Quantitative measurements of *CH** concentration in normal gravity and microgravity coflow laminar diffusion flames

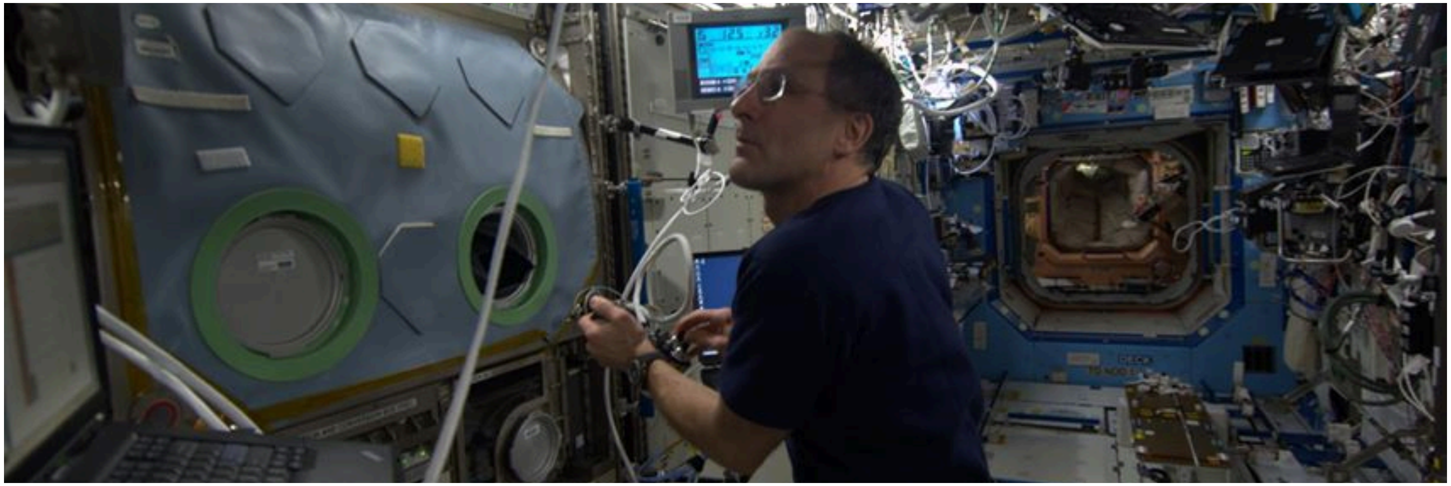
D. Giassi[1], S. Cao[2], D.P. Stocker[3], F. Takahashi[4],
B.A.V. Bennett[1], M.D. Smooke[1], M.B. Long[1]

(1) Yale University
(2) GE Global Research
(3) NASA Glenn Research Center
(4) Case Western Reserve University

31th ASGSR meeting
Alexandria, VA, November 12th, 2015

Outline

- Introduction
- SLICE
- Spectral considerations
- *CH** concentration diagnostics
- Results and conclusions



Introduction

Advantages of microgravity experiments:

- Simplification of the flow field due to the absence of buoyancy effects: provides easier test cases to refine computational models.
- Creation of flame conditions that do not exist in 1-g environment, e.g. increasing the flame stability: enables experimental/computational study near flame extinction.

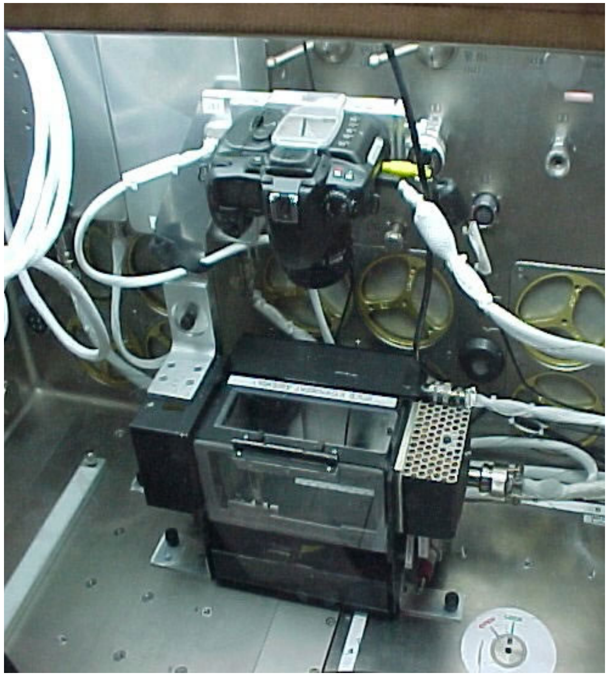
Why *CH**:

- Extend the study of microgravity flames from sooty[1] to "blue" flames.
- Chemiluminescent emission from excited state radicals naturally present in flames and easy to collect.
- Representative of flame front position and possible marker for heat release rate.

