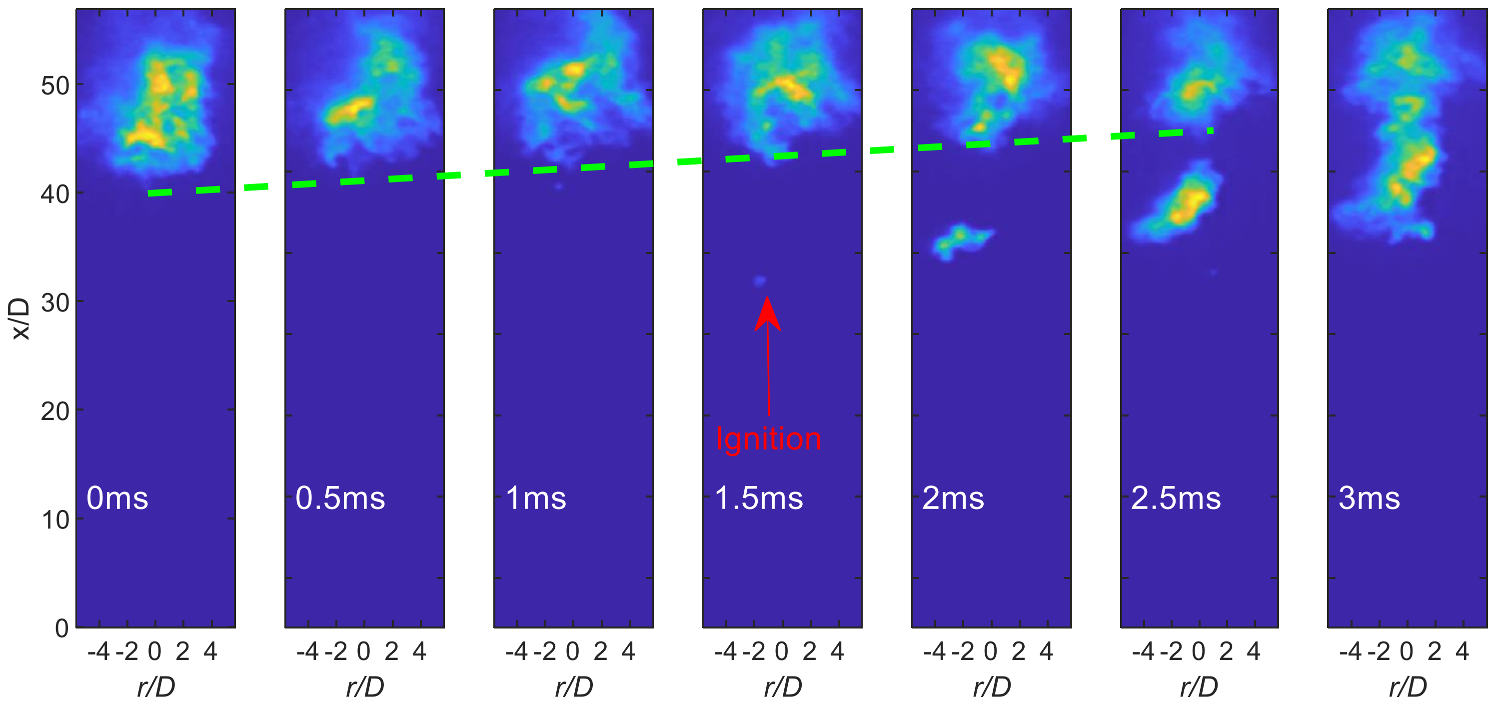
OH* NH_3 /H_2 Lift off heights



- For reduced coflow temperature more H_2 is required to create a ‘stable flame
- More than 40 % H_2 is required for Tc = 1050K
- The sensitivity of H_2 addition is different for different coflow temperatures
- **$Re_{NH3/H2:100/0}$= 20 100**
- **$Re_{NH3/H2:50/50}$ =9 900**

Next: Autoignition Kernels

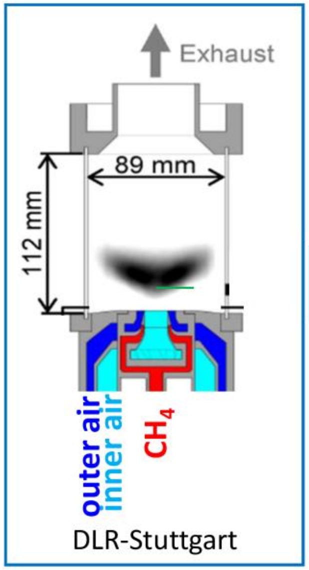
Future: High-speed Imaging of Heat Release zones to identify Ignition Kernels

