Curvature-Scalar Correlation and its Variations in NH3/H2 Premixed Swirling flames

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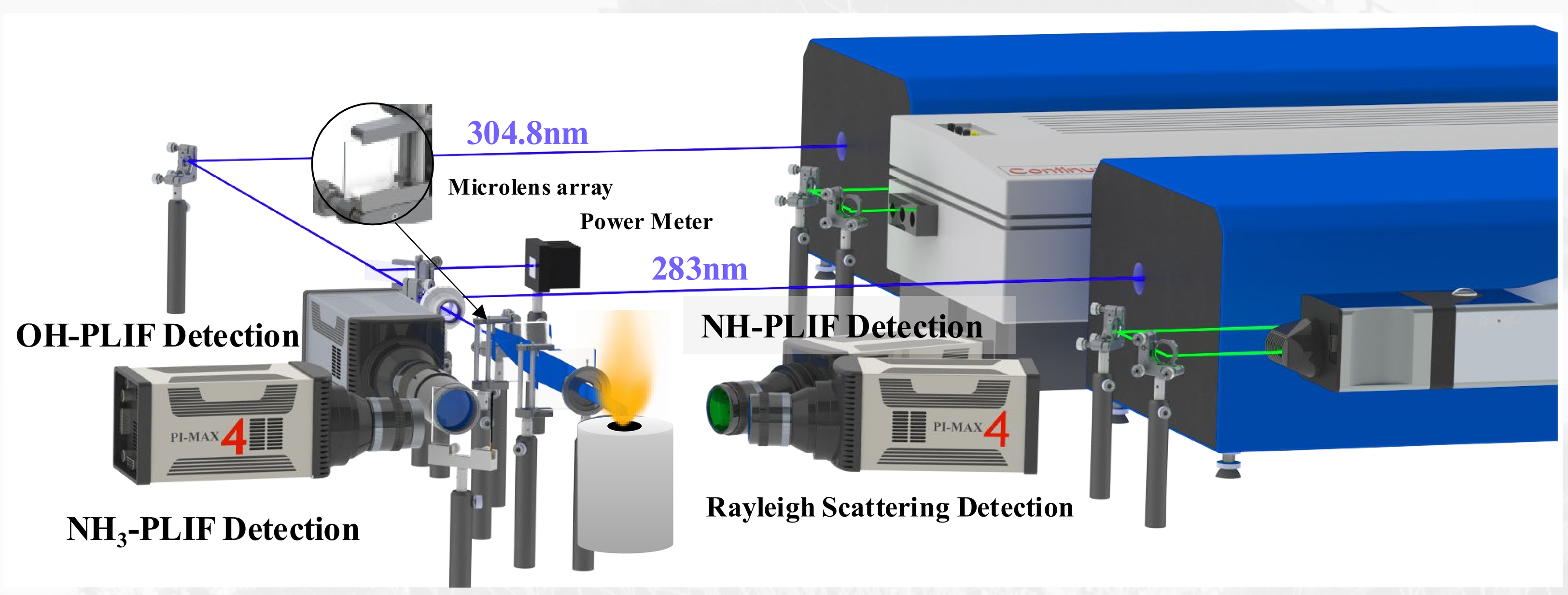
Fundamental Process:
Flame Dynamics and Transport Processes

