Panel Session: Observations Regarding Autoignition and Contributions of the UTSR Program

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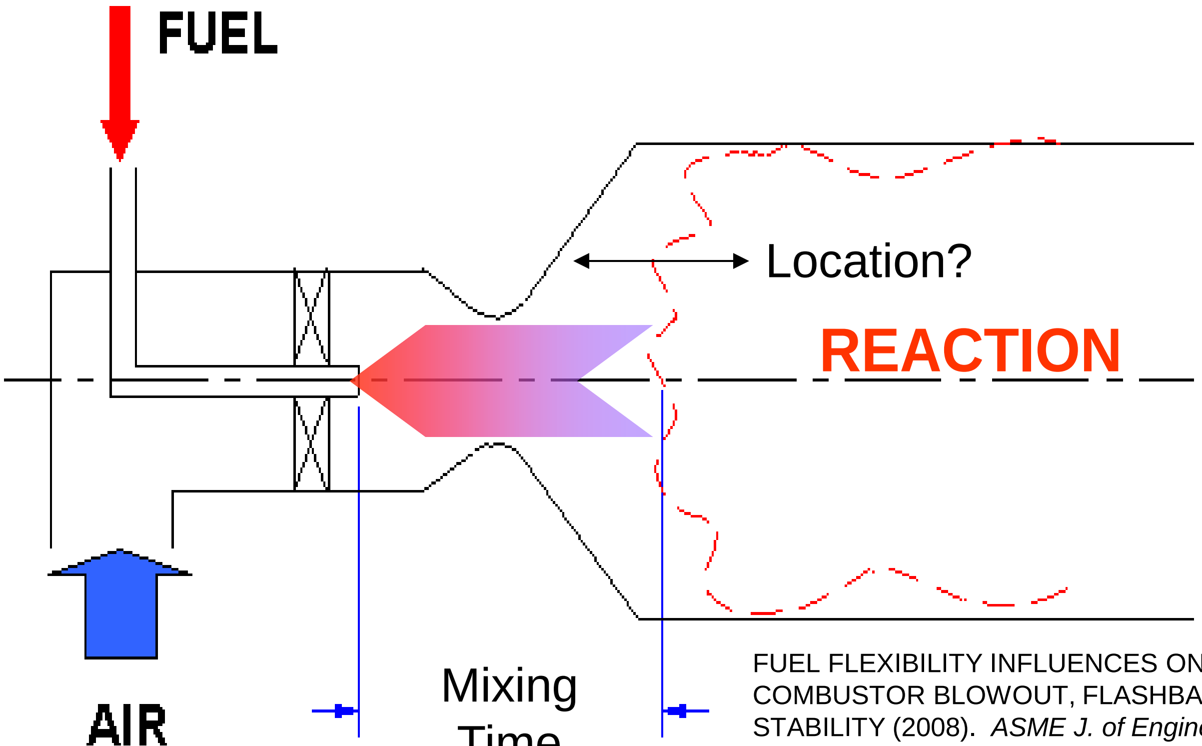
Vincent McDonell, Eric Petersen, Margaret Wooldridge

UTSR 2014 Workshop
West Lafayette, IN
21 October 2014

Ignition Delay

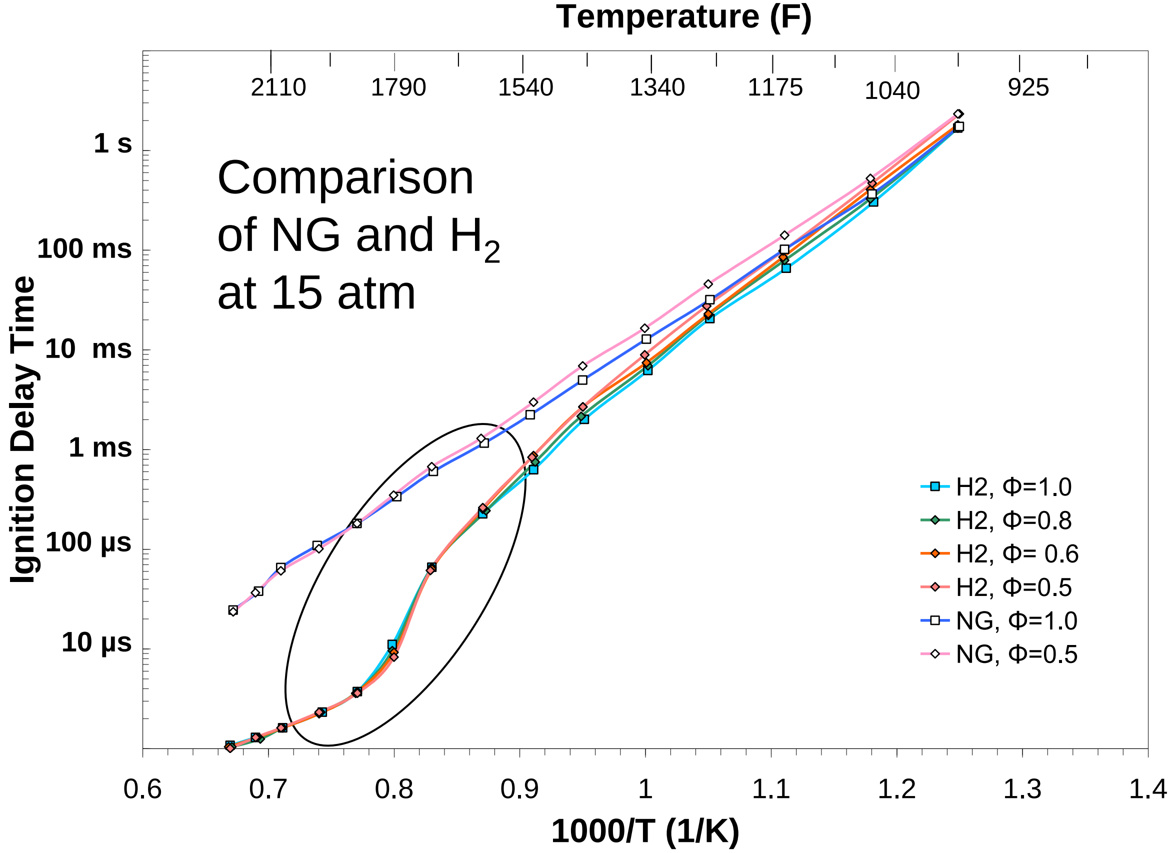
- **Why of interest?**
  - **If $\tau_{mix} > \tau_{ign}$, premixing (and associated temperature/emissions reduction) becomes a challenge for LPM systems**
  - **Relative location of reaction zone**
  - **Basic characteristic for kinetic mechanism validation**



FUEL FLEXIBILITY INFLUENCES ON PREMIXED COMBUSTOR BLOWOUT, FLASHBACK, AUTOIGNITION, AND STABILITY (2008). *ASME J. of Engineering for Gas Turbines and Power*. Vol. 130, January, pp. 011506-1 – 011506-10 (T. Lieuwen, V. McDonell, E. Petersen, and D. Santavicca)

