Comparison of Two Mixing Models with Experimental, Solid-Fuel, Swirl-Stabilized Flame Data

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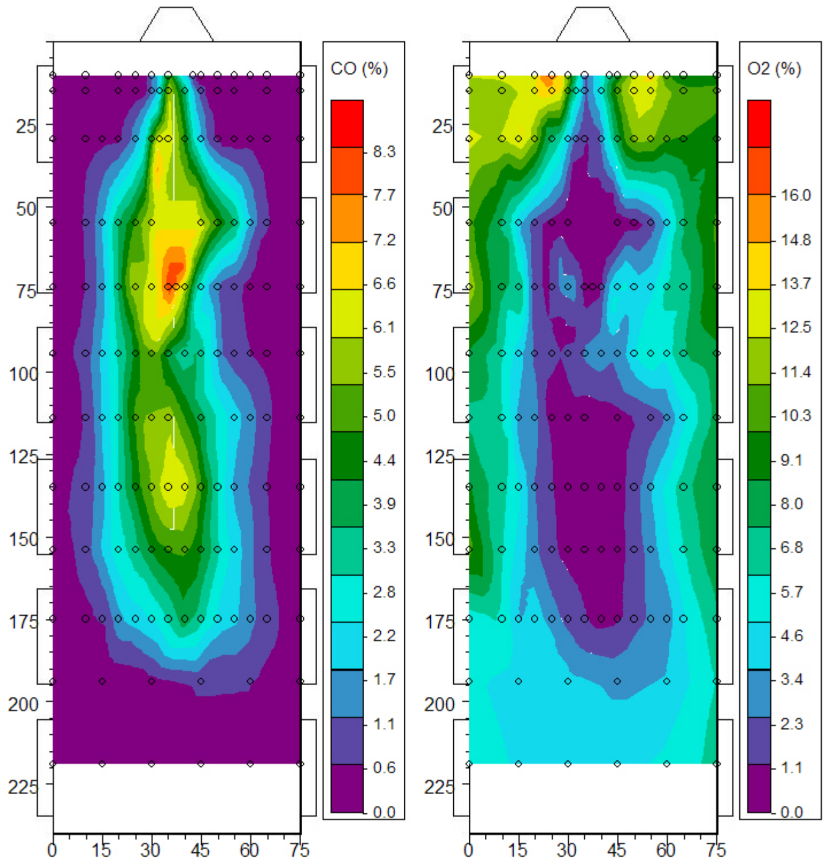
Introduction



- Significant overlap of CO and O_2
- How does this behavior occur?
- How to model this behavior?

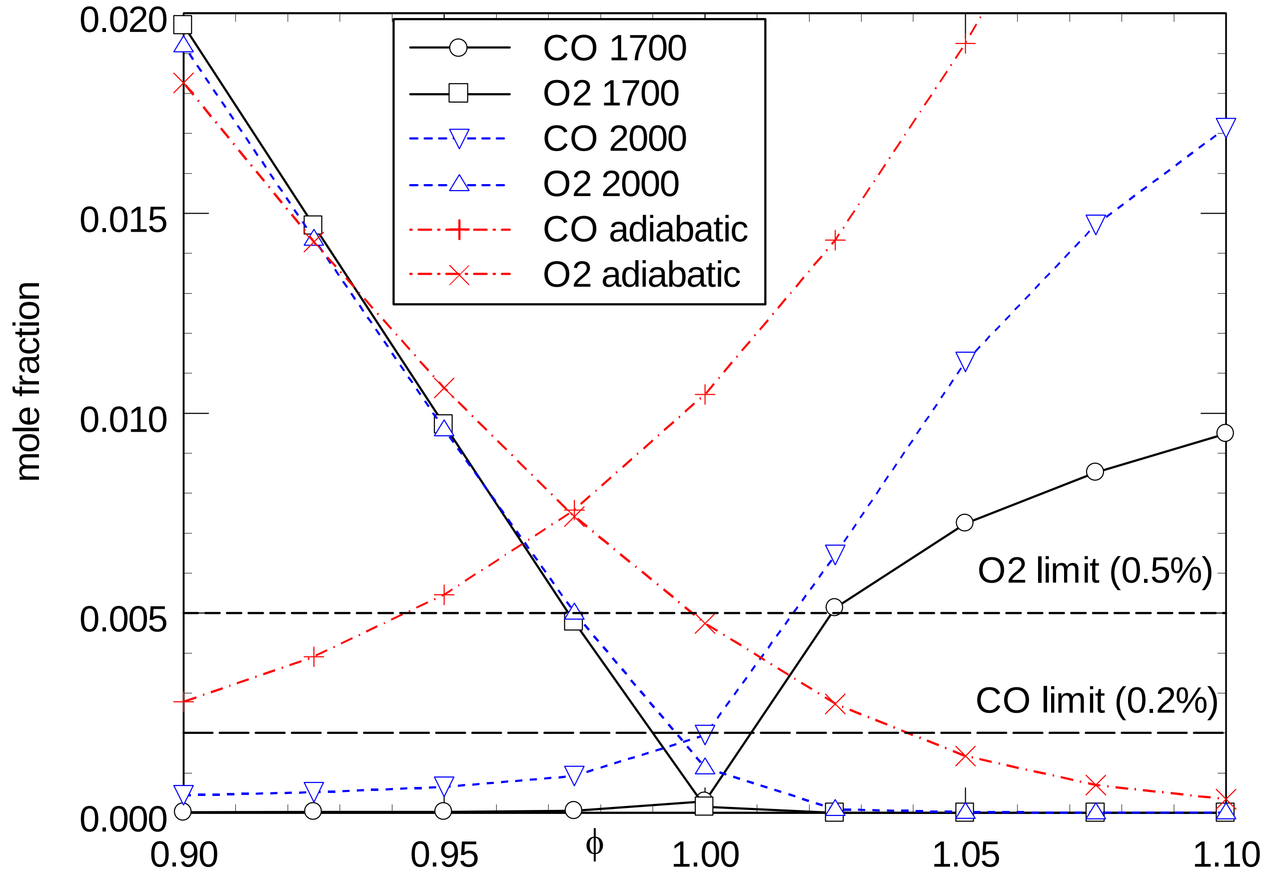
Objectives

- Show “Intermittency” in flame data
- Introduce new mixing model based on intermittency phenomenon
- Compare relative merits of new model and a current model often used in CFD predictions