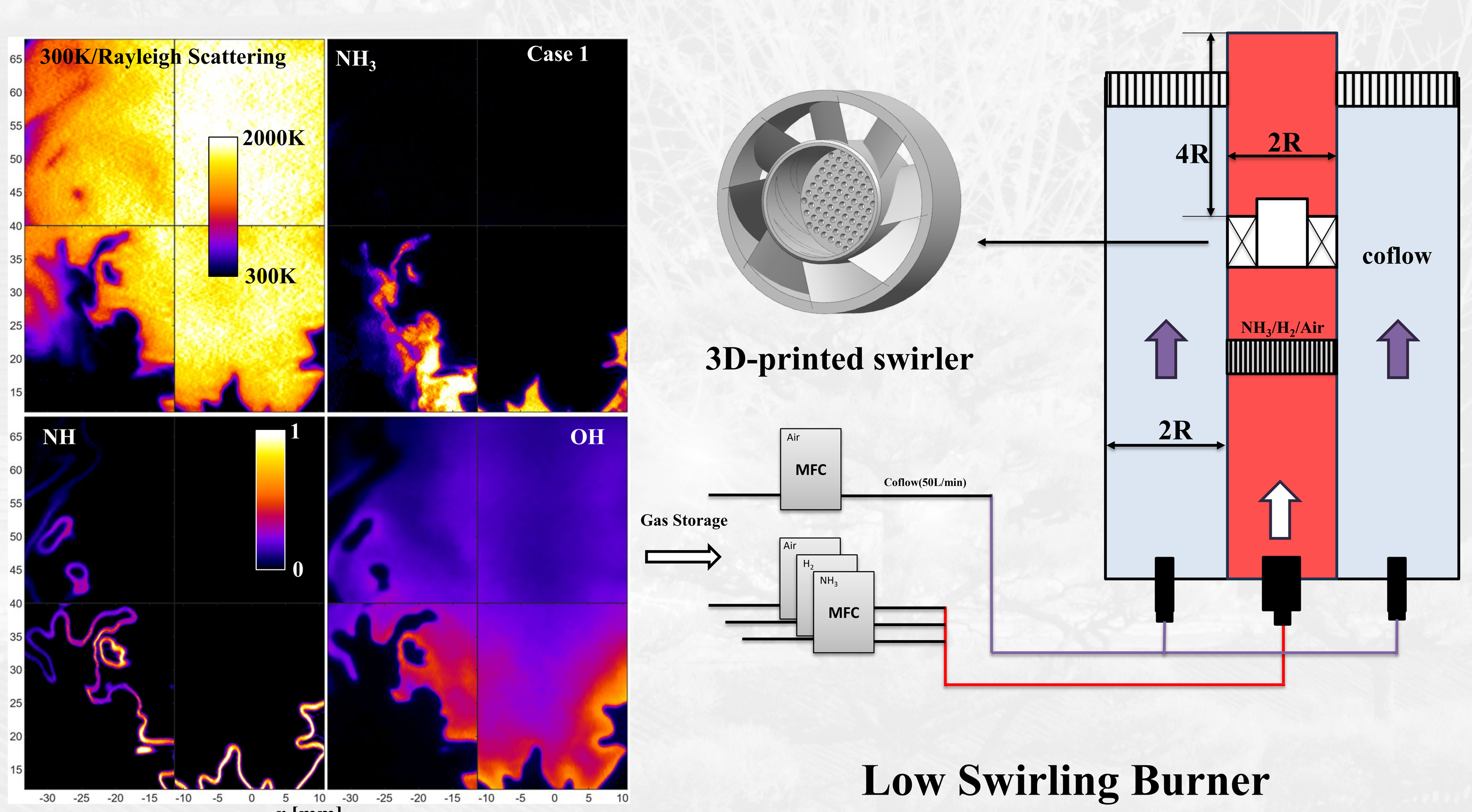
Introduction

- **Promising Carbon-Free Fuel:** Ammonia/hydrogen (NH_3/H_2) blends have emerged as highly promising clean energy alternatives, effectively combining the high reactivity of H_2 with the cost-effective storage and transportation of NH_3.
- **The Physical Challenge:** Premixed NH_3/H_2 flames are intrinsically susceptible to thermo-diffusive (TD) instability driven by differential diffusion (characterized by the Lewis number, *Le*). However, classical TD instability theory assumes an ***infinitely thin*** flame front.
- **The Diagnostic Gap:** While traditional single-scalar diagnostics (e.g., relying solely on OH-PLIF) are highly successful for assessing overall macroscopic turbulent flames, they may fail to capture the complex, curvature-induced structural shifts hidden inside real flames with ***finite thickness***.
- **Research Objective:** This study aims to investigate the length-scale dependency of curvature (κ)-scalar correlations and reveal internal structural misalignments in turbulent NH_3/H_2 /air swirling flames (*Le* = 0.94 and 1.05) utilizing simultaneous multi-scalar imaging (NH_3 ,NH, OH, and Temperature).