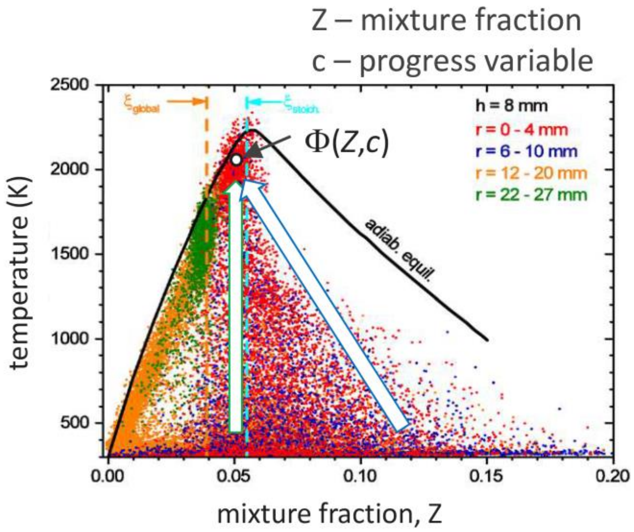


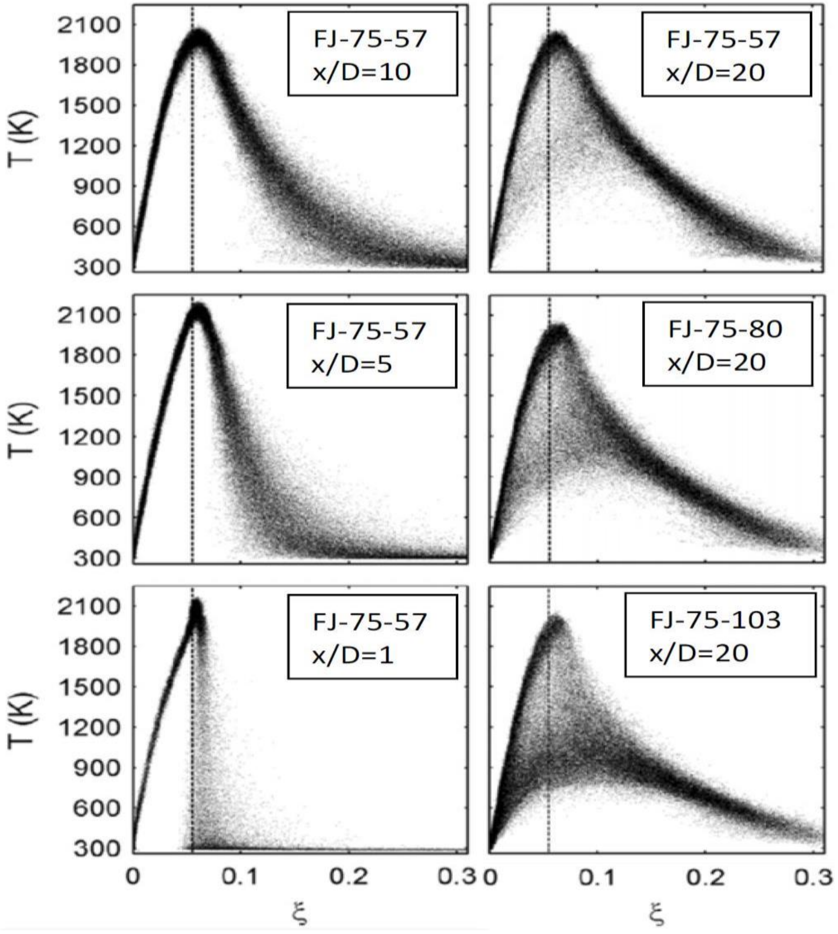
- An example of an autoignition event and its growth and advection downstream for Dimethyl Ether at U = 100 m/s

Mixed-Mode Combustion

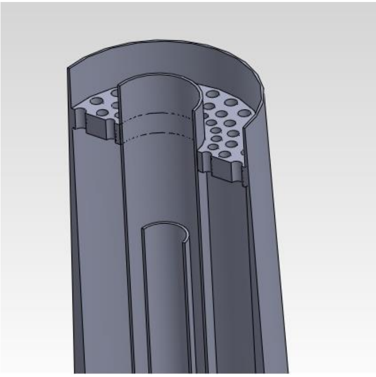
Common in practical combustors where diffusion, premixed and stratified flames may co-exist