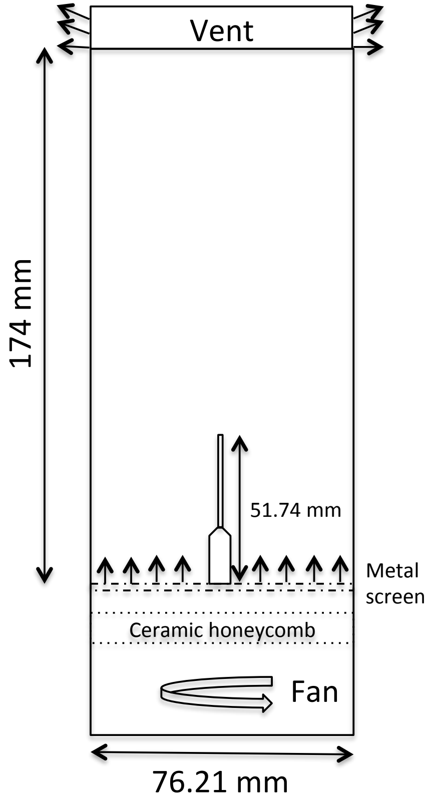
[1] B. Ma et al., Proc. Comb. Inst. **35**, 839-846 (2015)

SLICE

Structure and Liftoff In Combustion Experiments (2012)



SLICE hardware on the ISS



Nozzles ID:

0.4, 0.8, 1.6, 2.1, 3.2 mm

Fuels: (N_2 diluted)

40%, 70%, 100% CH_4

20%, 100% C_2H_4

Velocity:

Fuel: up to 320 cm/s

Coflow air: 15 - 70 cm/s

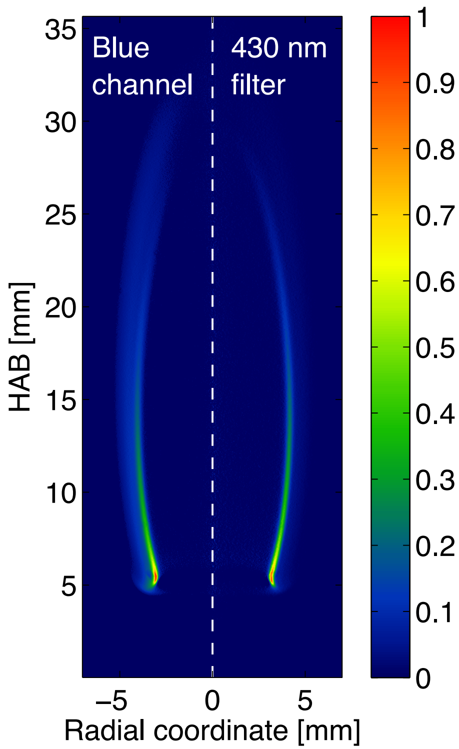
Diagnostic tool:

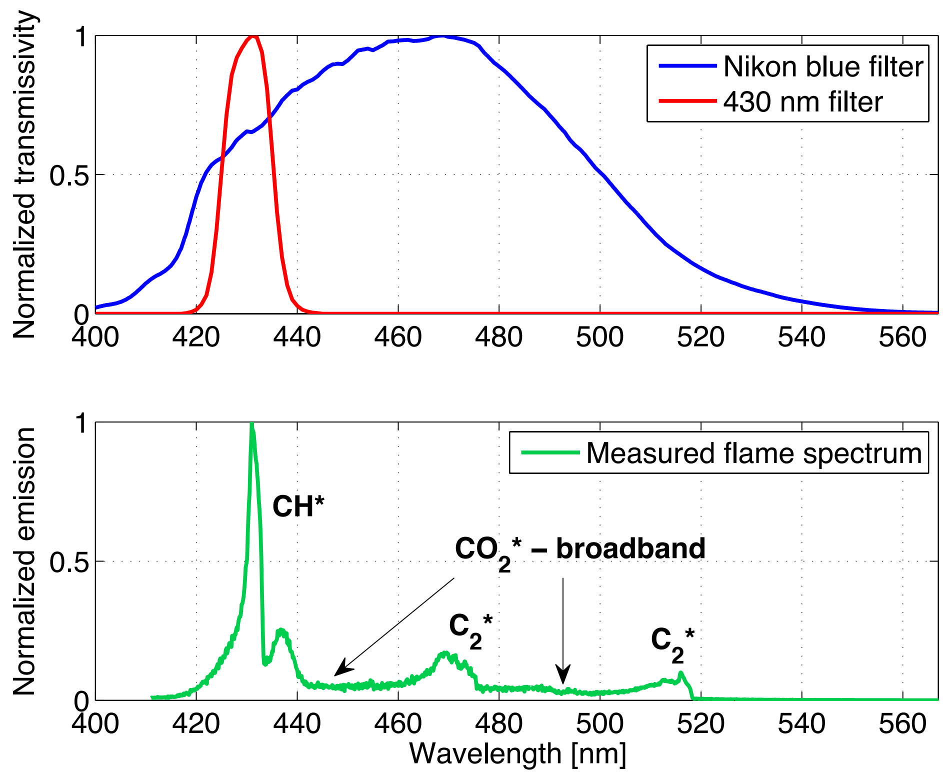
Nikon DSLR D300s with

BG7 color filter

DSLR camera characterization

- The Nikon blue channel signal was seen to be representative of the *CH** emission of the $A^2\Delta \rightarrow X^2\Pi$ transition centered around 431 nm.