Experimental Setup



Multi-Scalar Imaging System (NH_3-/NH-/OH-LIF, Rayleigh Scattering) [1]



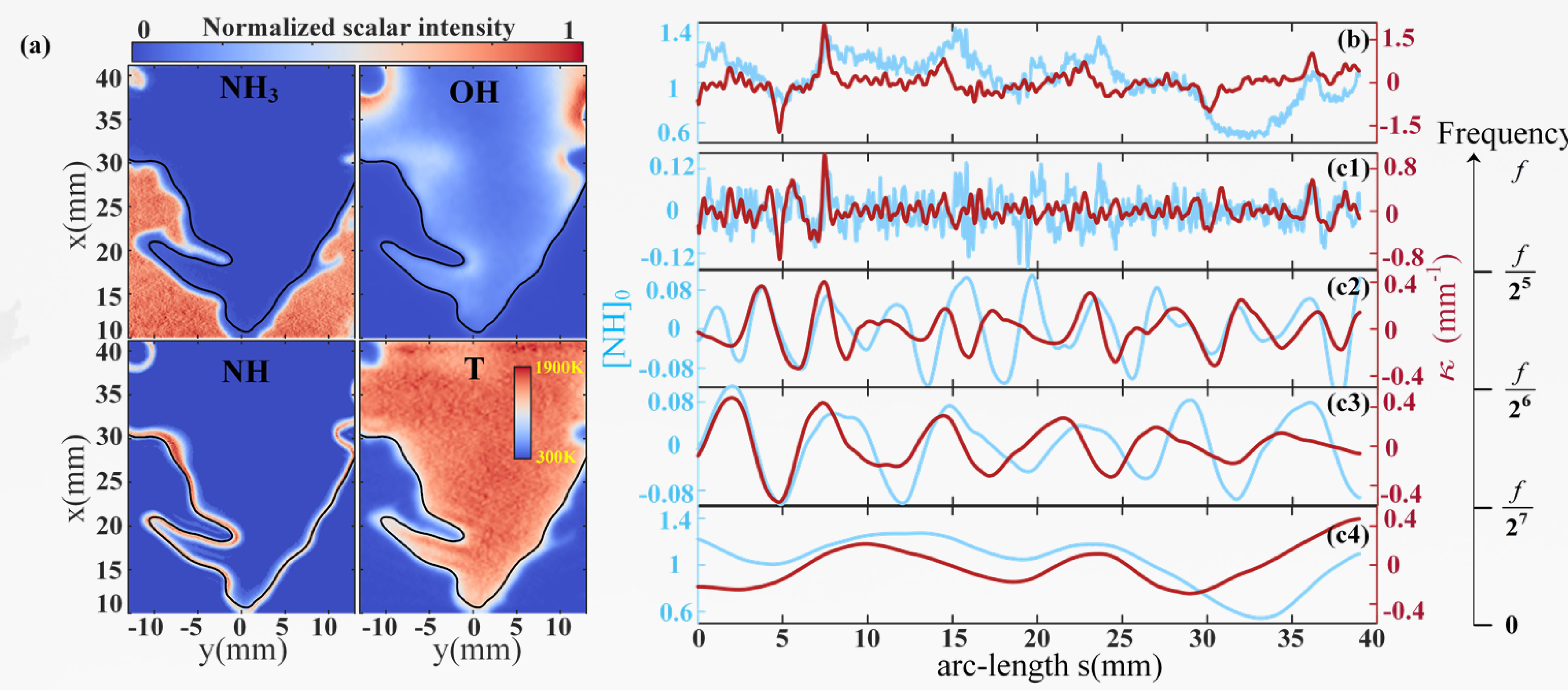
Low Swirling Burner