Ignition Delay

- **Typical Ignition Delay Plot**
  - **Log scale for Ignition Delay Time vs 1000/T (1/K)**
    - **Exponential dependency on T**
  - **Hydrogen behavior quite distinct from methane**



$$\text{Ignition Delay} \sim \frac{1}{\text{R.R.}}$$

$$R.R. = k[F][O]$$

$$k = AT^{n} \exp\left(-\frac{E}{RT}\right)$$

Autoignition Devices

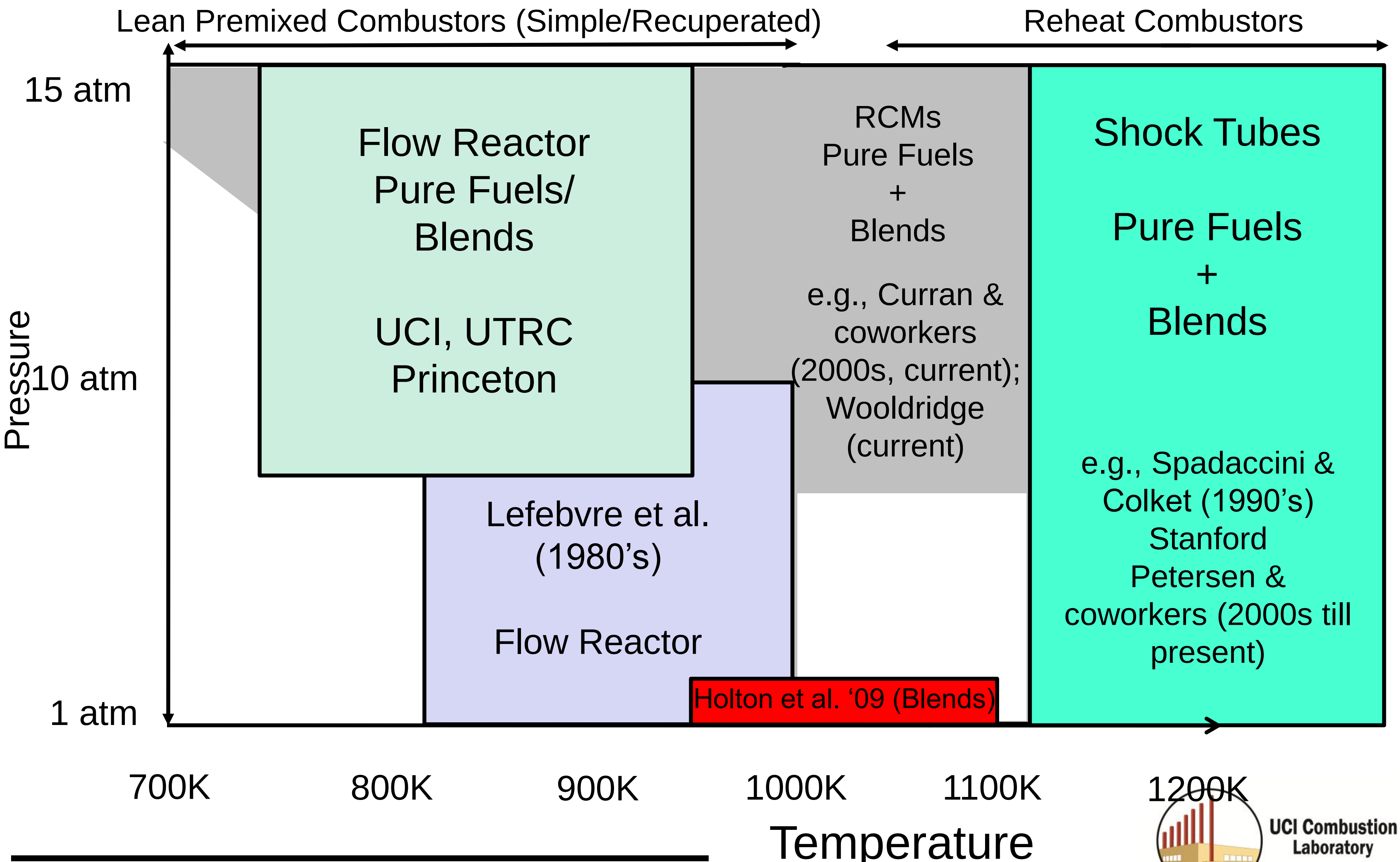
Devices:

- Shock tube – compress homogenous mixture with shock wave
- Rapid Compression Machine – compress homogenous mixture with piston
- Flow reactor – inject fuel into high temperature air stream and rapidly mix

	P	T	Test Times
Shock tubes	1- 100 atm	1000 to 3000K	< 10 ms
RCMs	1- 50 atm	900 to 1200K	1 to 50 ms
Flow Reactors	1 - 30 atm	300 to 1000K	50 to 500 ms

- Each device has relative advantages/disadvantages along with different range of operating conditions