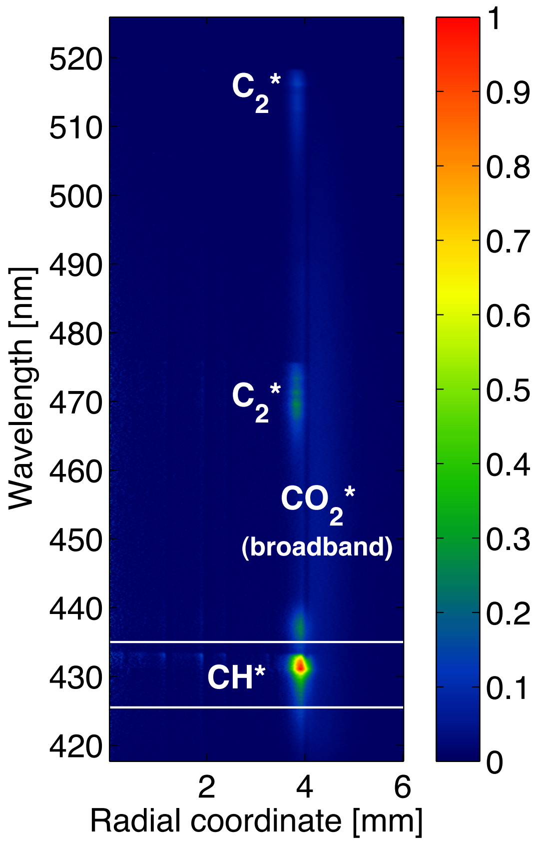


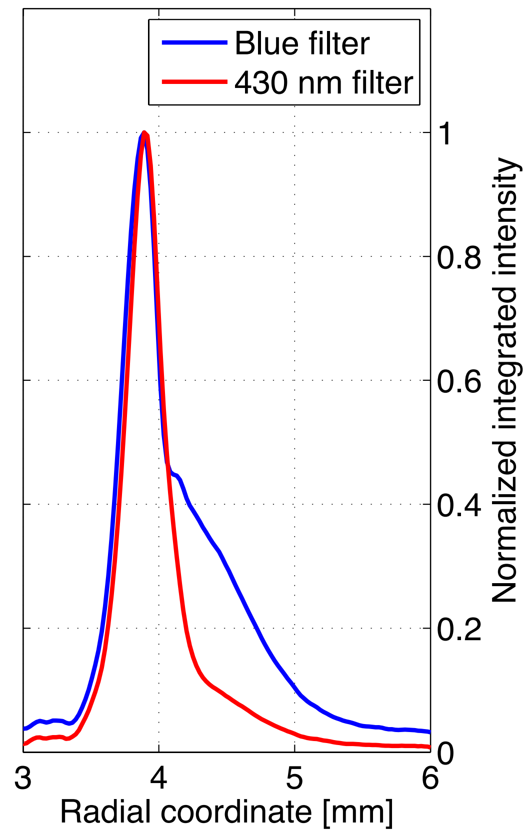


- The blue channel radial profile is broader than the interference filter one.
- The broadband blue filter will collect light emitted from species other than *CH**.

Spectral considerations

- Spectral analysis of a target nitrogen-diluted 65% methane flame (7.5 mm above the burner).

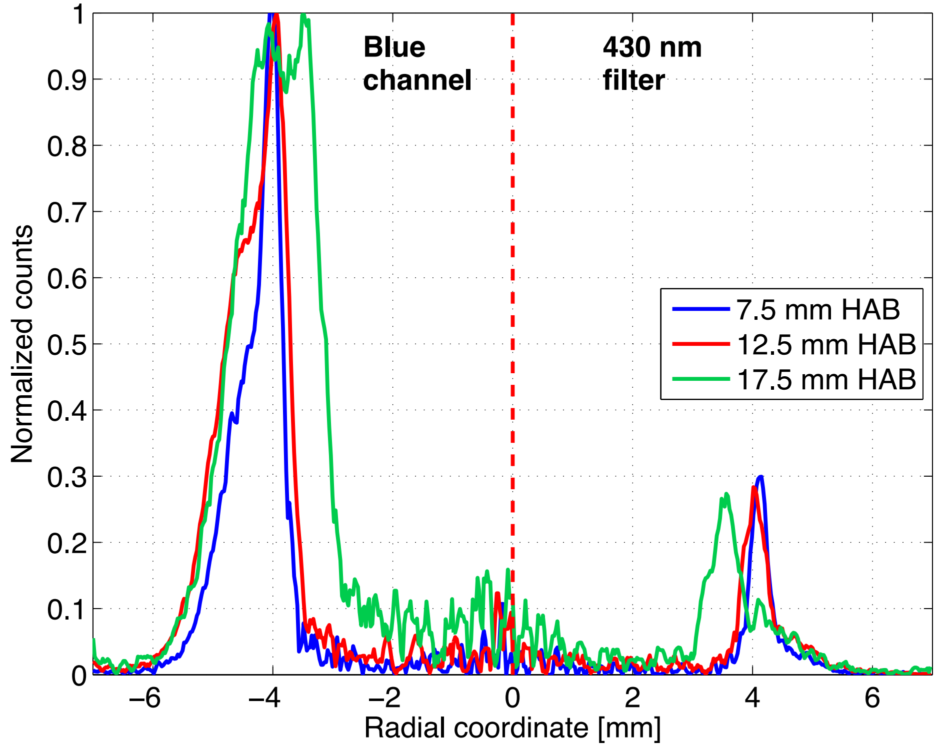




- The integration over the entire blue spectral range results in a broader radial profile.