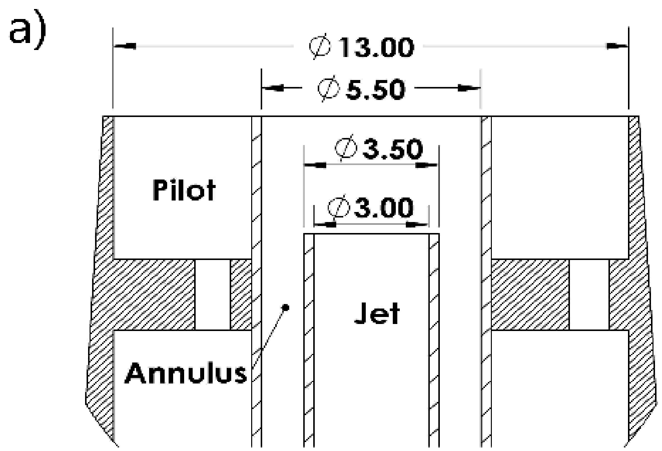
Sydney Piloted Inhomogeneous Burner creates this medium in laboratory.

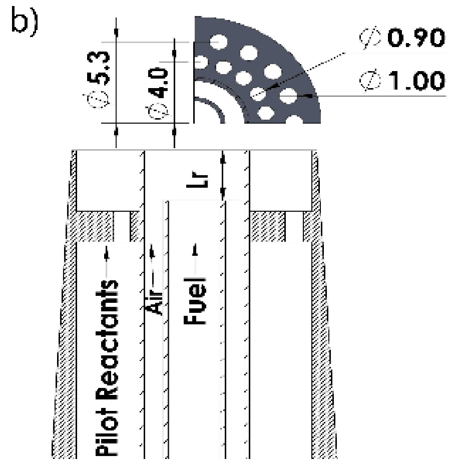


Meier et al., Exp. Thermal & Fluid Sci. 73 (2016) 71–78

Courtesy of Dr Robert Barlow, Sandia National Labs, Livermore CA

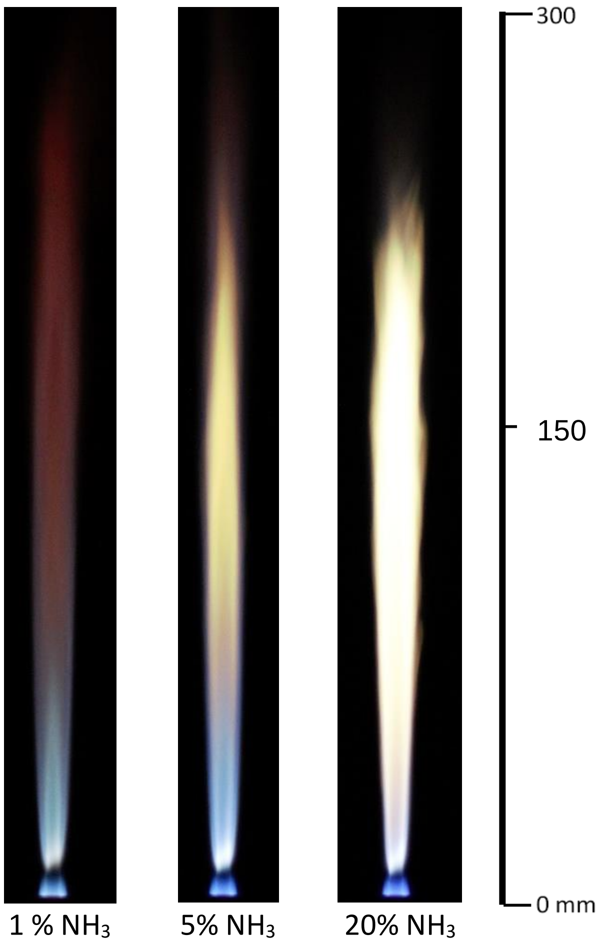
Turbulence chemistry interaction of NH_3 flames Sydney inhomogeneous Burner





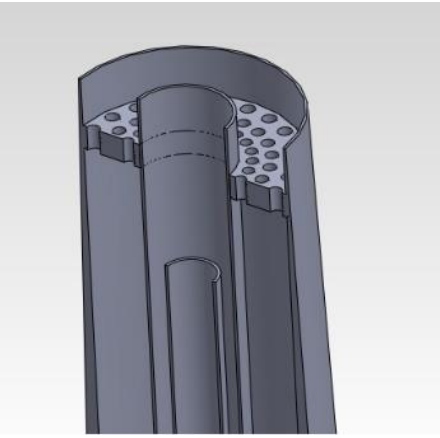
- Three concentric tubes
  - Pilot ($\emptyset = 13\ mm$), Annulus ($\emptyset = 5.5mm$) and inner fuel Jet ($\emptyset$ =3mm)
- Fuel jet recessed (L_r = 0 - 300 mm) to premix fuel and air within the burner
  - L_r = 0mm, Diffusion flame
  - L_r=300mm, Premixed flame