Gas Turbine Context



Panel Session: Autoignition and UTSR

Flow Reactor Perspective

Vincent McDonell

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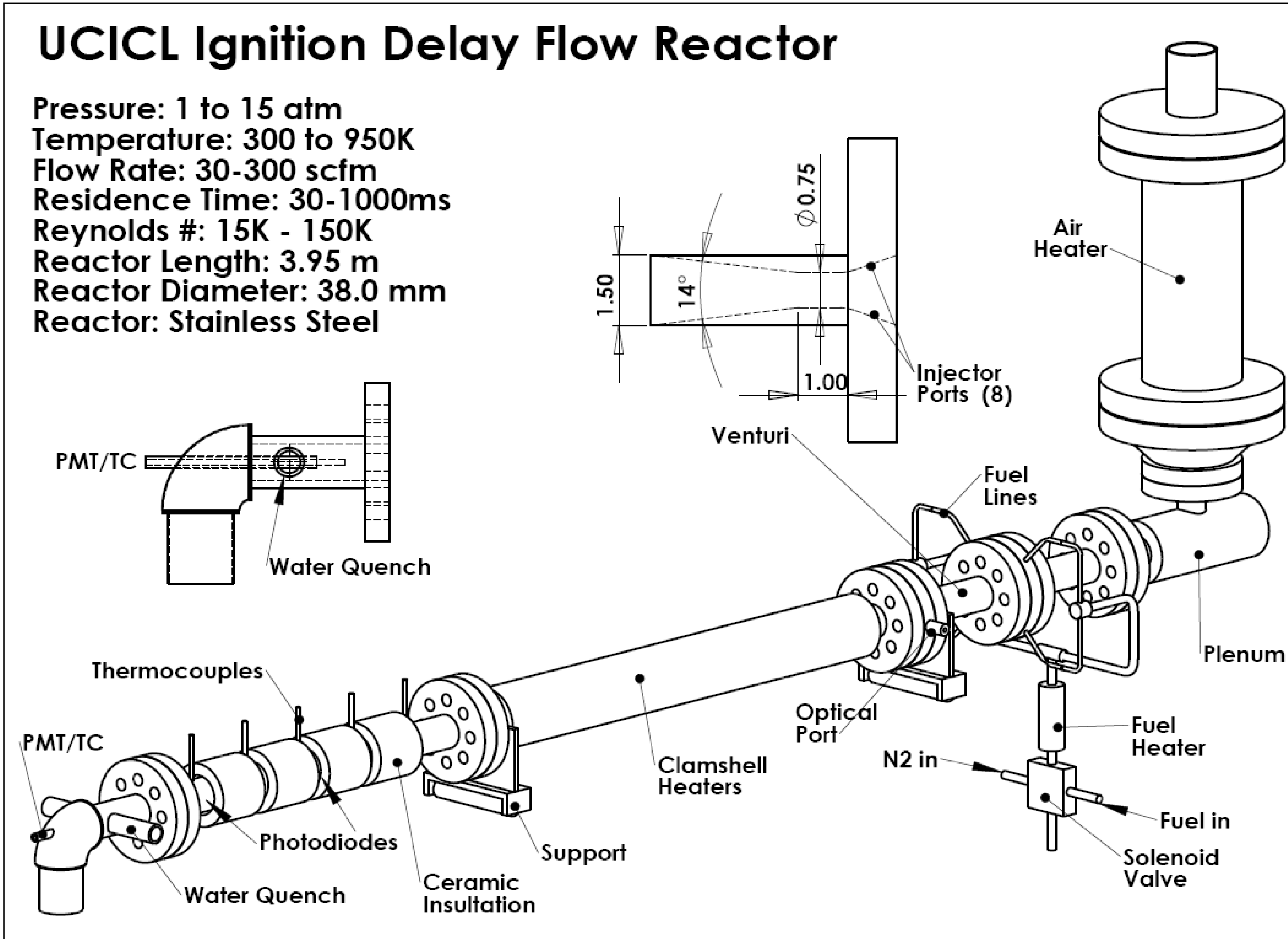
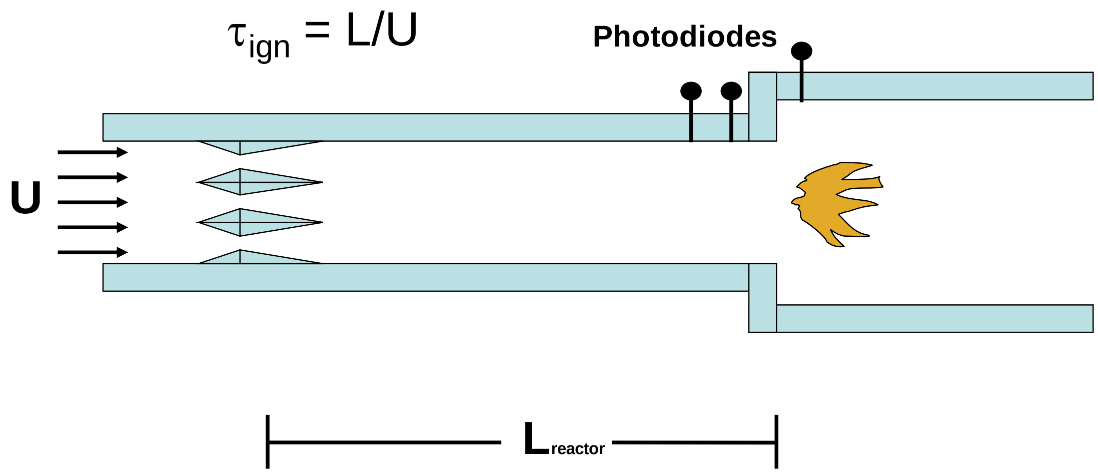
UCICL Flow Reactor



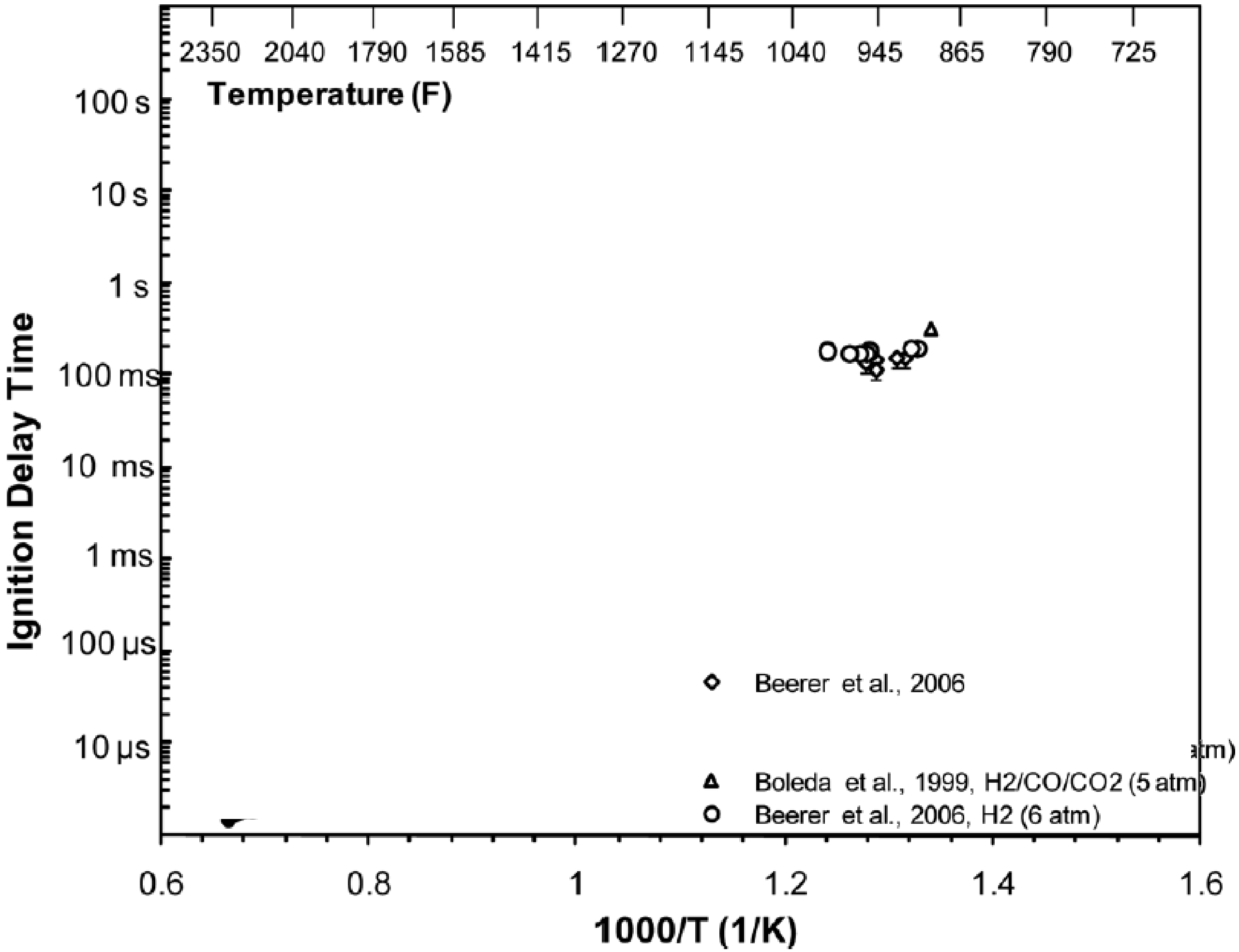
Steady Flow Technique for Hydrogen

- **Conditions for Ignition slowly approached**
  - **Method of Spadaccini (1976) and co-workers at UTRC**
  - **Small step increases in inlet T until ignition observed**
  - **Ignition occurs at end of reactor as that point will have longest time**