Spectral considerations

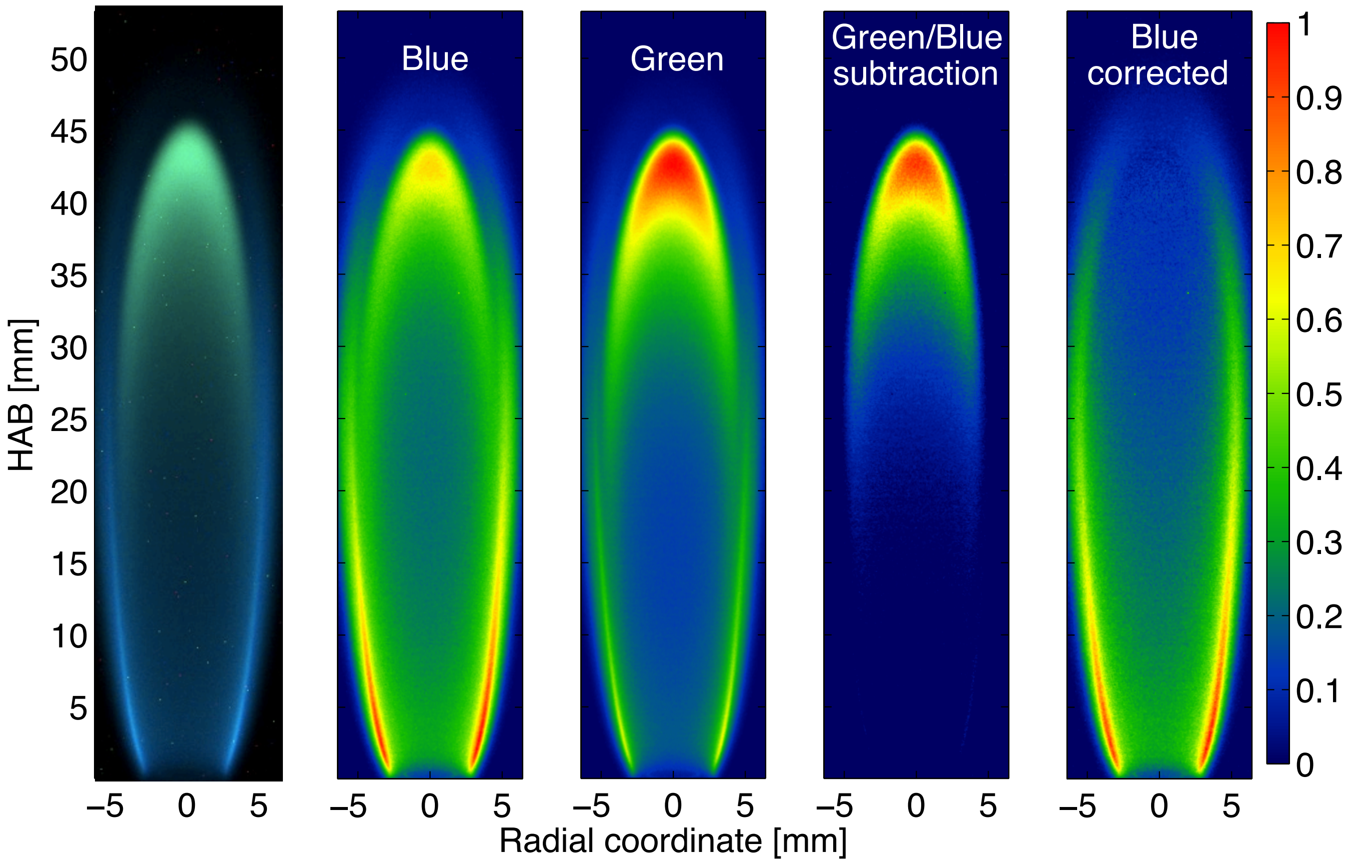
- The additional C_2* and CO_2* chemiluminescence will contribute to the blue counts recorded by the camera.



- If uncorrected, the blue signal would overestimate the peak *CH** concentration by a factor of ~3.3.

Soot correction

- If not accounted for, soot luminosity will result in corruption of the blue channel signal.