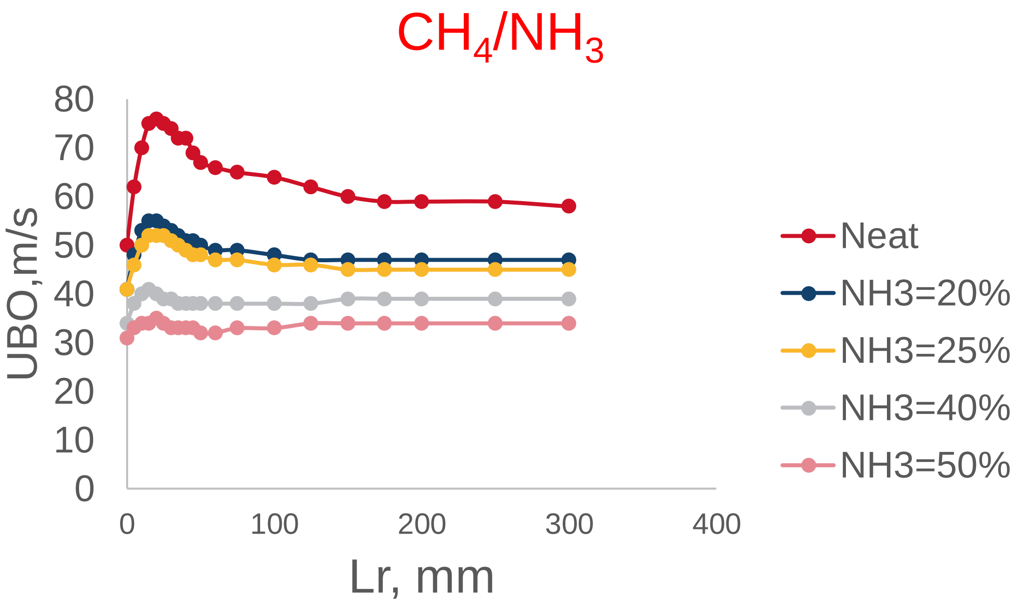
Appearance of Hydrogen Flames with various % of NH_3