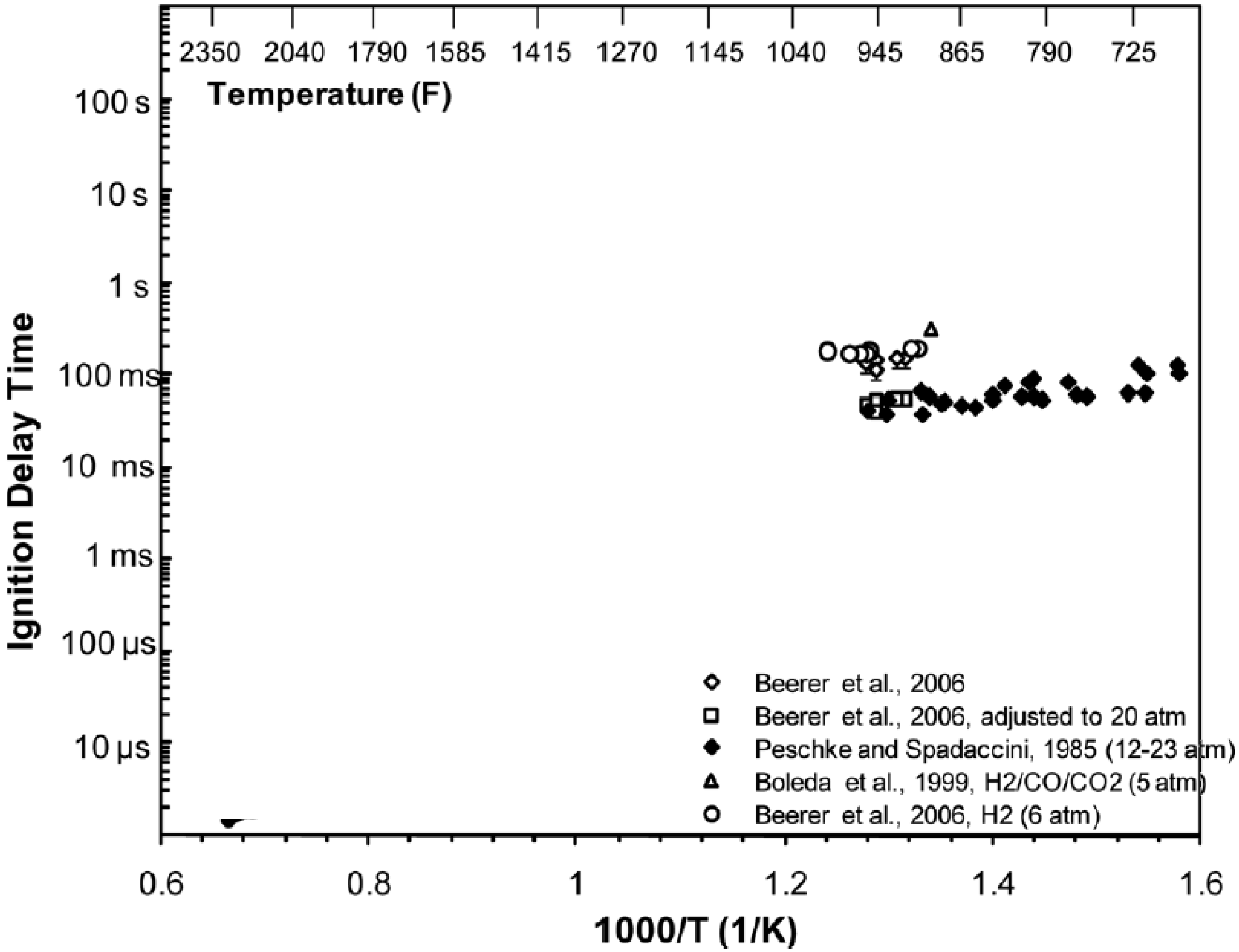
- Other more efficient/effective methods developed and used for later alkane studies

Experimental Results for Hydrogen



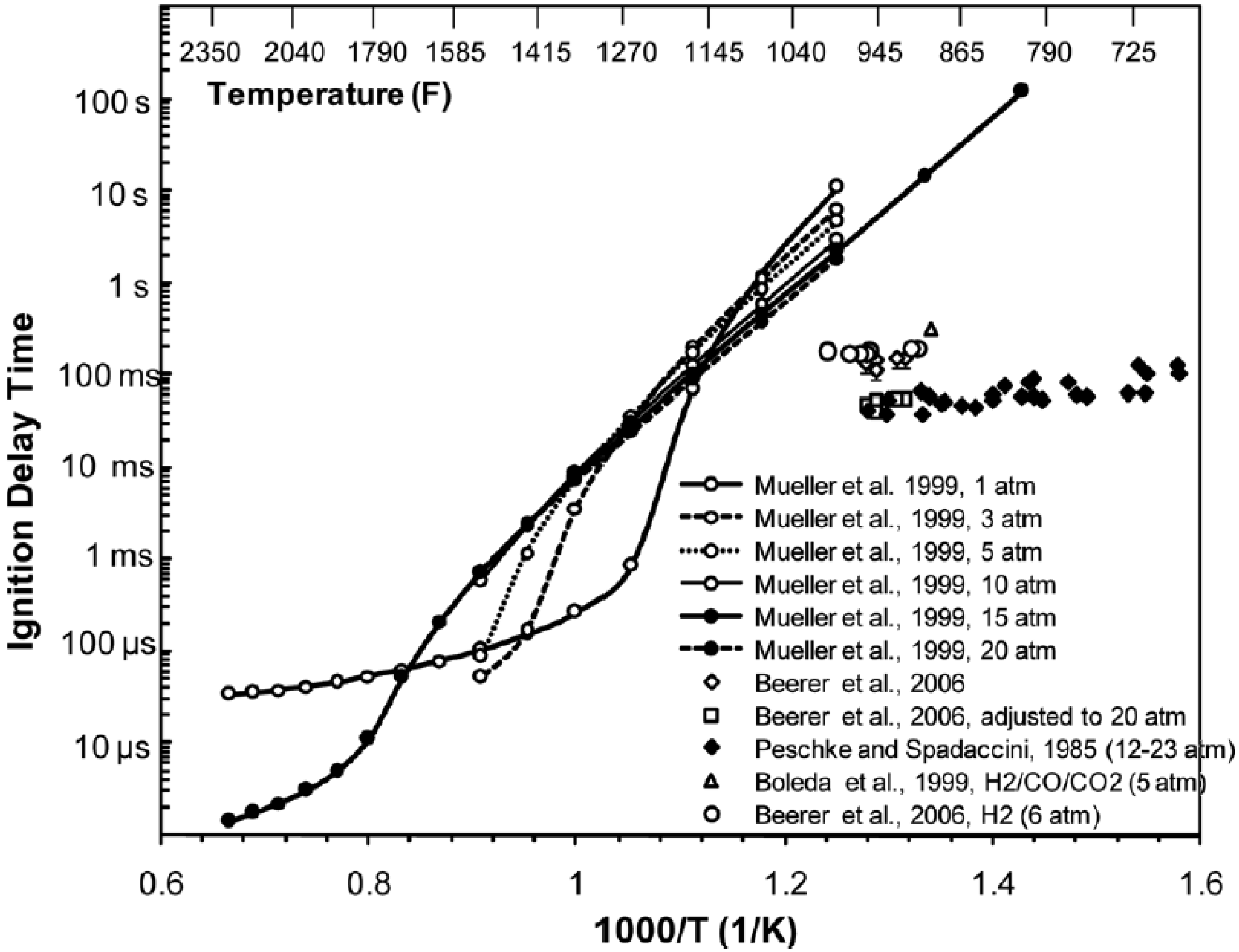
Boleda et al. (1999)—UCI EPRI Report
Beerer et al (2006)—UCI UTSR Final Report 03-01-SR112