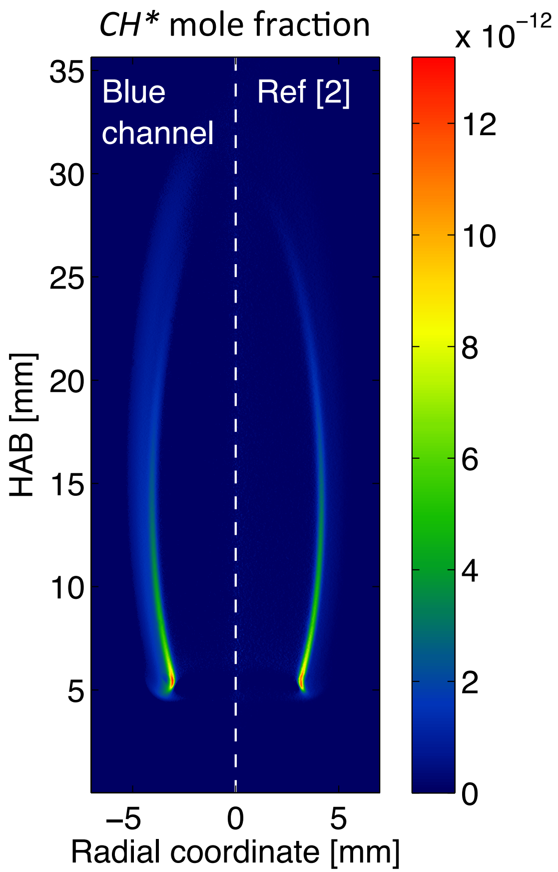
70 % CH_4 – Fuel 89 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm

CH^* concentration diagnostics

- Chemiluminescence emission S_{em} collected by a detector:

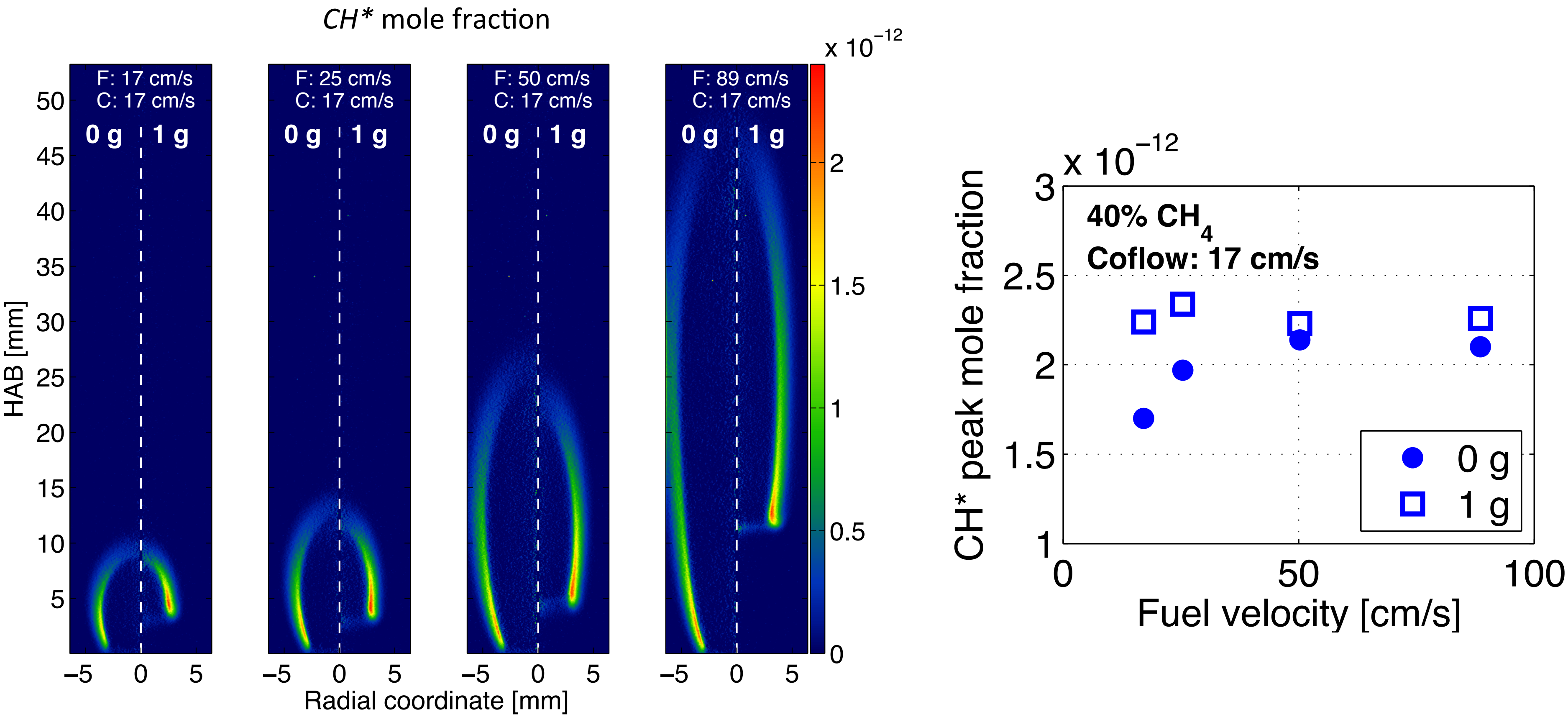
$$S_{em} = \frac{1}{4\pi} A_{21} \tau V_{em} N^* K C \gamma_{CH}$$

A_{21}: Einstein A coefficient
τ: exposure time
V_{em}: pixel volume
N^*: number density
K: intensity calibration constant
C: contribution from other emitting species
γ_{CH}: transmitted energy of a photon in the blue channel



[2] K. T. Walsh, et al., Proc. Comb. Inst. **30**, 357-365 (2005)