Intermittency

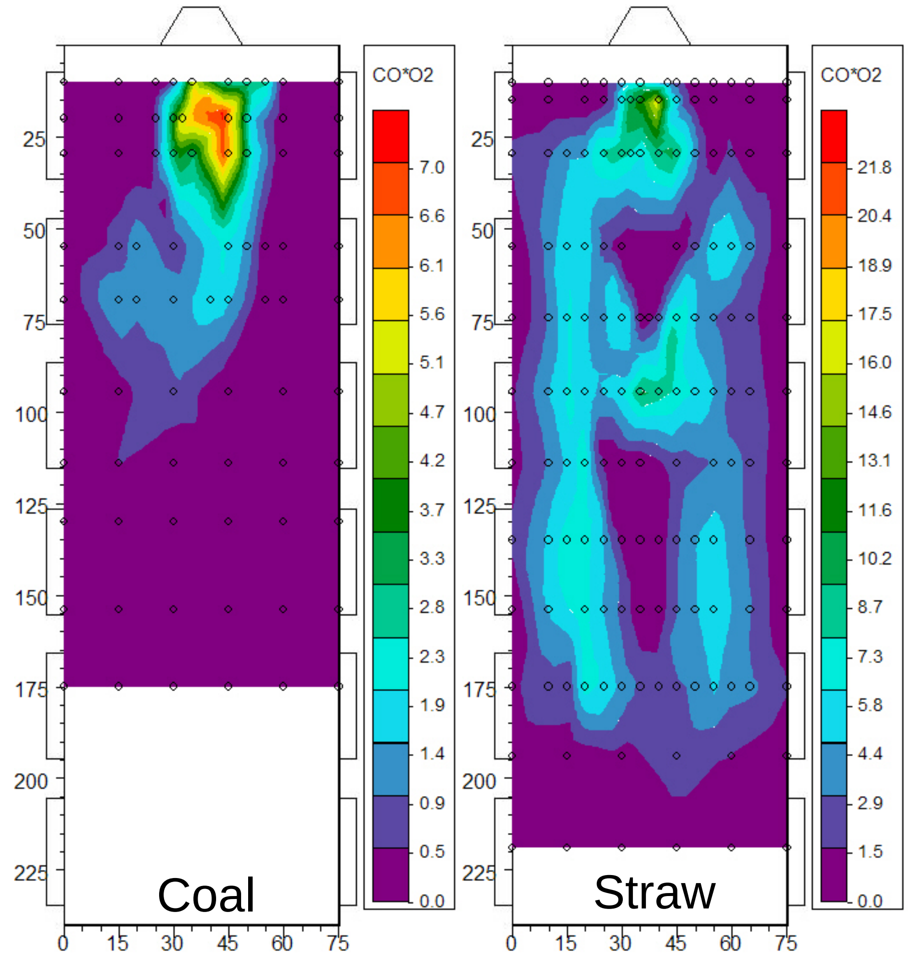
- Flame intermittency: The movement of a flamelet in and out of a region in space
- Distributed vs wrinkled vs candle flames
- In a sampling volume, both CO (from a flamelet) and O_2 (from the surrounding gas) will be recorded

Equilibrium O_2 and CO



Intermittency Maps

- Multiplying O_2 with CO gives an indication of where flame intermittency is occurring
- Even in coal, intermittent flame behavior is common



Intermittency Maps

- Most intense near burner
- Holes in the straw, wood and cofiring flames

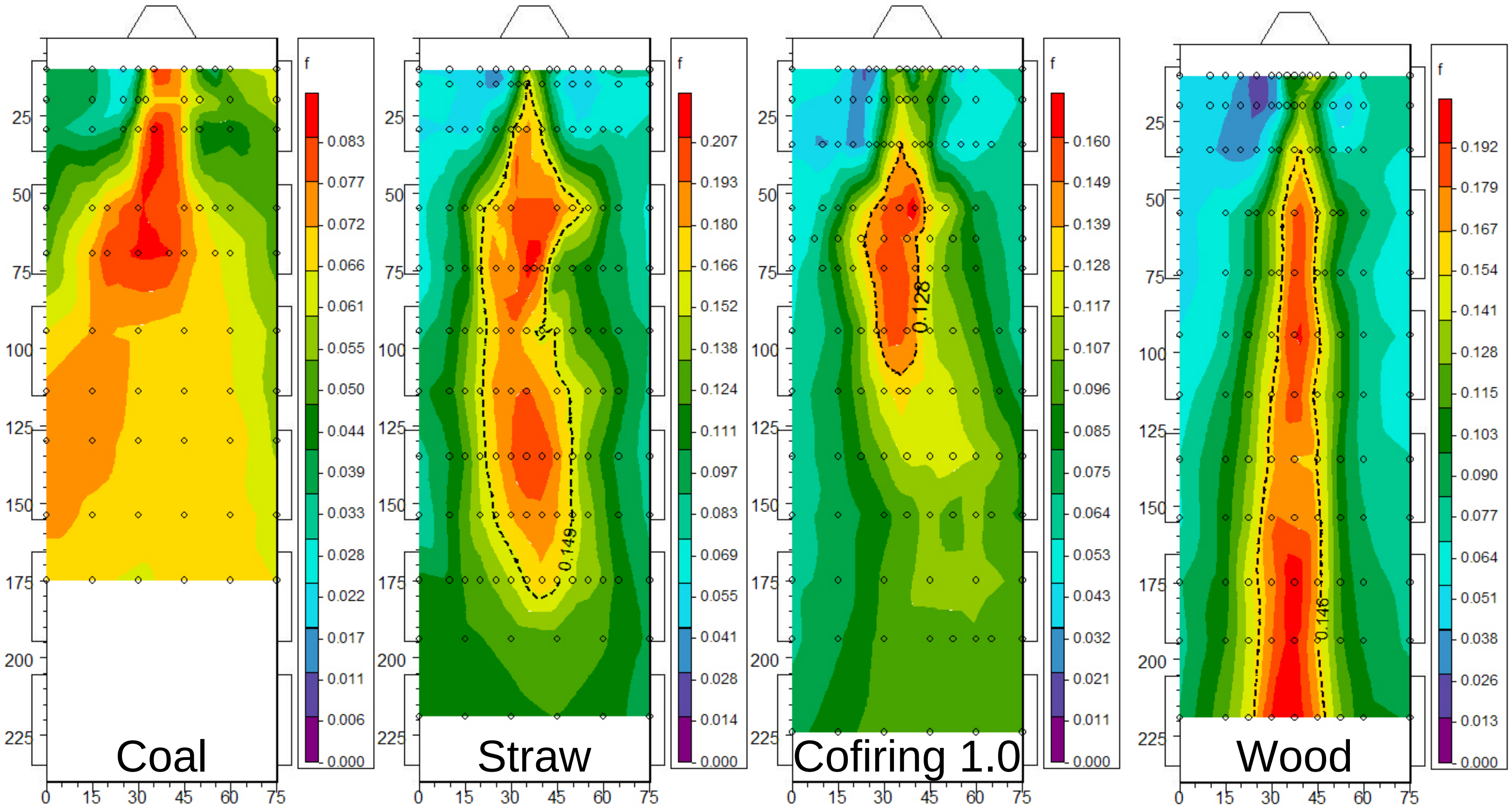
- Also show intermittent behavior:
- Non-penetration Coal Flames
  - Truelove 1988, Truelove 1990, Weber 1992, Godoy 1988, Godoy 1989, Costa 1991, Jensen 1994, Illerup 1994, Wu 2006
- Penetration Coal Flames
  - Smart 1988, Visser 1990, Abbas 1992, Abbas 1993, Smart 1996, Ballester 2005
- Cofiring Flames
  - Abbas 1994, Wu 2006, Damstedt 2006
- Biomass Flames
  - Ballester 2005, Wu 2006

Predictability

- Overlap of O_2 and CO not a new observation
- Predictive models in terms of the mixture fraction: f

