激波管化学动力学研究进展及关键科学问题

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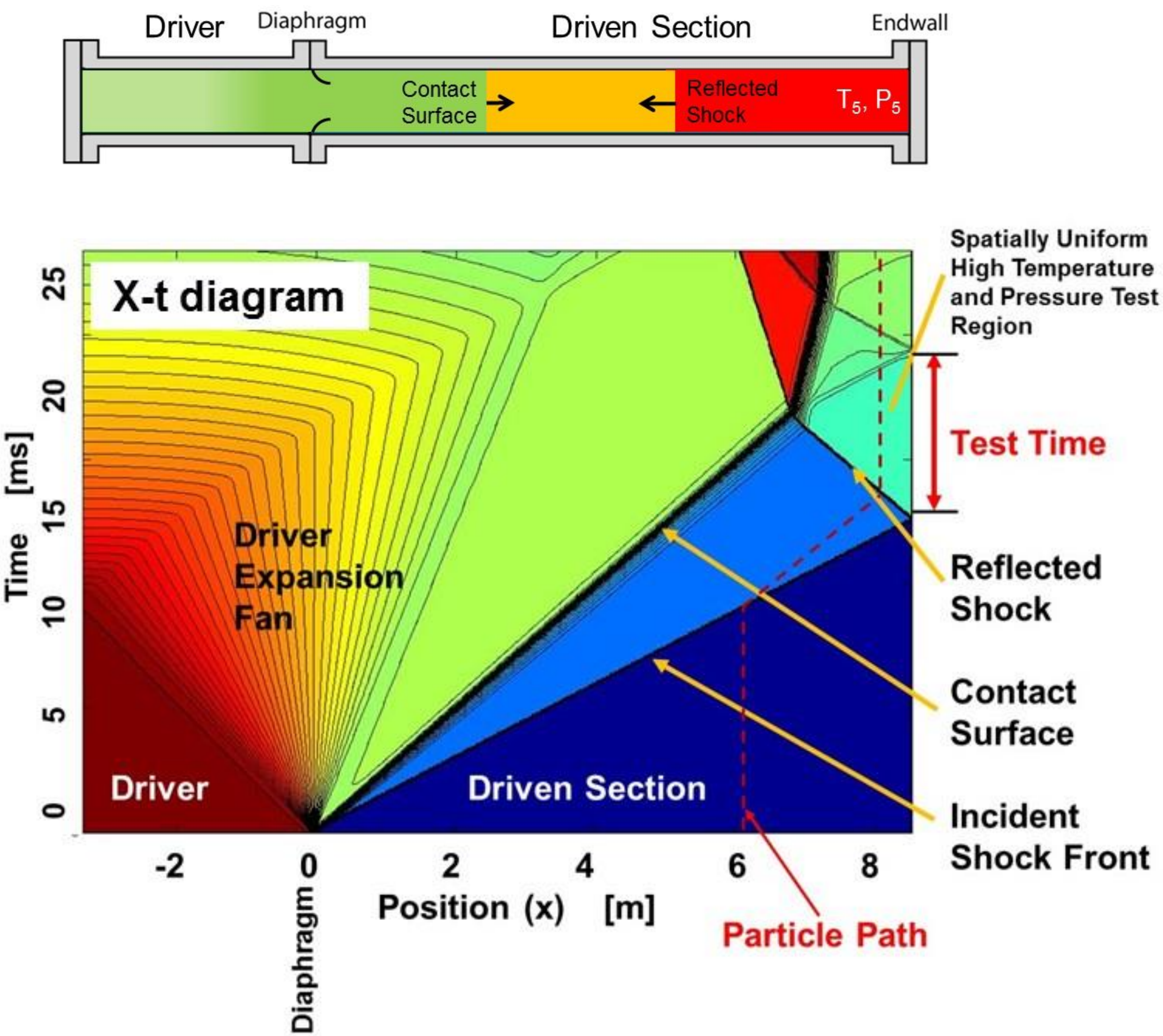
过去的工作

- 激波管流场参数测量
- TDLAS激光诊断
- 激波管化学反应动力学

激波管 (Shock Tube)