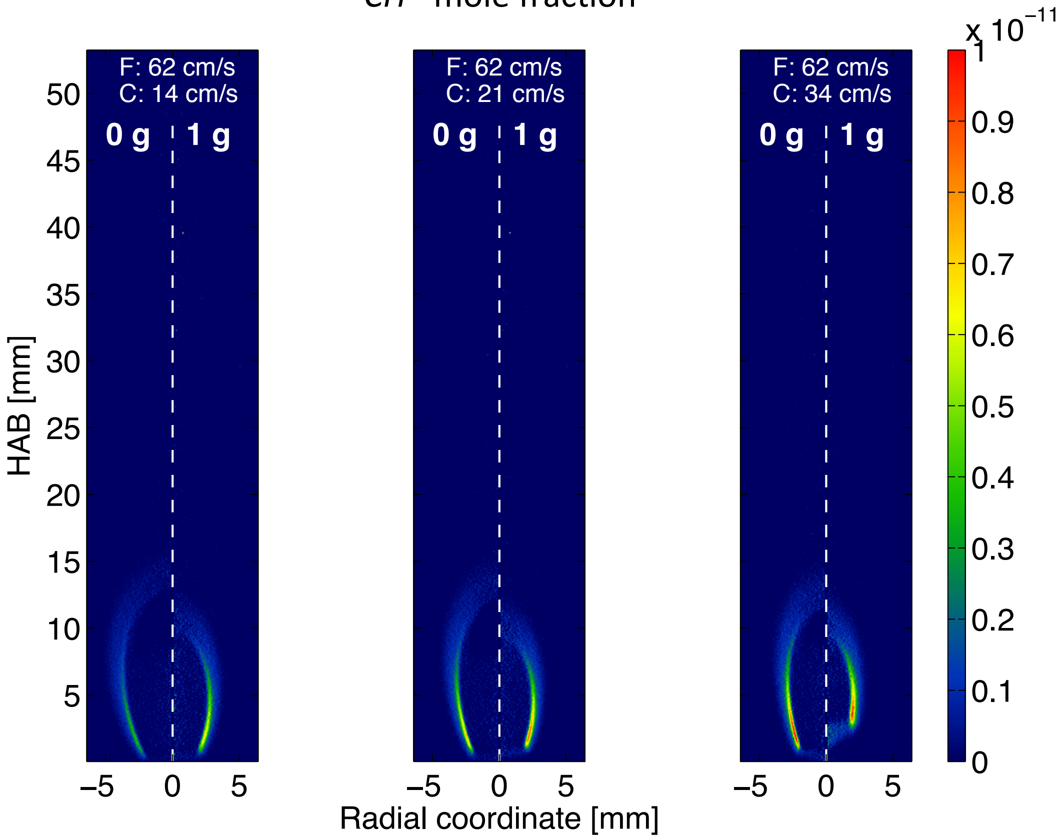
Results: fuel flow variation

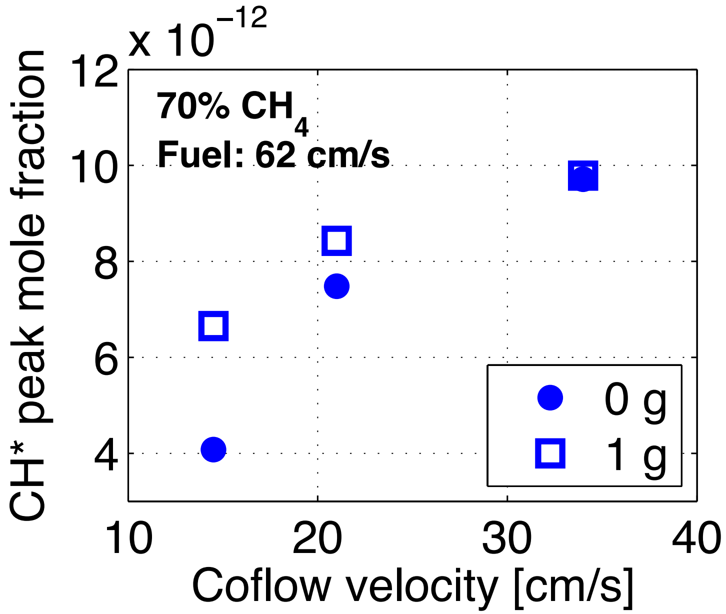


40 % CH_4 – Fuel 17 to 89 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm

Results: coflow variation

*CH** mole fraction

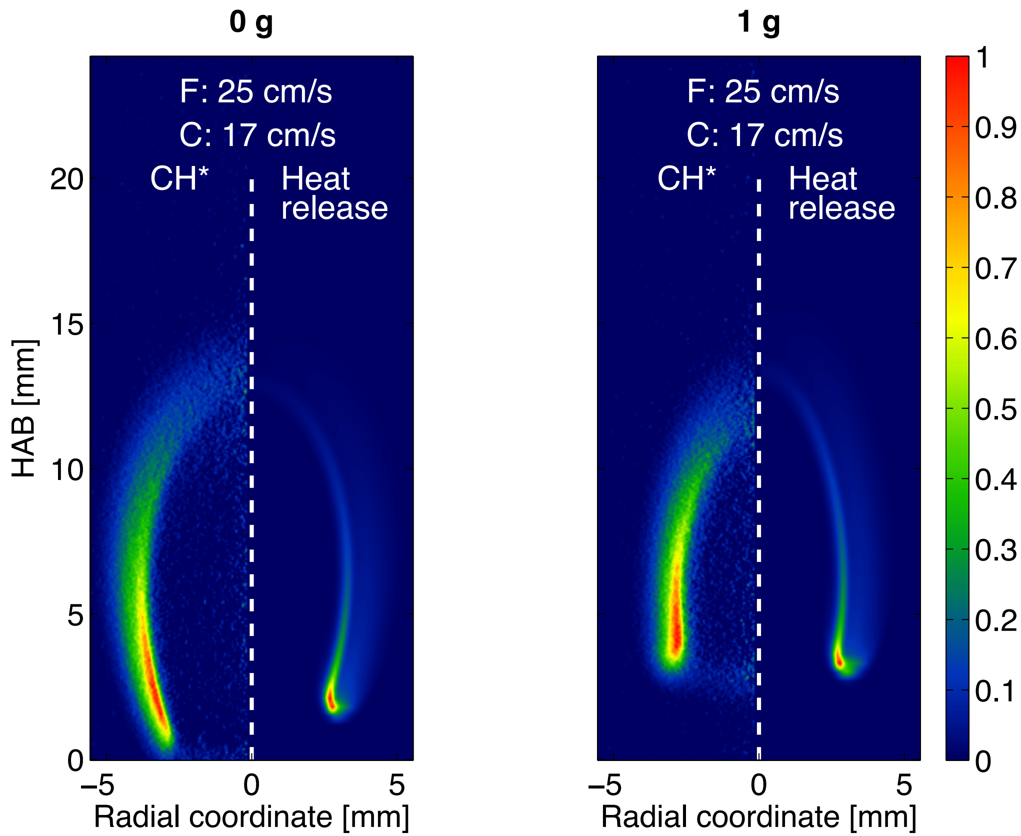




70 % CH_4 – Fuel 62 cm/s; Coflow 14 to 34 cm/s – Nozzle 1.6 mm

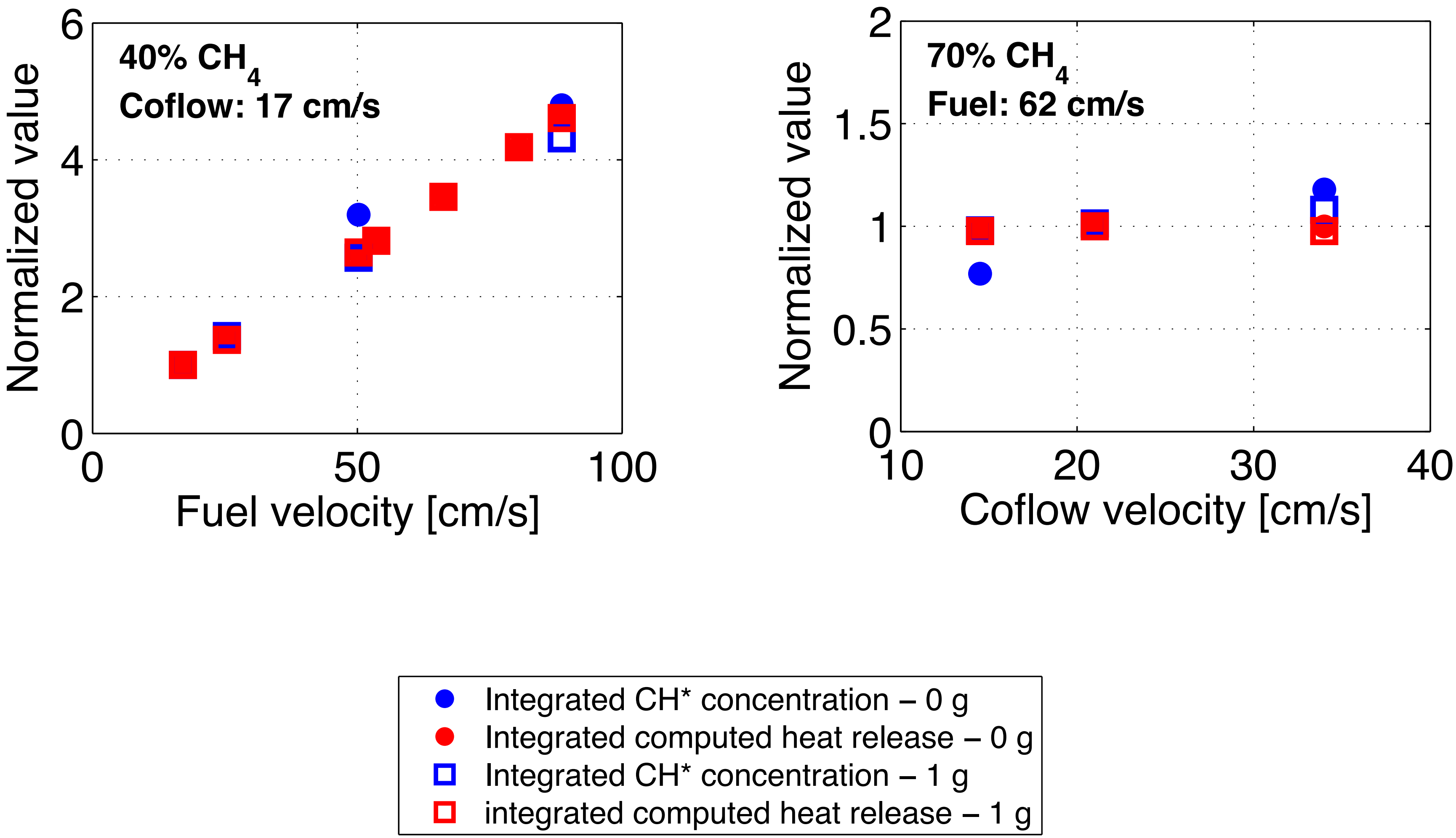
Results: local heat release rate

- Flame numerical simulations are available to complement the experimental data



40 % CH_4 – Fuel 25 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm

Results: total heat release rate



Conclusions

- Quantitative measurements of *CH** concentration have been performed on selected microgravity and normal gravity SLICE flames.