Flame conditions

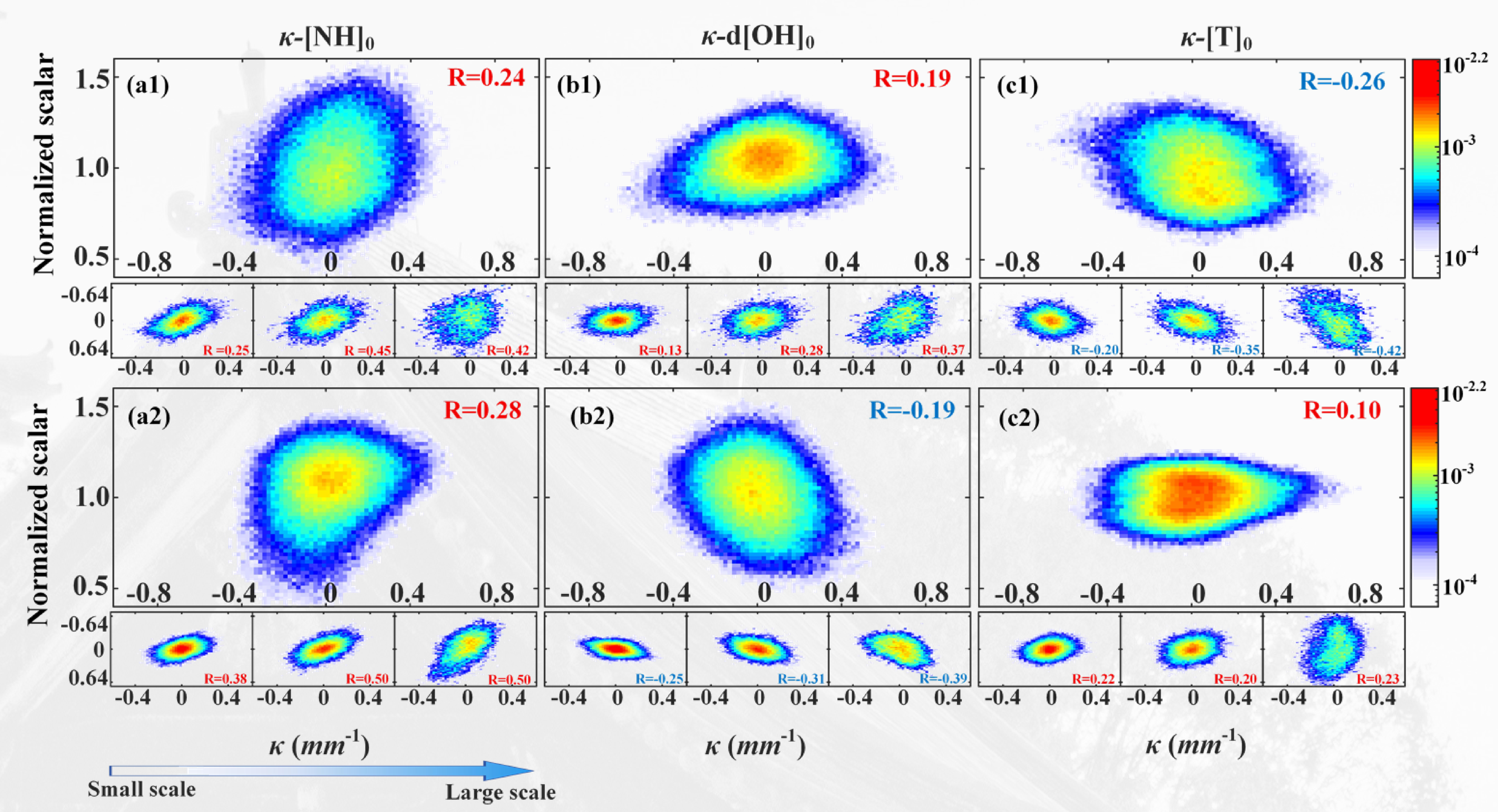
Case	Φ	H_2/NH_3	*Le*	ω_2 [3]	$\overline{U_0}$
1	0.8	35/65	0.95	-11.6	5 m/s
2	1.0	20/80	1.05	-21.2	