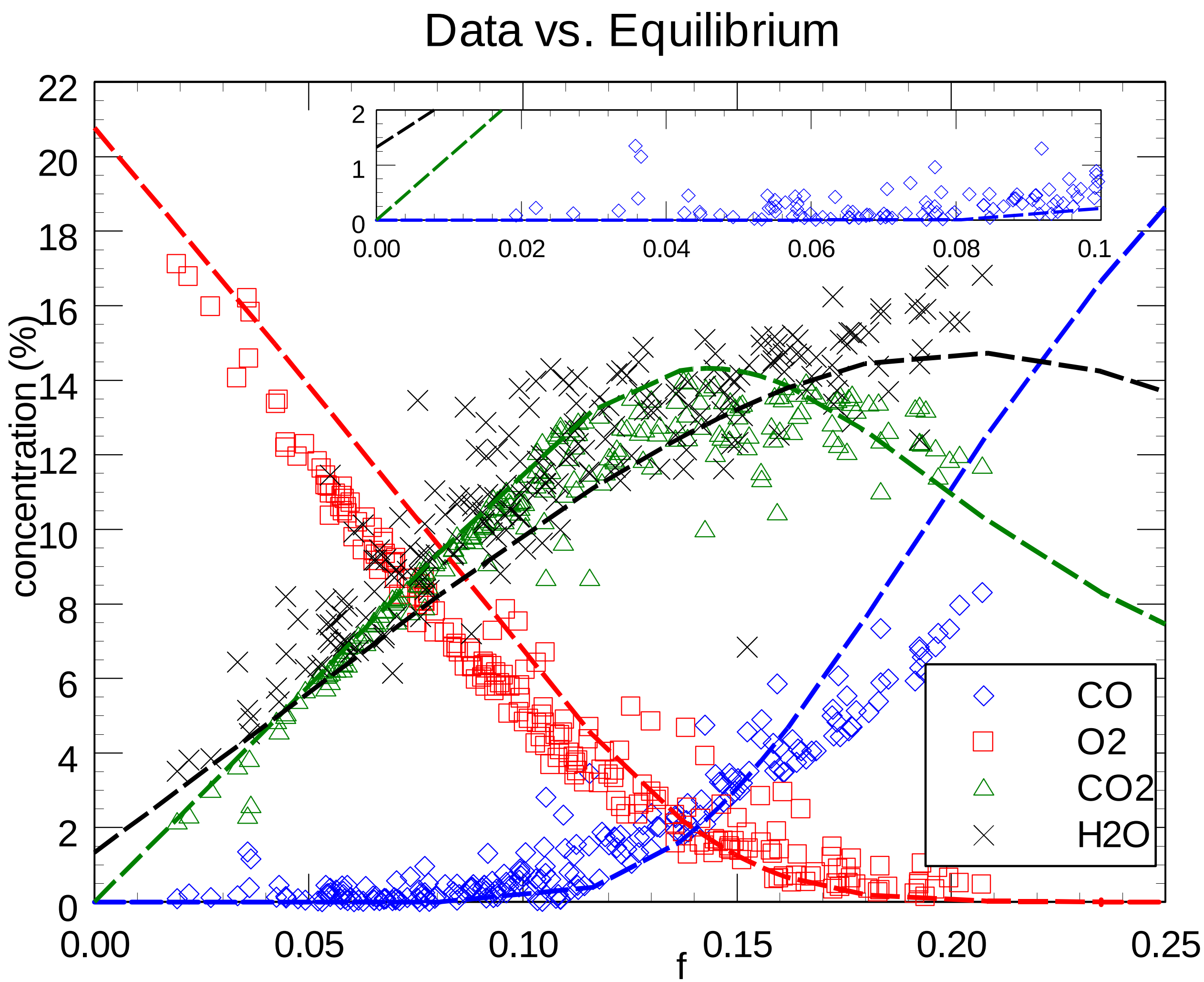
Data Regression

- Based on carbon species, estimate f

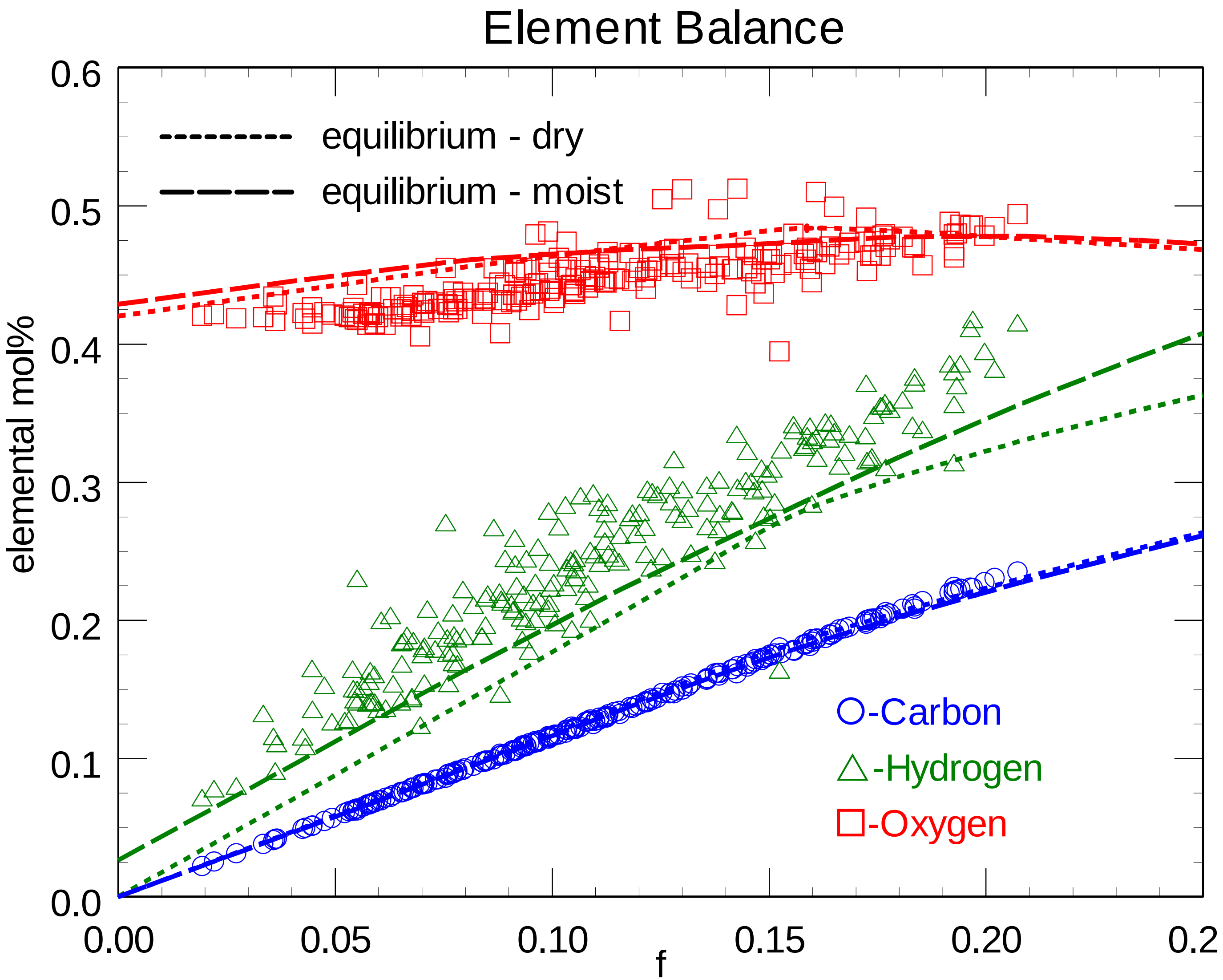


$$f = \frac{m_f}{m_{tot}} = \frac{MW_c \cdot \sum x_i \cdot \xi_i}{MW_{tot} \cdot y_c}$$