Experimental Results for Hydrogen



Peschke, W.T. and Spadaccini, L.J. (1985) Determination of Autoignition and Flame Speed Characteristics of Coal Gases Having Medium Heating Values. Final Report for AP-4291 Research Project 2357-1

Results for Hydrogen vs Models



Mueller, M.A., Kim, T.J., Yetter, R.A., and Dryer, F.L. (1999a) Flow reactor studies and kinetic modeling of the H2=O2 reaction. Inter. J. Chem. Kinetics, 31, 113

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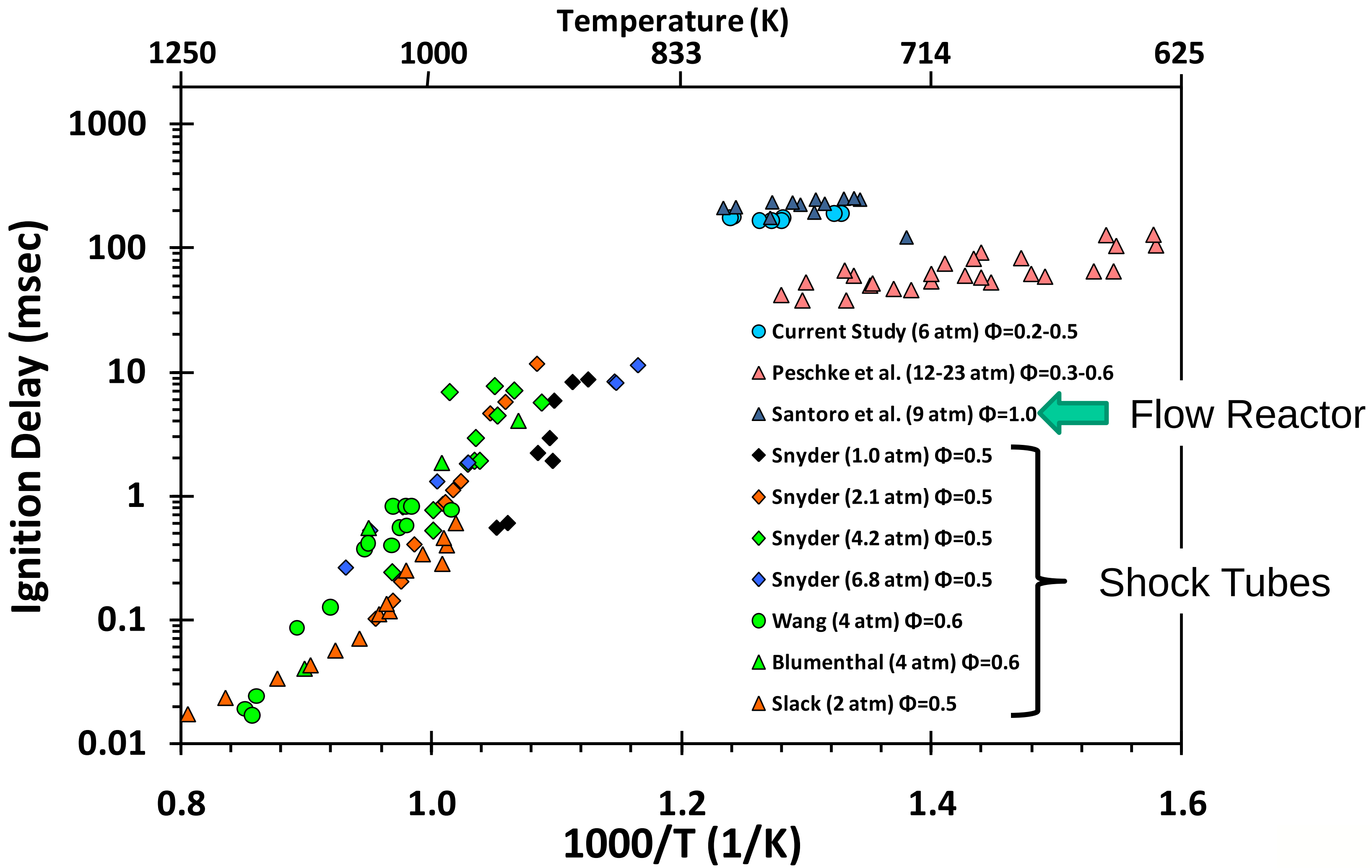
Experimental Results for Hydrogen



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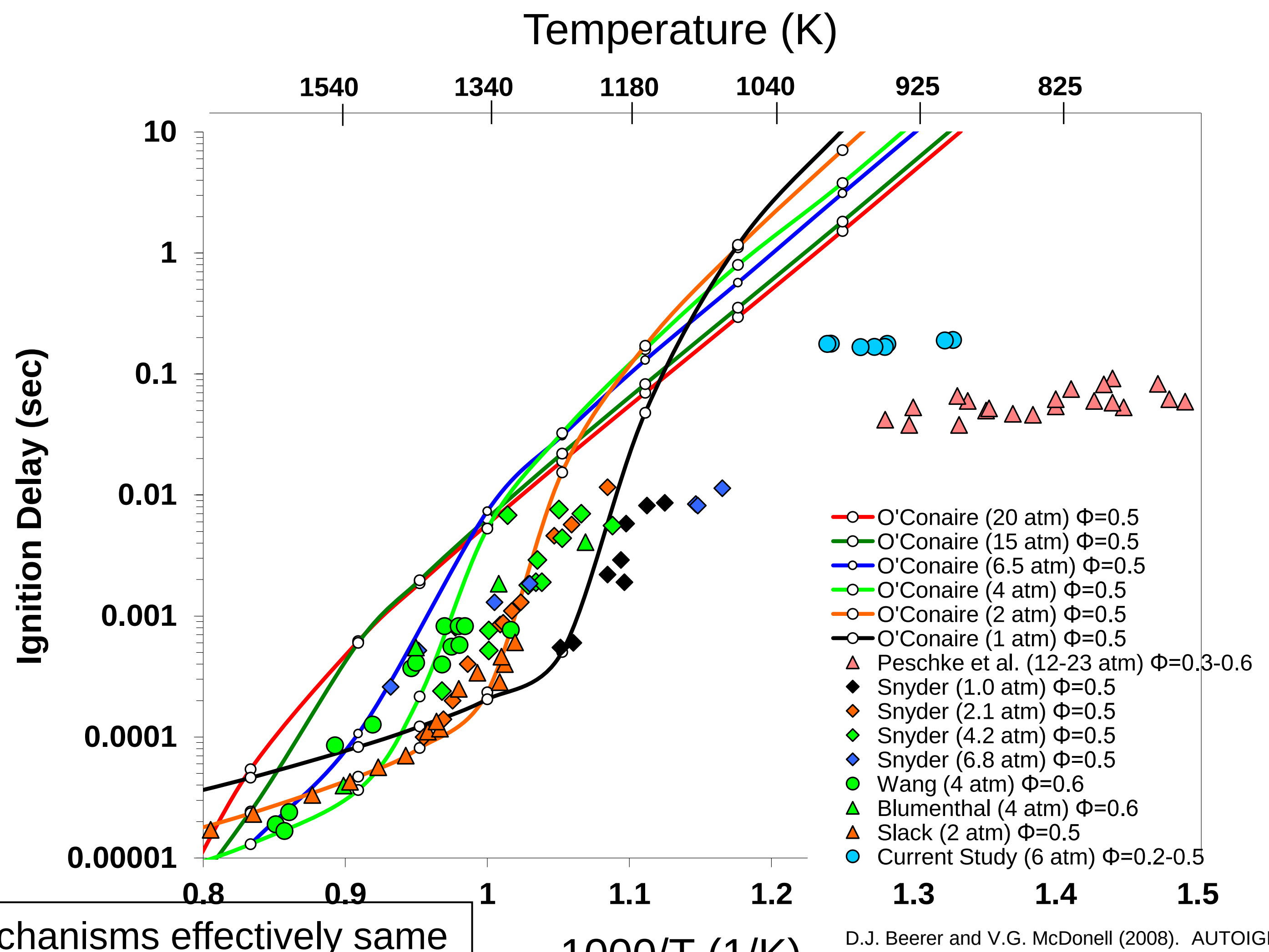
Results for Hydrogen vs Models