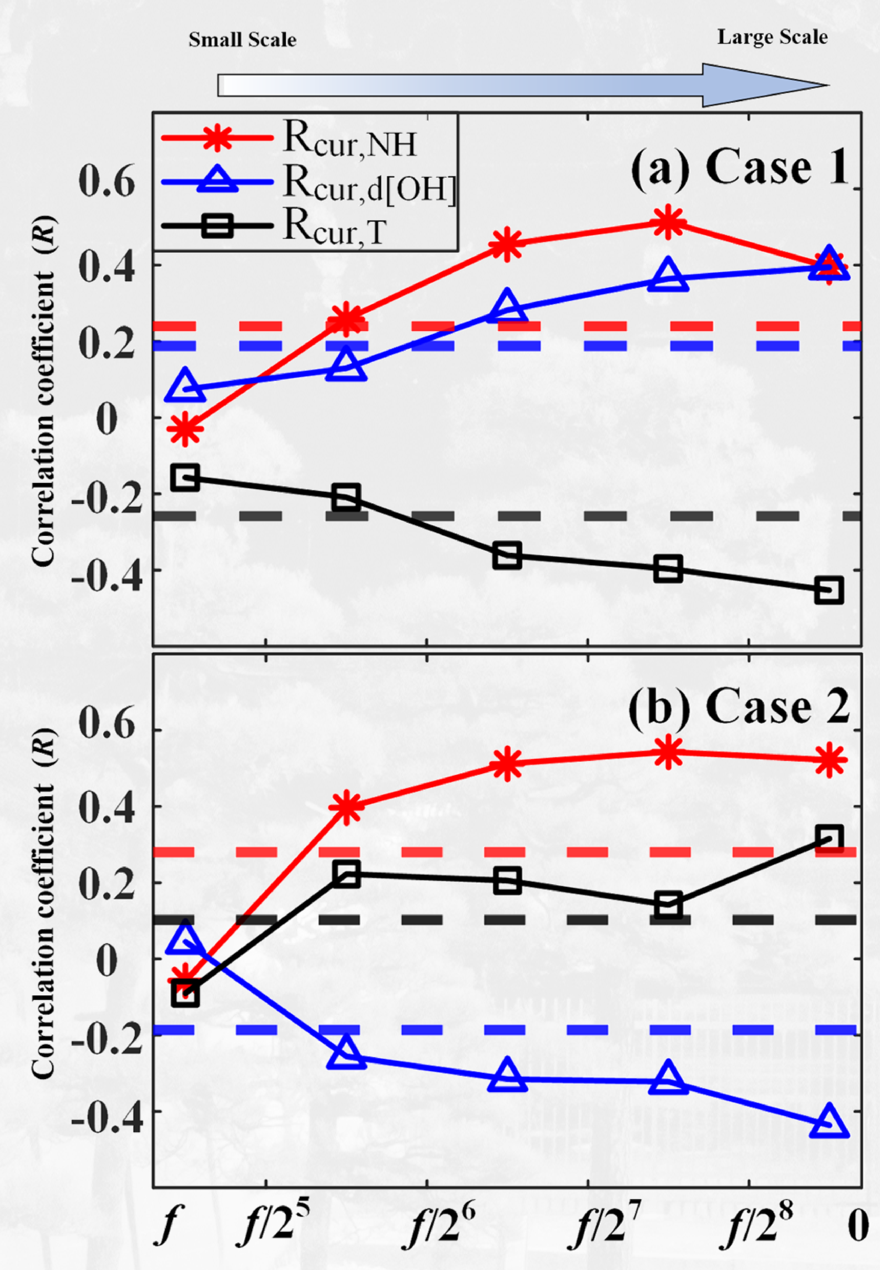
Result I: Scale-Dependency & Macroscopic TD Response

Wavelet decomposition (DB6)