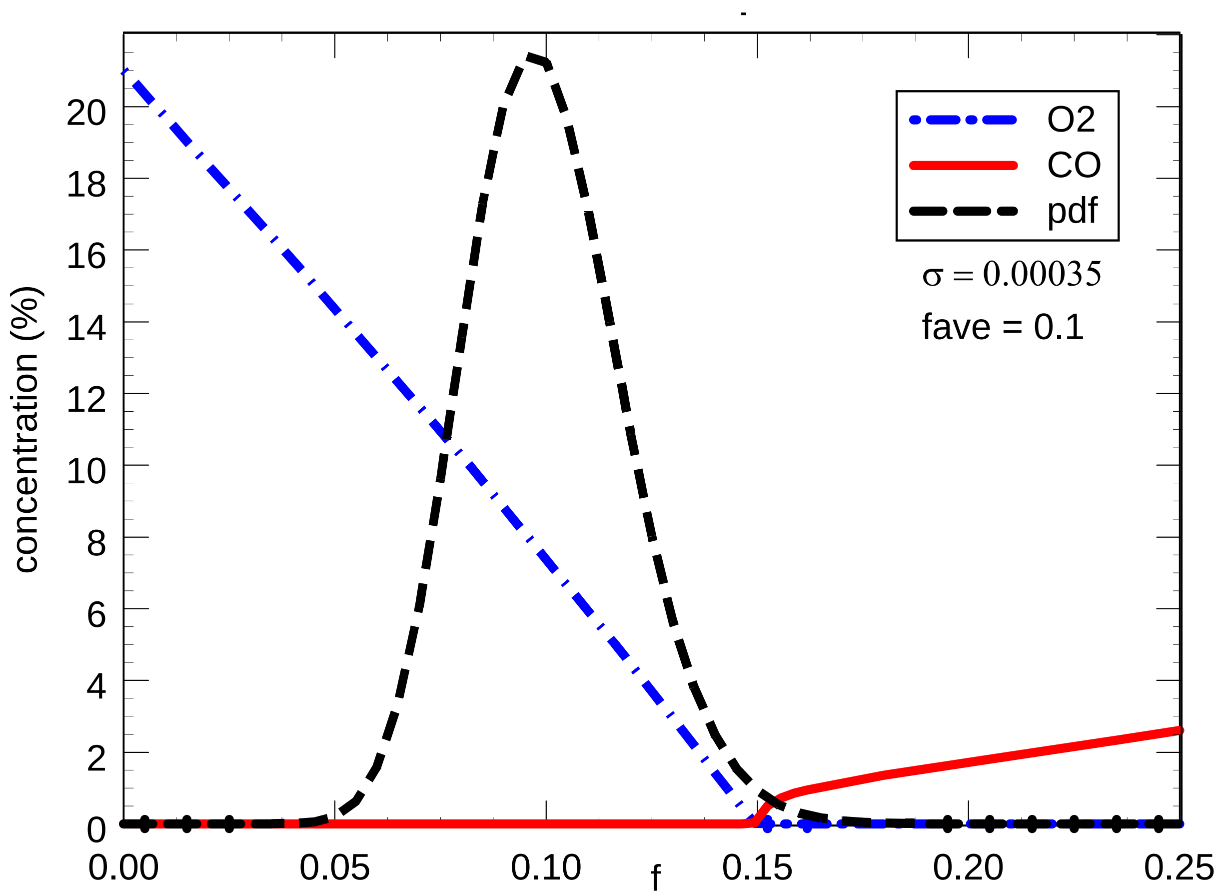
Data Regression



Data Regression

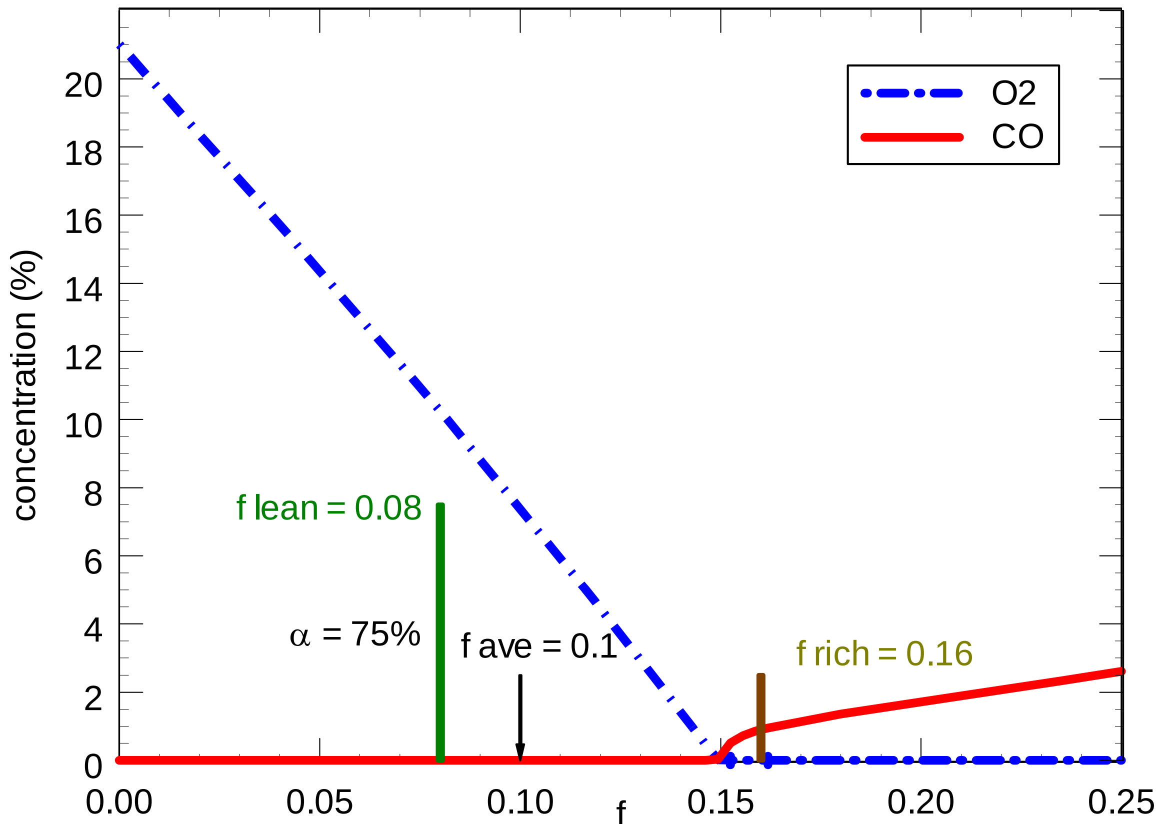


Gaussian pdf Model



$$\overline{x_i} = \int_0^1 pdf(f,\sigma) \cdot x_{i,equil}(f)\, df$$

Dual Delta Function Model (DDF)