- All mechanisms effectively same
- 1985 data--100x faster ignition

D.J. Beerer and V.G. McDonell (2008). AUTOIGNITION OF HYDROGEN AND AIR IN A CONTINUOUS FLOW REACTOR WITH APPLICATION TO LEAN PREMIXED COMBUSTION (2008). *ASME J. Engr. Gas Turbines and Power*, Vol 130, 051507-1 to 051507-9, September.

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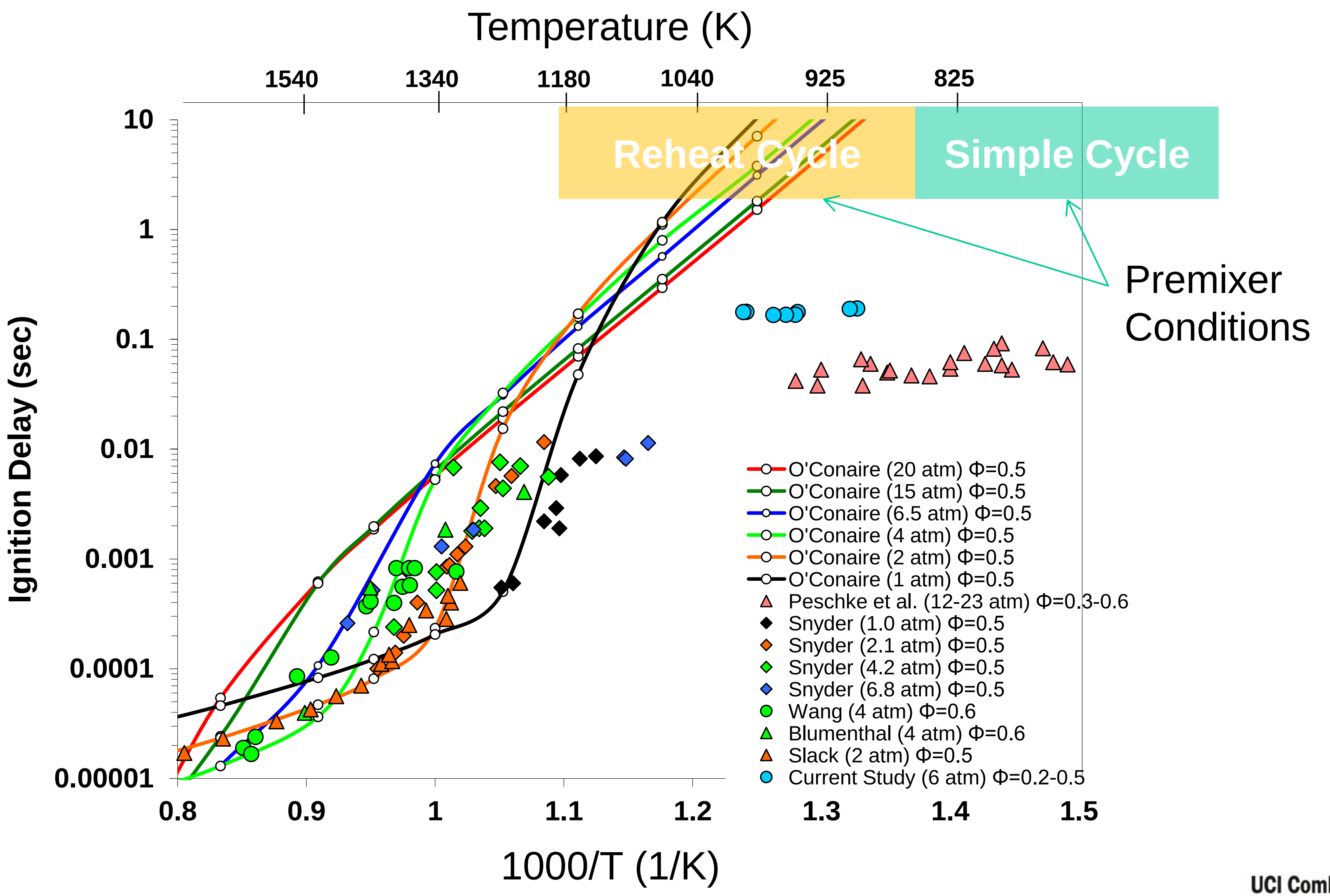

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Ignition Delay

- **Engine Implications**

Engine	Pressure (atm)	Air Temp (K)	Estimated Ignition Delay Time: H2/CO Based on Experiments	Estimated Ignition Delay Time: H2/CO CHEMKIN (Mueller)
GE 9H *	23	705	85	11800
Solar Taurus 65	15	670	153	-
Solar Taurus 60	12.3	644	221	-
Solar Mercury 50**	9.9	880	59	4941
GE LM6000 *	35	798	35	34850
Siemens V-94.3A *	17.7	665	141	-
Siemens V-94.2 *	12	600	336	-
Capstone C60**	4.2	833	140	1869

* Inlet temp estimated from ideal gas, isentropic compression

** Recuperated Engine

 - represents no ignition within 1 min.