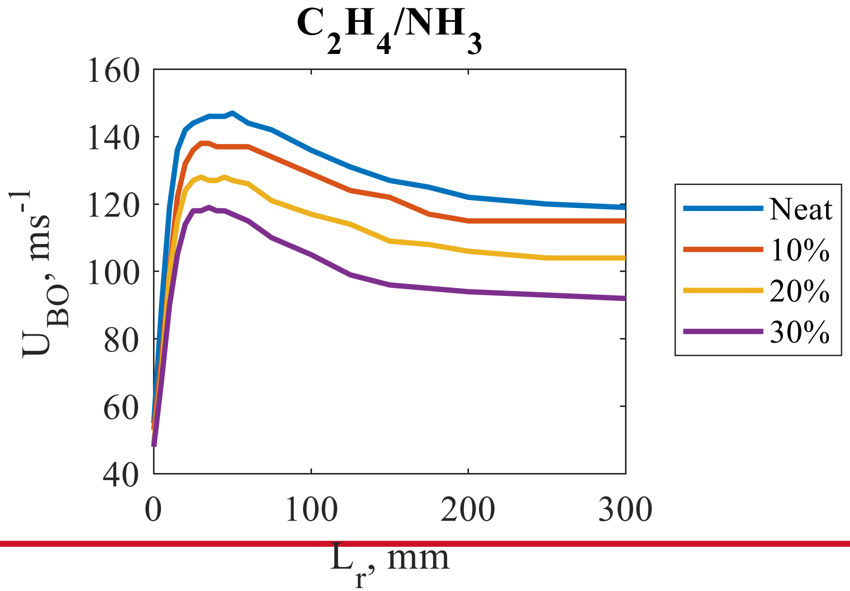


Multi-Mode Combustion

Sydney Inhomogeneous Burner

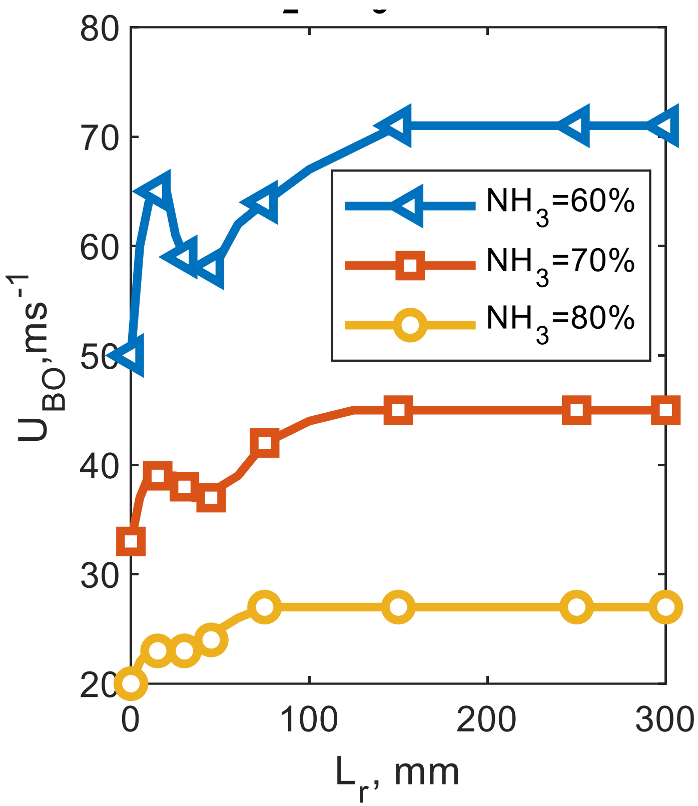






Enhanced stability for Green Fuels in Co-firing modes at optimal recess, L_r

Stability Plots: H_2/NH_3:Air

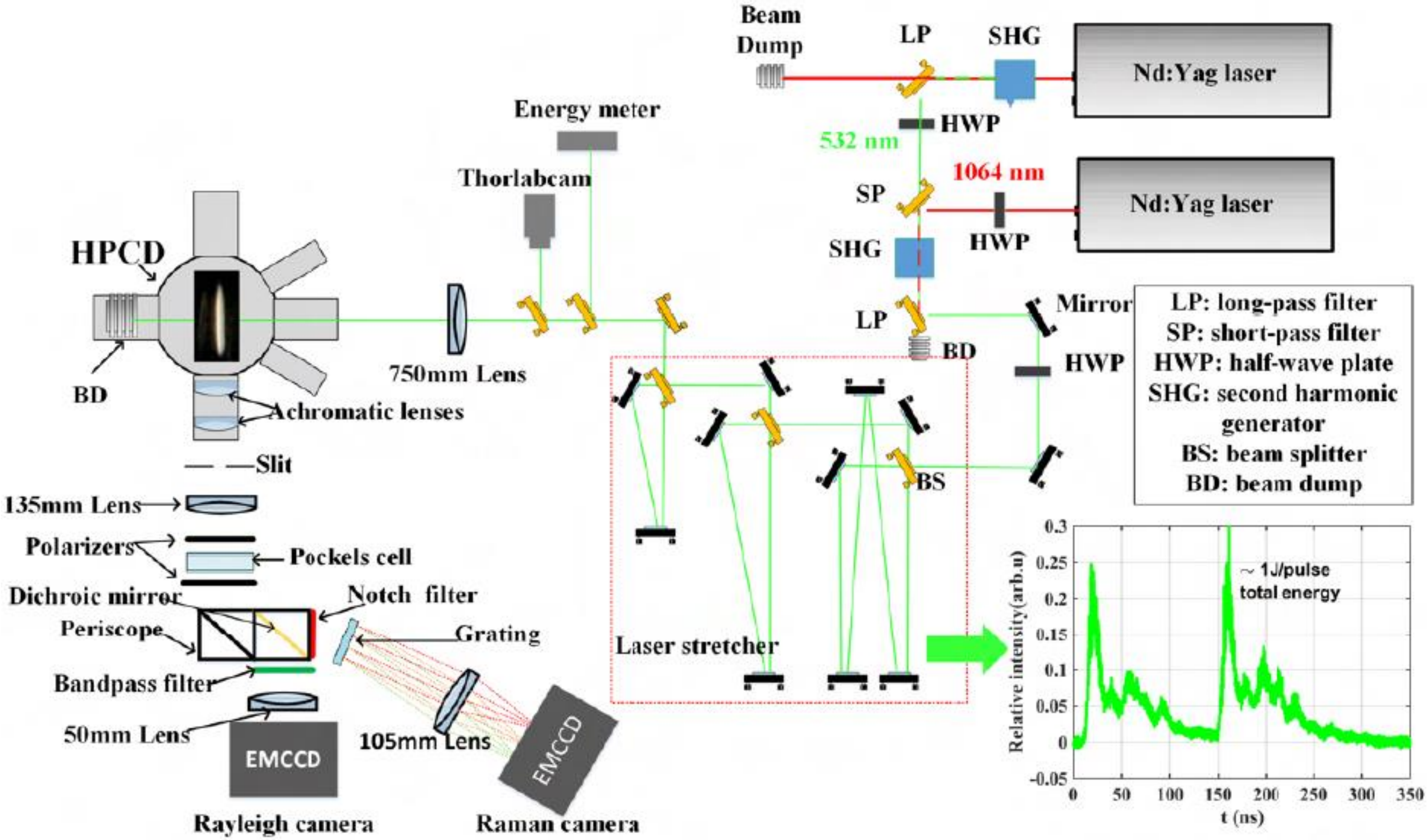


Ethylene-air pilot, $\dot{Q}_P = 285$ W

- Local peak in blow-off velocity (U_{BO}) L_r = 25mm
- Peak, U_{BO} is suppressed with NH_3 addition
- Homogenous limit (L_r=300) reduces U_{BO} significantly with NH_3 addition; reduction corresponds to the laminar flame speed
- **Global φ_{GLBL} = 4.76**