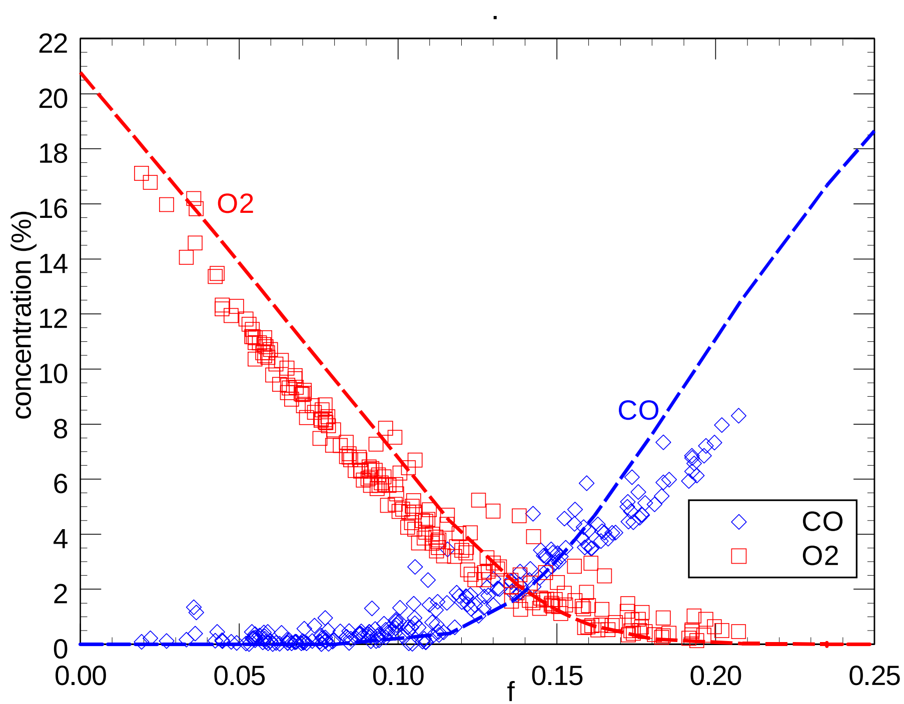


$$\overline{x_i} = \alpha \cdot x_{i,equil}\left(f_{lean}\right) + \left(1-\alpha\right) \cdot x_{i,equil}\left(f_{rich}\right)$$

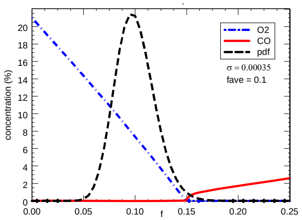
$$\bar{f} = \alpha \cdot f_{lean} + \left(1-\alpha\right) \cdot f_{rich}$$

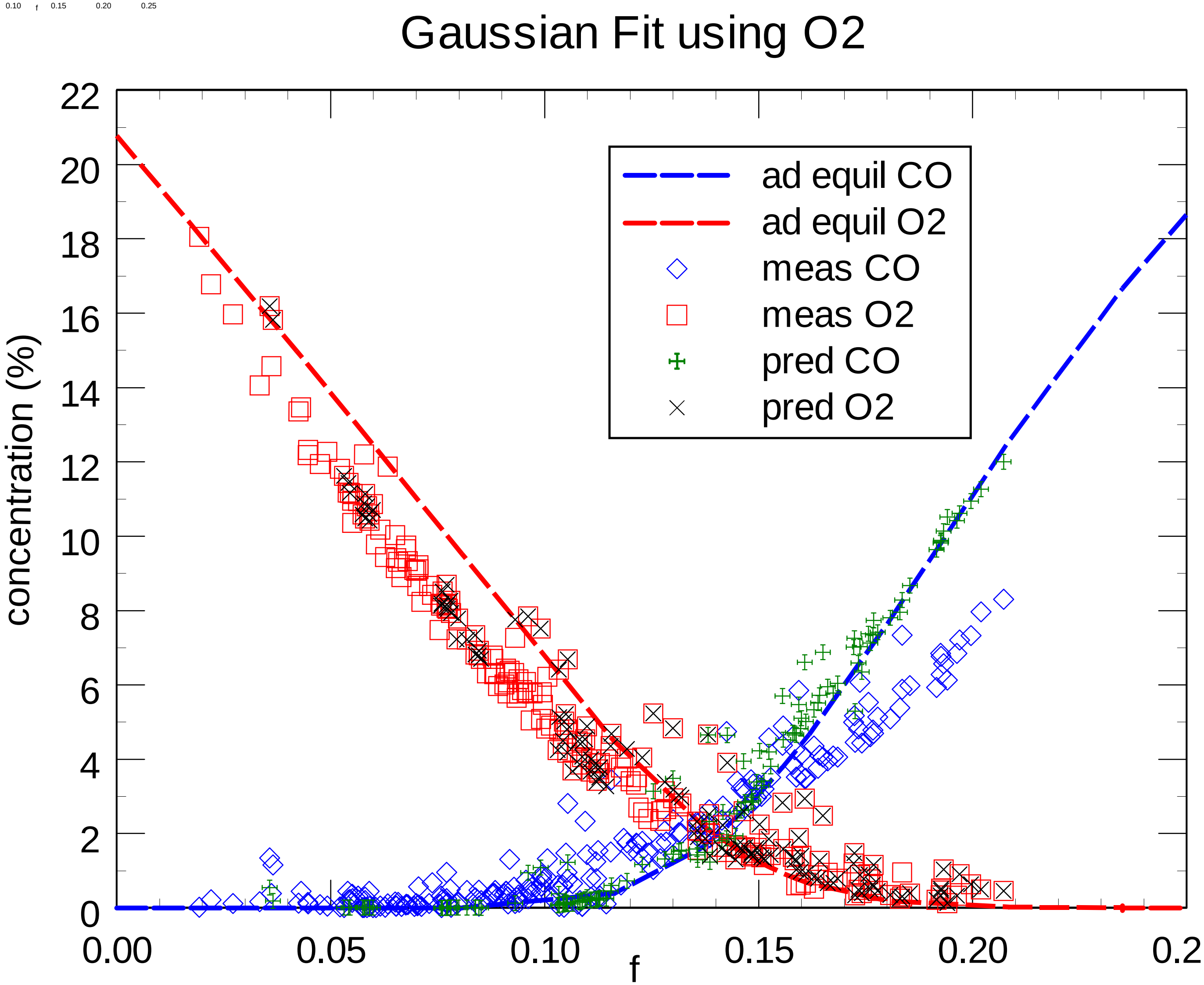
Comparing Models

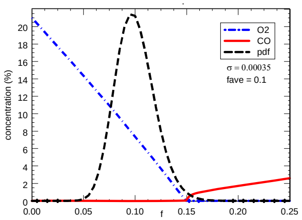
- Use both models to fit flame data by varying model parameters
  - Gaussian pdf: vary σ (get σ_{O2} and σ_{CO})
  - DDF: vary f_{lean} and f_{rich}