What about wall surface effects, radiation, poor aerodynamics?
(ignition at 800K with 1/8” rod inserted into flow vs 1000K w/o)
Part load conditions

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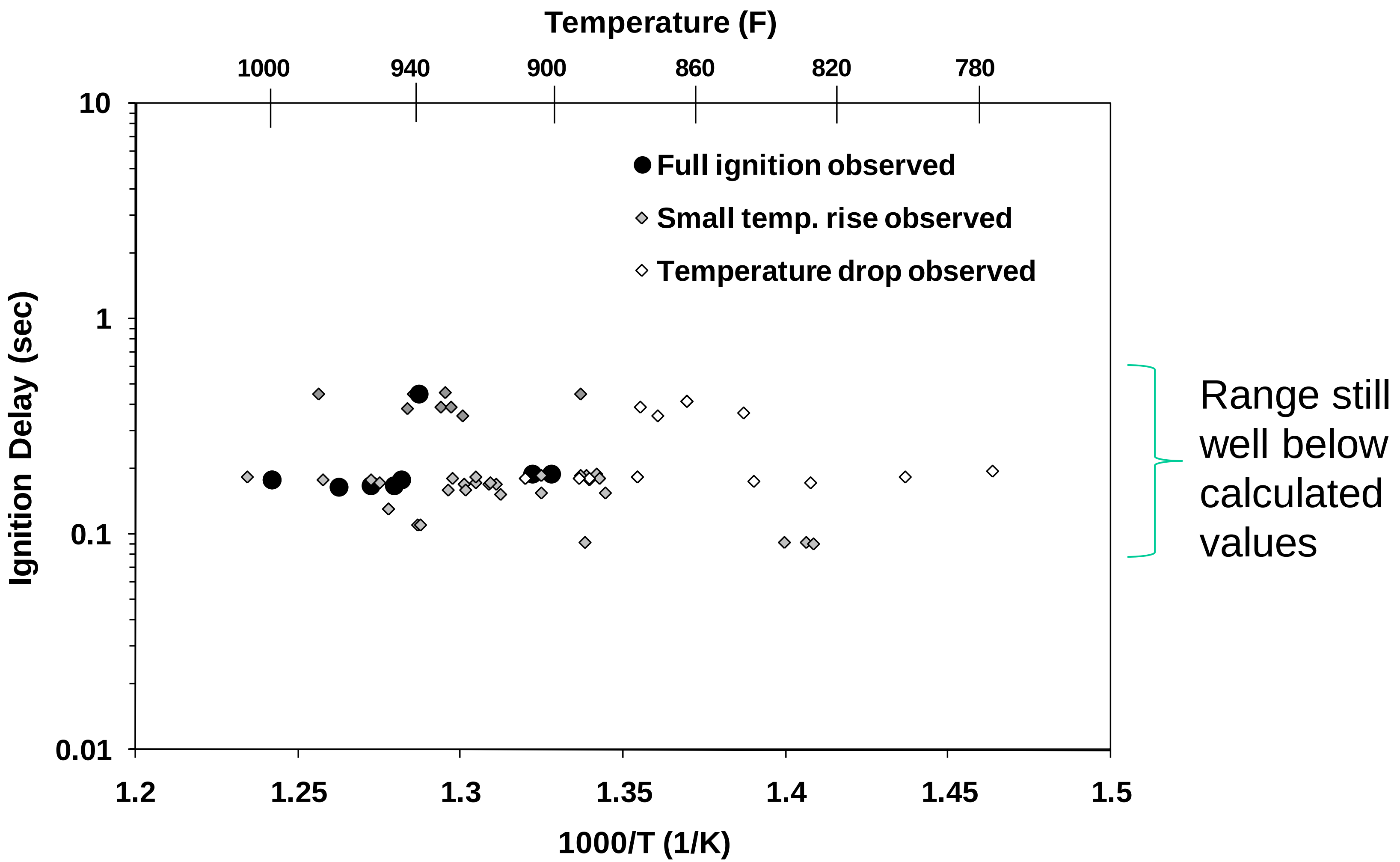
Experimental Results for Hydrogen



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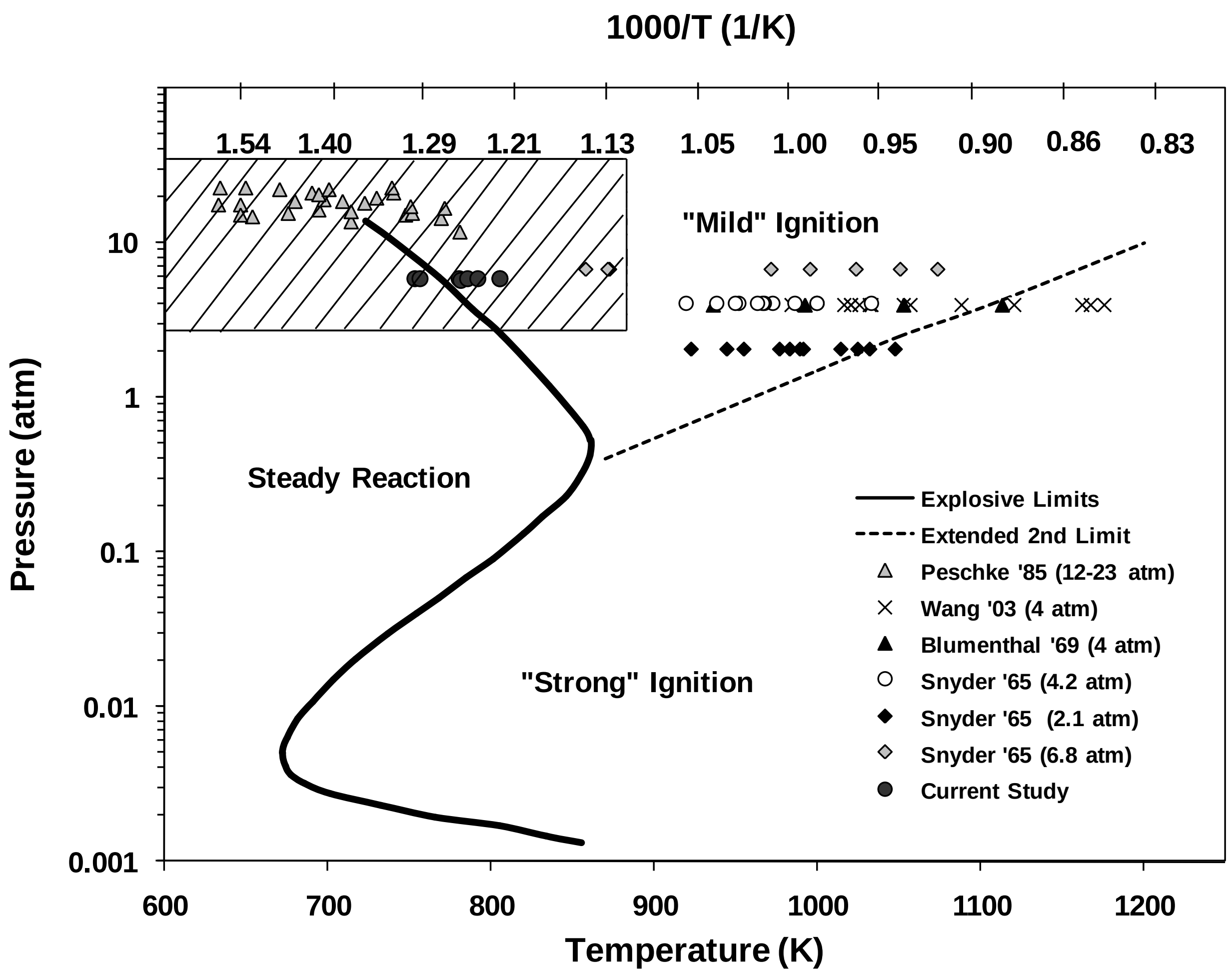
Experimental Results for Hydrogen