Turbulent NH_3-H_2 Flames

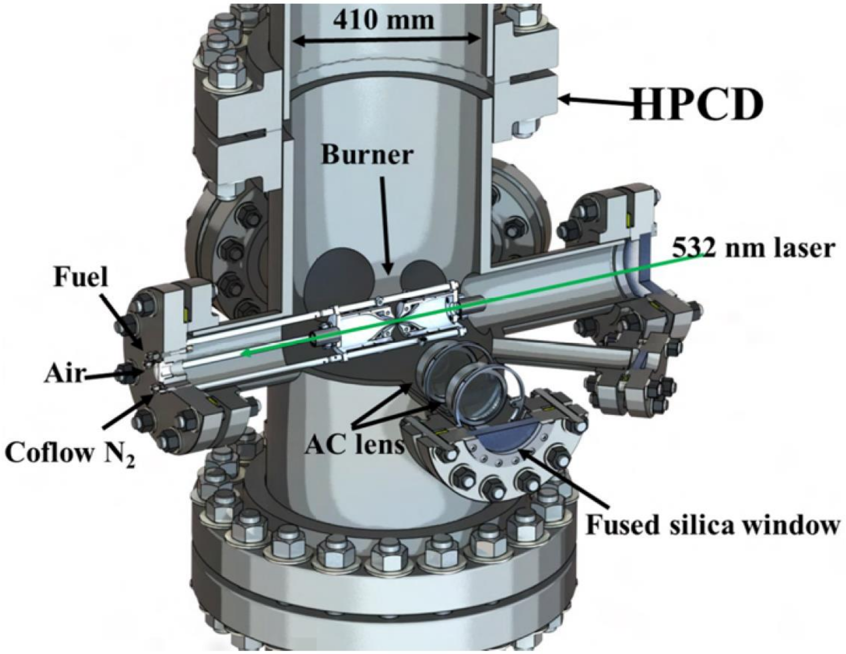
The KAUST Raman Rayleigh 1D system

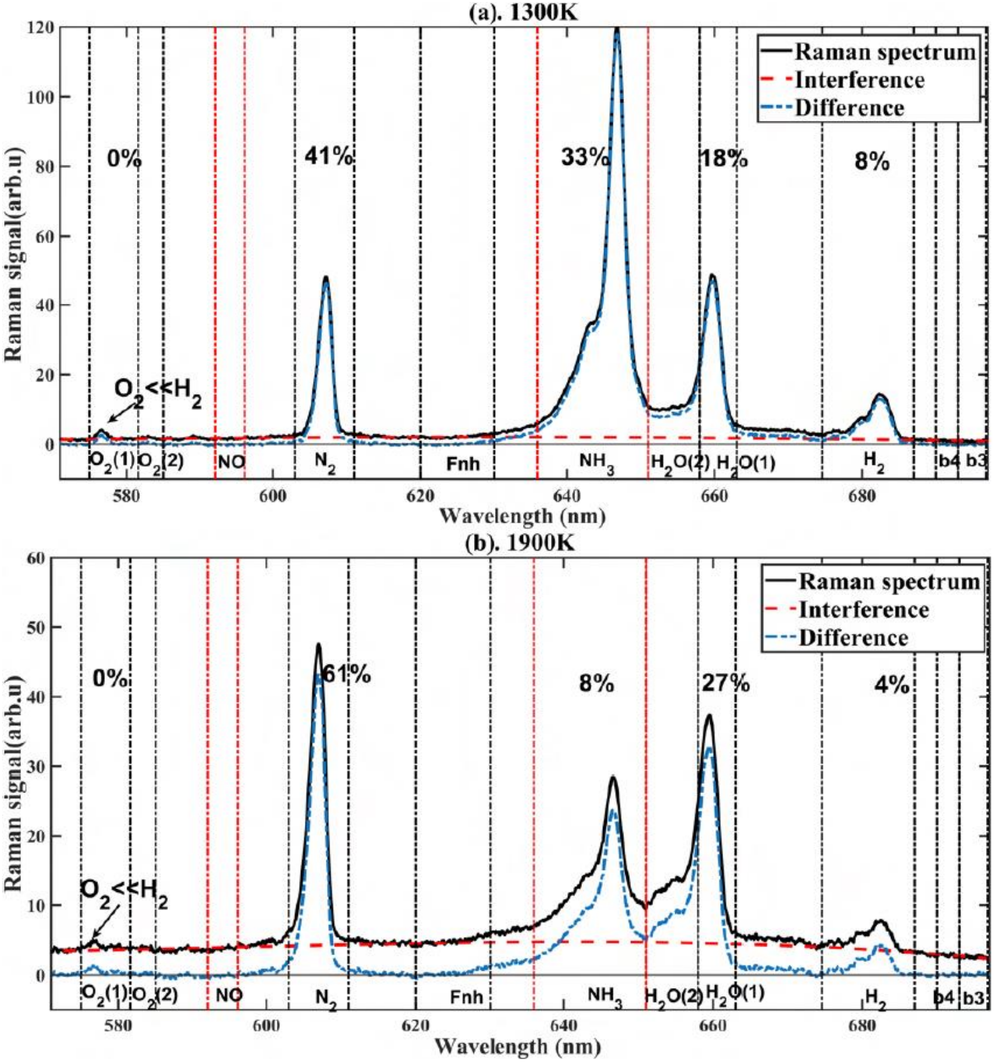


Adapted from: Dr Hao Tang, PhD Thesis, "Development and Application of Quantitative 1D Raman/Rayleigh Spectroscopy on Ammonia Combustion", KAUST, 2022.

Turbulent NH_3-H_2 Flames

Raman Interferences
In laminar counterflow flames of NH_3-H_2 at two temperatures.