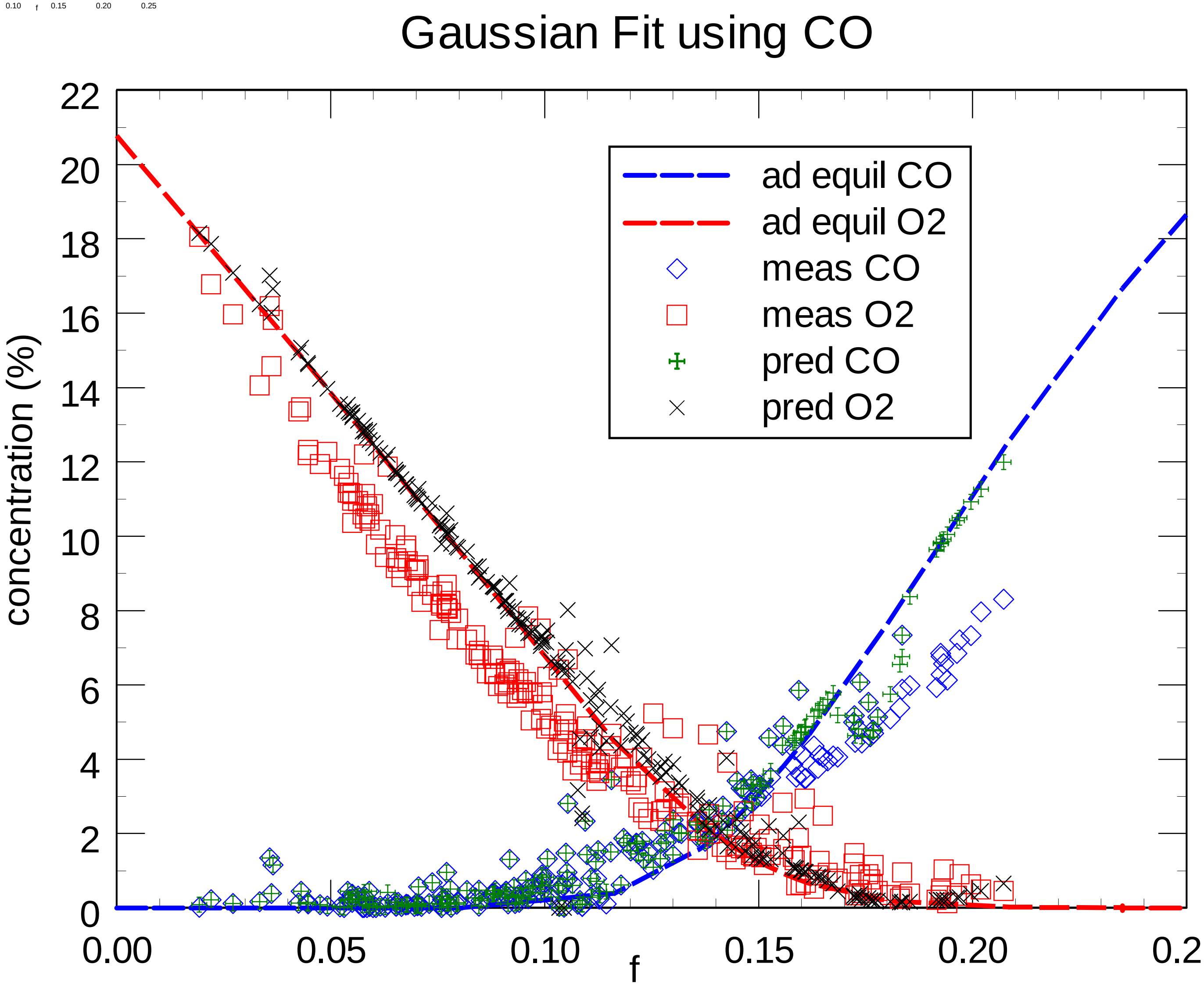
Gaussian pdf – O_2 fit

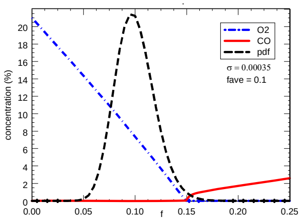




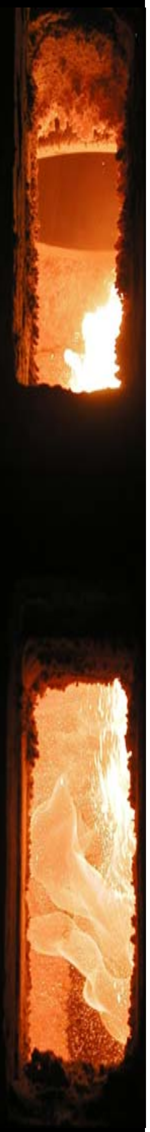


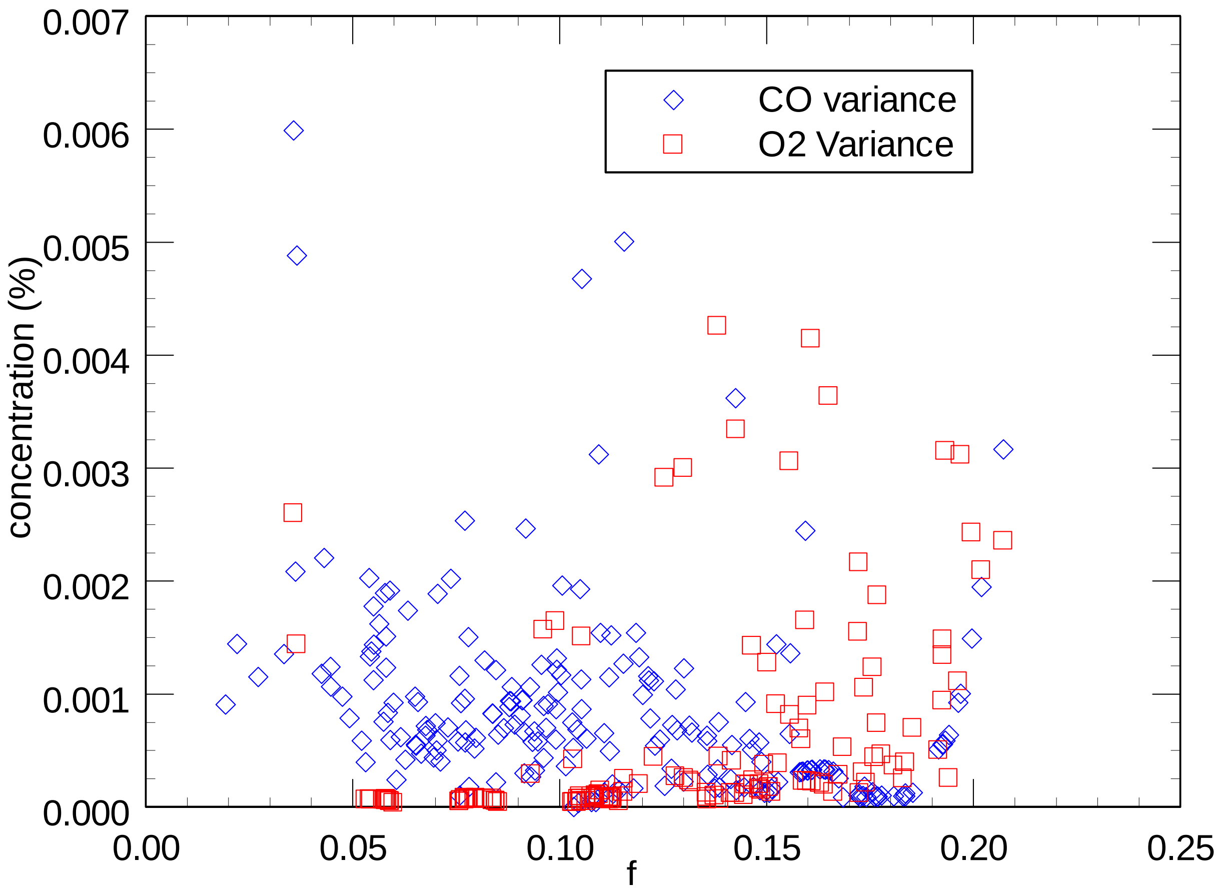
Gaussian pdf – CO fit



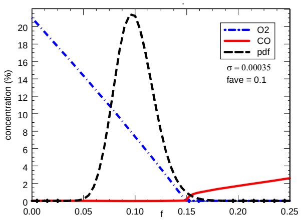


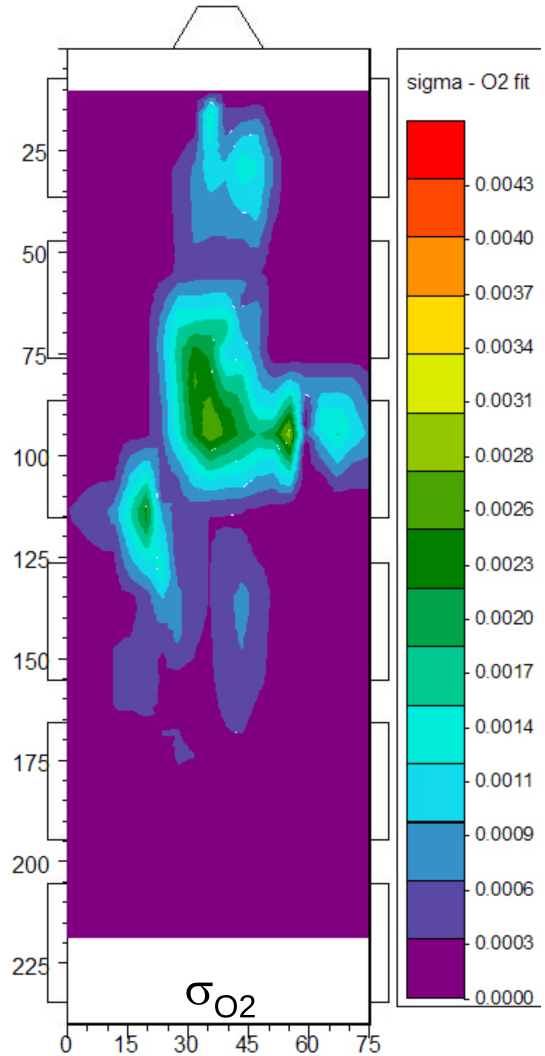
σ_{O2} and σ_{CO}

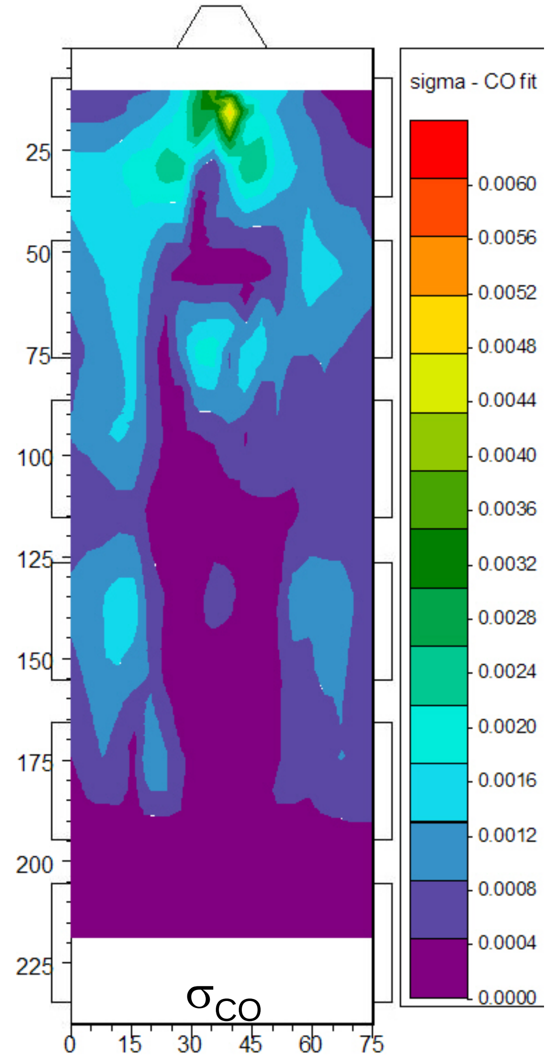




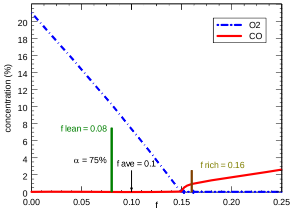
σ_{O2} and σ_{CO}