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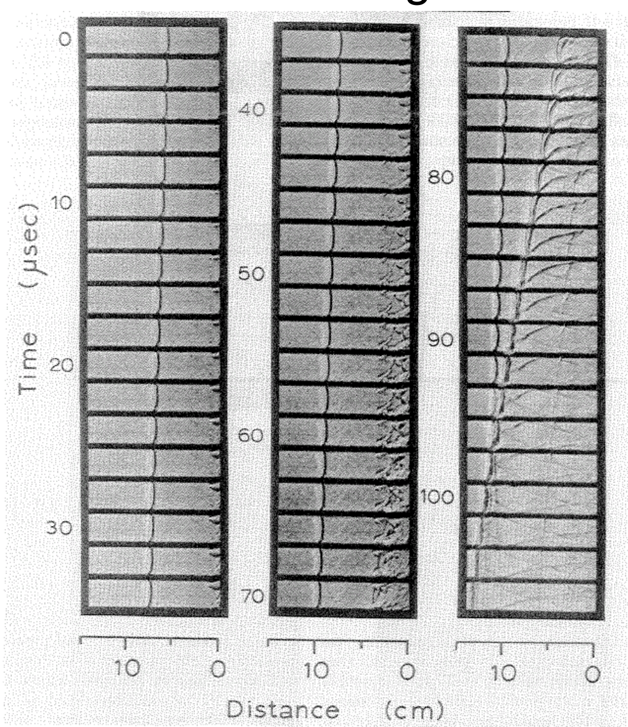
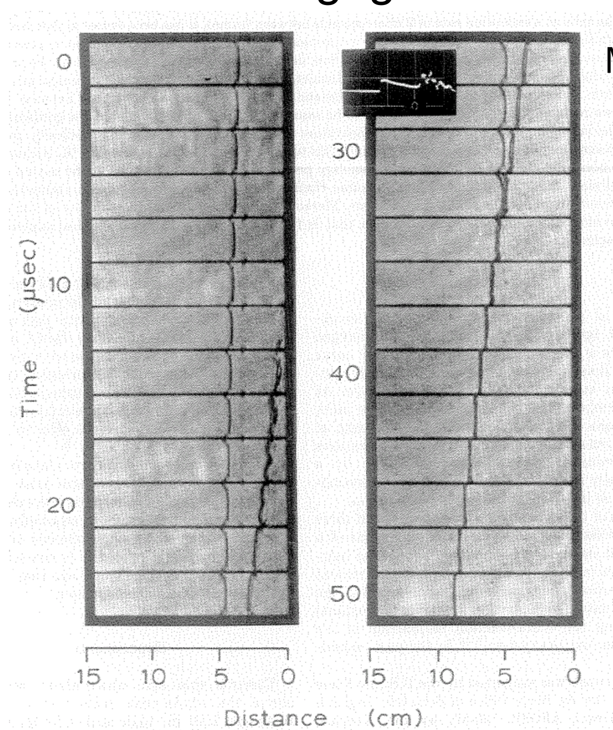
Ignition Delay

- **Reasons for Discrepancy?**
  - **Flowing gas/wall effects shorten delay time?**
    - **Noted by some (most GT premixers have flowing gas/walls)**
  - **Homogeneous ignition vs "localized"?**

"Mild" Ignition



"Strong Ignition"



Meyer & Oppenheim, 1971

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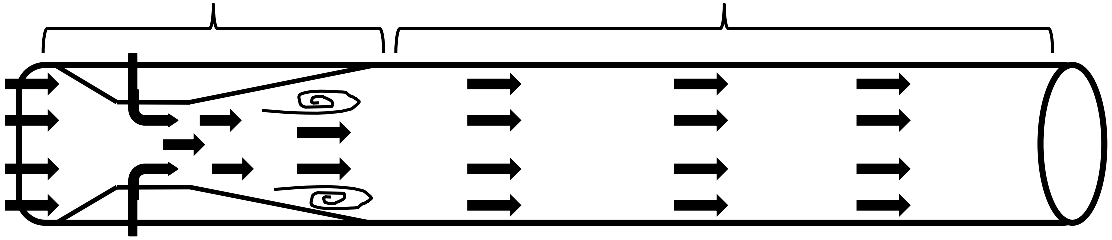
Flow Reactor Homogeneity

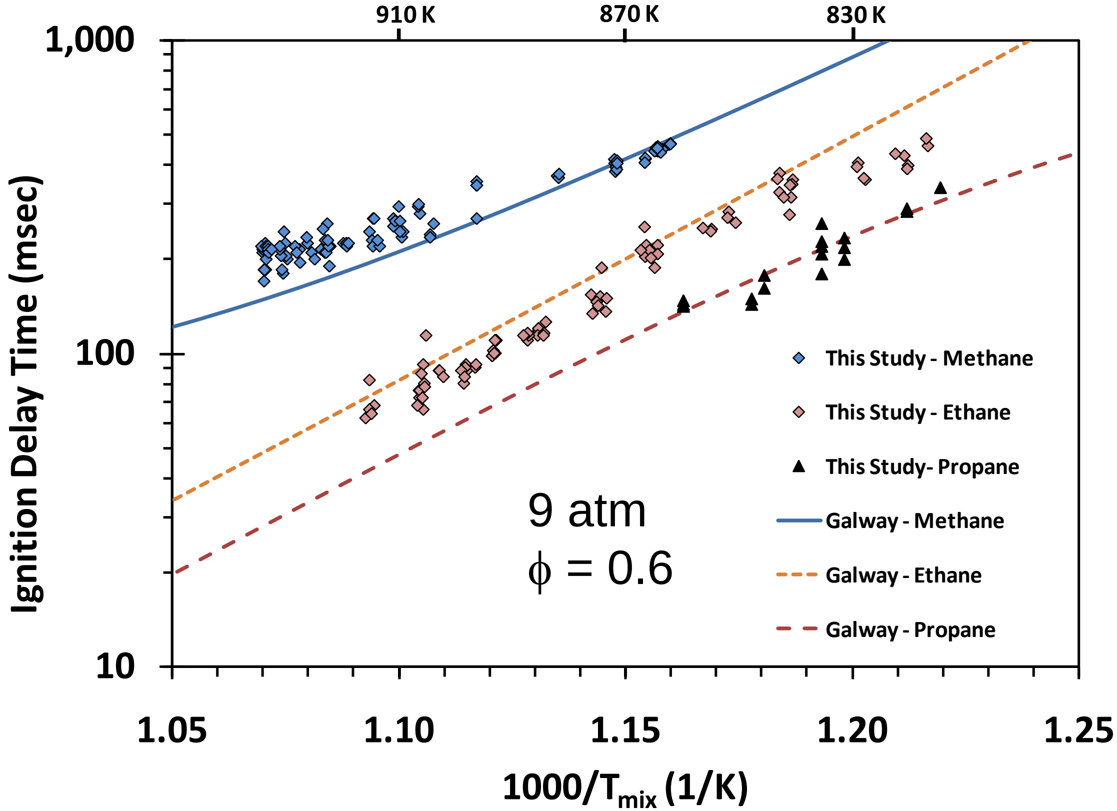
- **Regions in the reactor are clearly not fully homogeneous with respect to mixing/velocity……**



- **…..but are representative of the processes/rates within practical devices**

Alkane Behavior

- **What about results for alkanes?**
  - **Unlike H_2, model/measurements agree well in low T region (at least for this study)**



D.J. Beerer and V.G. McDonell (2011). AN EXPERIMENTAL AND KINETIC STUDY OF ALKANE AUTOIGNITION AT HIGH PRESSURES AND INTERMEDIATE TEMPERATURES. *Proceedings of the Combustion Institute,* Vol 33, pp. 301-307.

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