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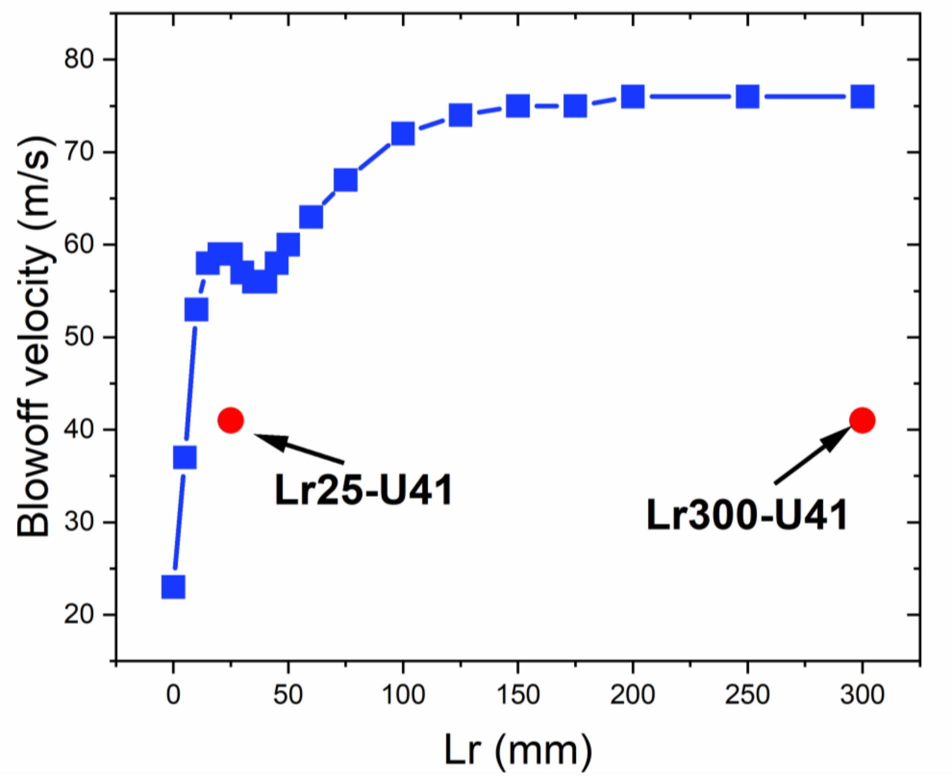
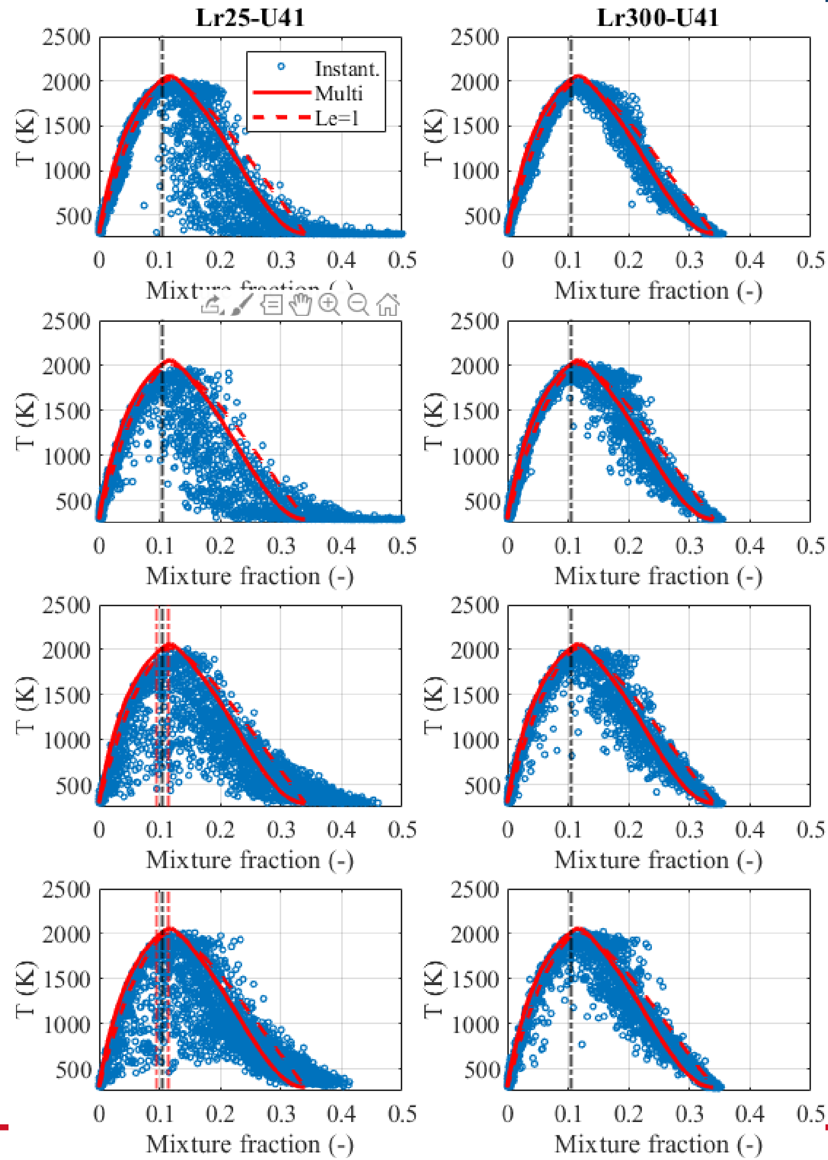
NH_3/H_2=60/40 Stability Plot



- There is a local improvement in stability for the optimal recess (Lr=25)
- Premixed samples don't provide enough power to offset the pilot

NH_3/H_2 T vs f_{Bilger}, Lr= 25 and 300



- The optimal recess has rich to lean premixed burning samples
- Downstream, for Lr =25, the flame burns closer to a diffusion flame
- Lr=300 is burning as a diffusive flame
- Noise (hump) occurs near f =0.2 due to NH2 interference
- Subtracting the NH_2-LIF depolarized camera with the wavelet denoising algorithm is to be applied

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Future Work

- **Imaging of N-Related species in turbulent flames of ammonia.**
- **Study the flash-atomization of ammonia jets and subsequent ignition/combustion.**
- **Study cold-ignition of ammonia using pre-chamber combustion.**