- The spectral characterization of the SLICE color camera allowed the blue channel to be considered representative of the *CH** emission around 431 nm.
- A reference diffusion flame was analyzed to investigate the influence of emitting species other than *CH**, and to validate the proposed approach.
- The measured peak *CH** concentration displayed higher sensitivity to coflow rather than fuel variations, and it was generally higher in normal gravity flames.
- In laminar diffusion flames, the integrated radial *CH** concentration scales proportionally to the integrated flame heat release rate.
- The two-dimensional *CH** and heat release rate distributions agree reasonably well, but the variations in spatial intensities and gradients do not match.

Acknowledgments

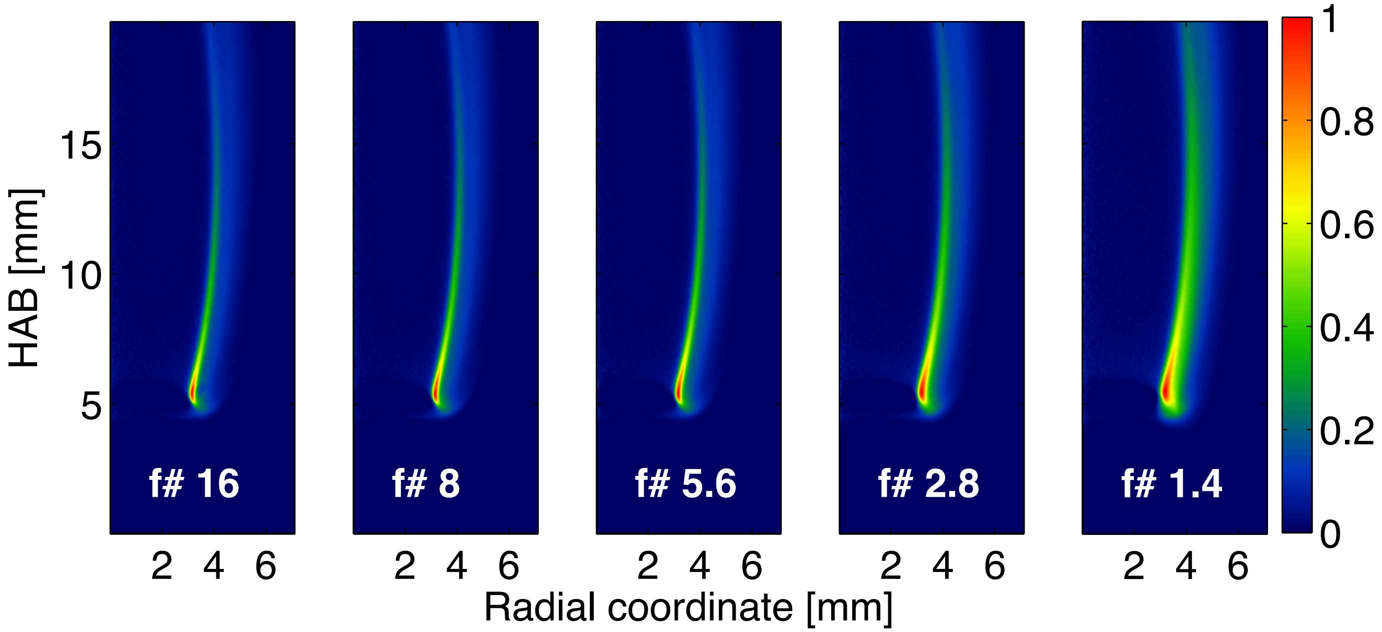
Supported by NASA under contract NNX11AP43A.

The authors would like to thank astronaut D. Pettit for conducting SLICE's microgravity tests, SLICE Project Manager R. Hawersaat, and operations team members C. Bunnell, T. Lorik, J. Owens and C. Reynolds.

Imaging consideration

Radial chemiluminescence profiles obtained through an Abel deconvolution:

- Assumes the collected rays to be parallel.
- If rays are not parallel the reconstructed profile is broadened and the peak value is underestimated.



SLICE flame images were taken with *f*-numbers of 2 or 4 to minimize exposure time