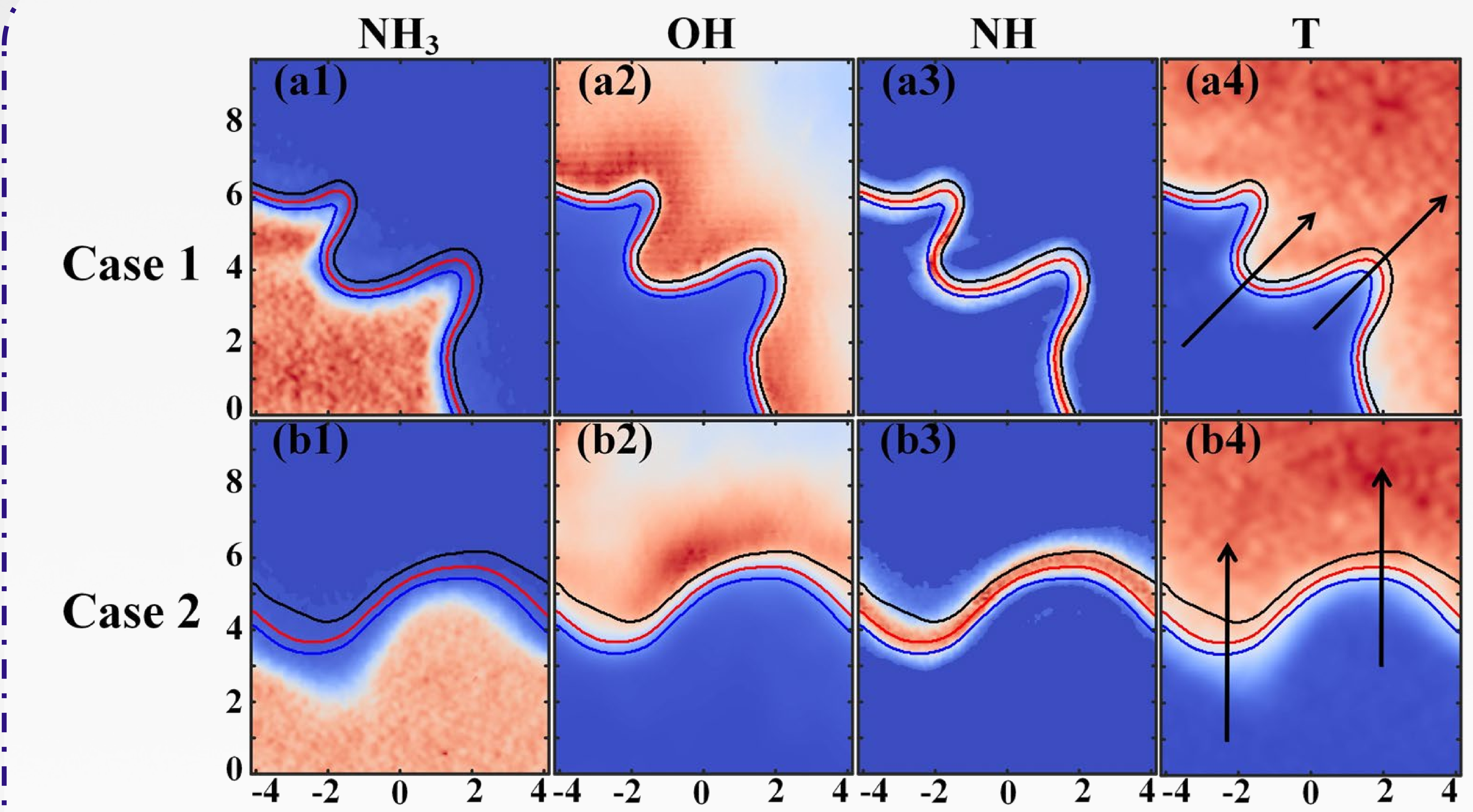
Curvature (κ)- Scalars Correlations

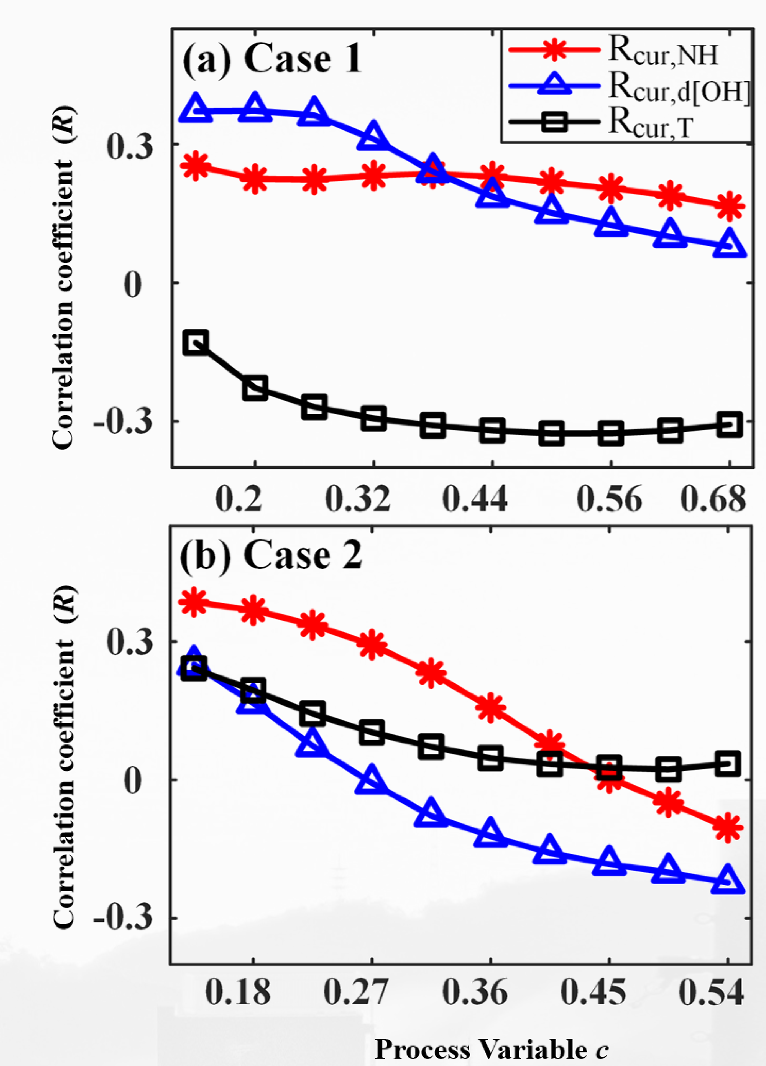




- **"Low-Pass Filter" Effect:** At microscopic scales (< **1.2 mm**), the flame dampens local curvature perturbations.
- **Macroscopic Emergence:** Coherent thermo-diffusive (TD) responses only appear at scales exceeding the thermal thickness (> 1.2 mm) .

Result II: Internal Structural Misalignments





- **Spatial Misalignment:** Curvature induces a physical separation between the OH-defined flame front and the actual reaction zone (NH peak) .
- **Isocontour Sensitivity:** Due to this structural shift, extracted correlations are highly sensitive to the chosen reference boundary, and can even reverse polarities.

Conclusions

- **Length-Scale Dependency**: Curvature(κ) - scalar interactions in turbulent NH_3/H_2 flames are profoundly scale-dependent. Coherent macroscopic TD responses only emerge at spatial scales exceeding the flame's thermal thickness (> 1.2 mm).
- **Key Significance**: While traditional single-scalar diagnostics are highly effective, this study demonstrates that ***multi-scalar measurements provide indispensable complementary insights*** into the complex internal dynamics and curvature-induced structural shifts of finite-thickness turbulent flames.

[1] Ze Wang, Xun Li, Lunang Li et.al., Strategy for simultaneous multi-scalar imaging in turbulent NH3/H2 premixed flames using a single laser system, Combust Flame 242 (2022) 112185.
[2] O. Chaib, S. Hochgreb, I. Boxx, An experimental marker of thermo-diffusive instability in hydrogen-enriched flames, Proc. Combust. Inst. 40 (2024) 105763.
[3] T.L. Howarth, A.J. Aspden, An empirical characteristic scaling model for freely-propagating lean premixed hydrogen flames, Combust. Flame 237 (2022) 111805.

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