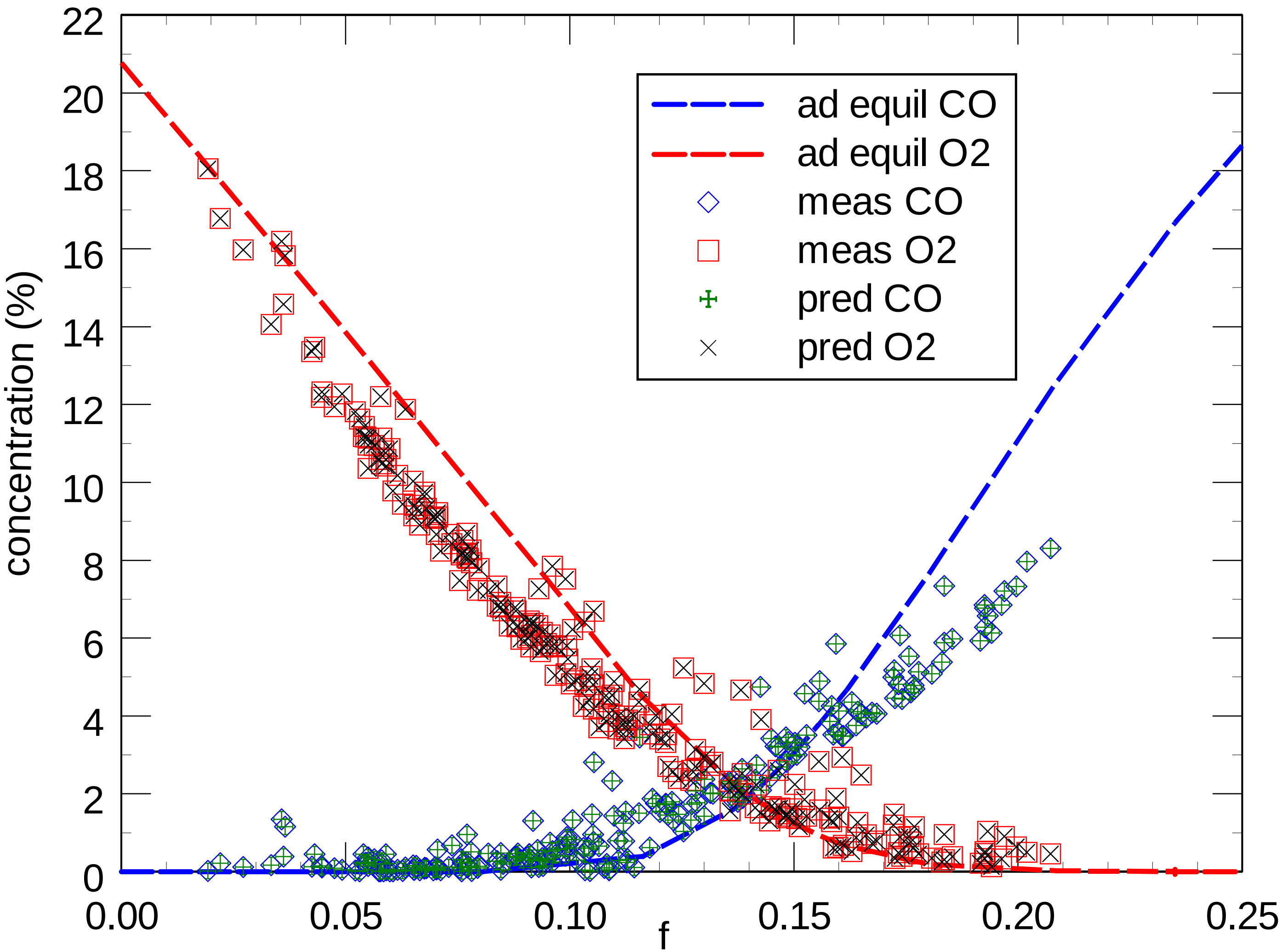


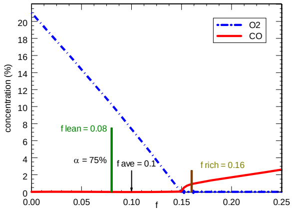




DDF fit

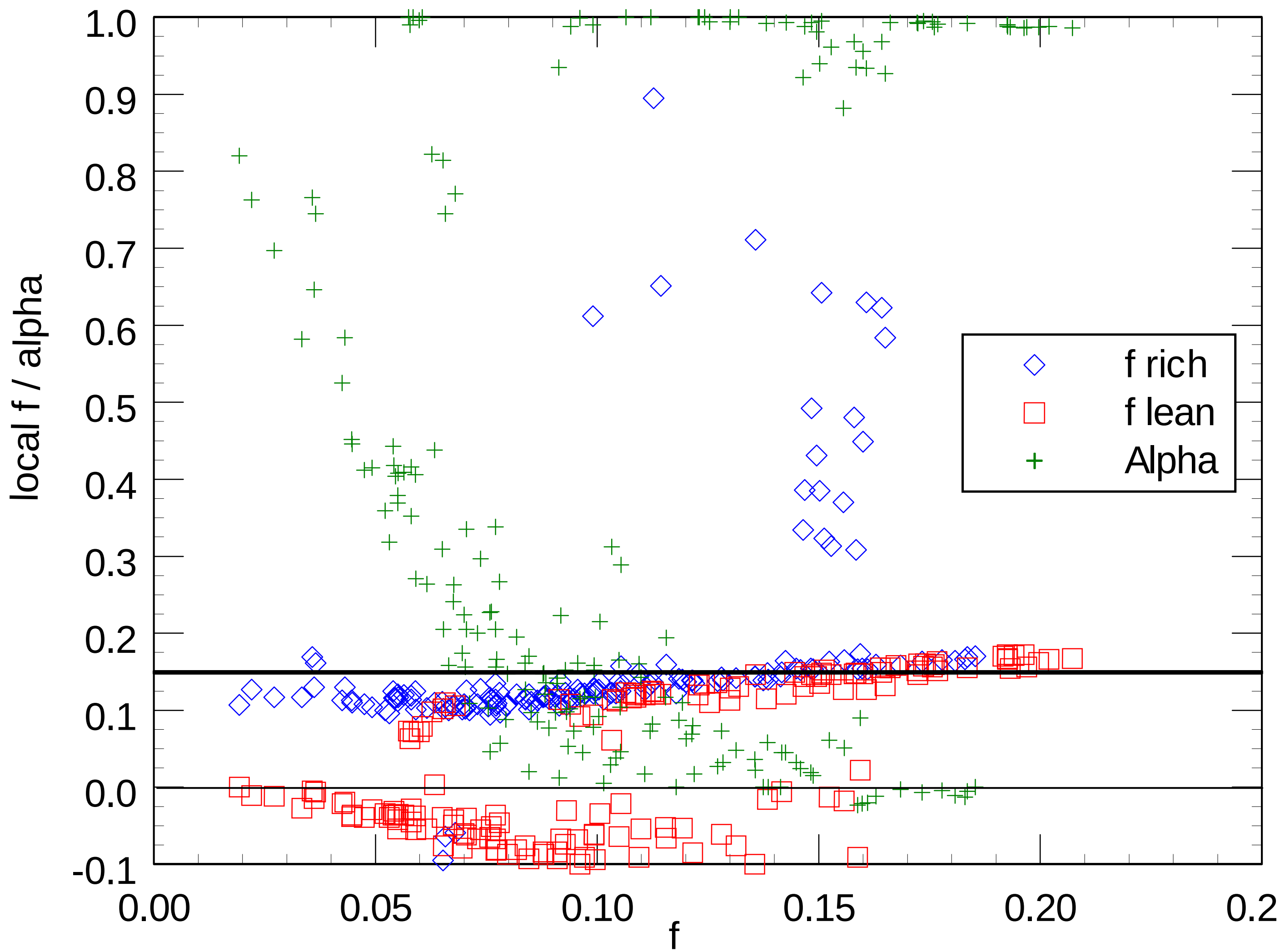

O2
CO
concentration (%)
f lean = 0.08
α = 75%
f ave = 0.1
f rich = 0.16
f
0.00
0.05
0.10
0.15
0.20
0.25


ad equil CO
ad equil O2
meas CO
meas O2
pred CO
pred O2
concentration (%)
f
0
2
4
6
8
10
12
14
16
18
20
22
0.00
0.05
0.10
0.15
0.20
0.25



f_{lean} and f_{rich}

Parameters for DDF fit



Conclusions

- Intermittent flame behavior is prevalent in pulverized fuel flames
- The current modeling approach, Gaussian pdf, is unable to satisfactorily capture intermittent behavior
- An approach using dual delta functions captures intermittent phenomenon
  - Produces physically unrealistic f_{lean}
- Neither model shows great advantages over the other

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