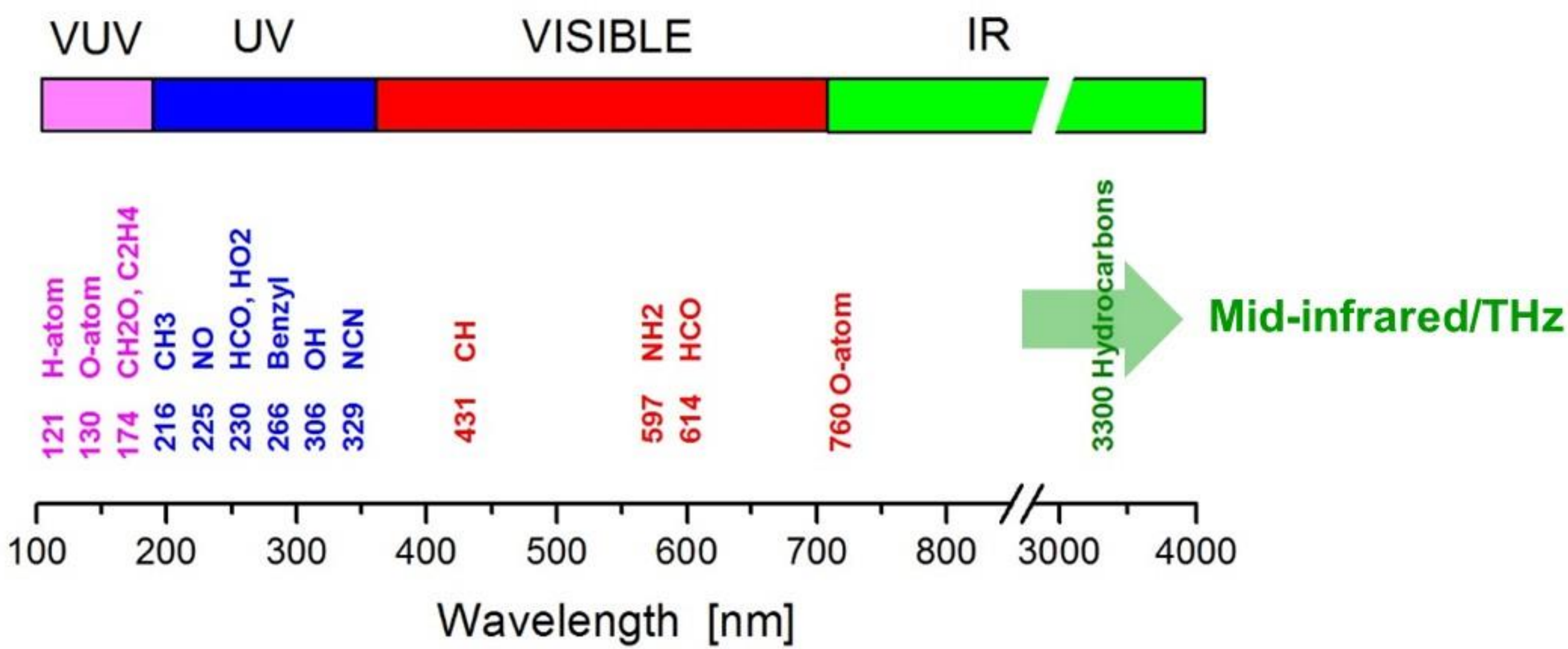


Advantages:

- Near-constant-volume reactor
- Reflected shock stagnates test gas mixtures
- Accurately known initial T and P
- Allows for combustion studies with wide range of T

TDLAS激光诊断

- 随着半导体技术的发展，近-中红外吸收光谱诊断技术逐渐应用到燃烧研究中。

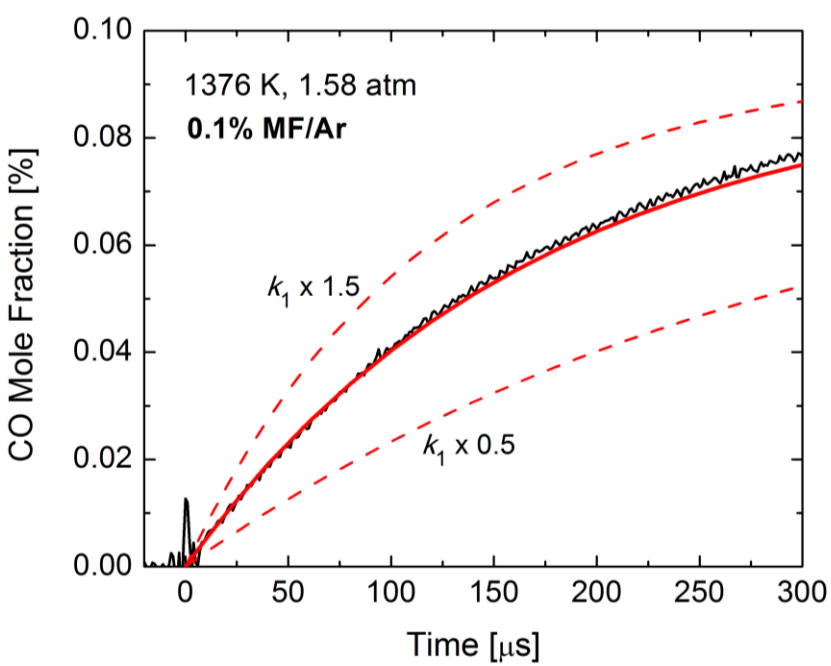


- *W. Ren, J. B. Jeffries, and R. K. Hanson, Meas. Sci. Tech., 21(10), (2010).*
- *W. Ren, A. Farooq, D. F. Davidson, and R. K. Hanson, Appl. Phys. B, 107(3), 849–860 (2012).*
- *W. Ren, D. F. Davidson, and R. K. Hanson, Int. J. Chem. Kinet., 44(6), 423–432 (2012).*
- *R. M. Spearrin, W. Ren, J. B. Jeffries, R. K. Hanson, Appl. Phys. B, 116(4), 855–865 (2014).*

激波管化学反应动力学

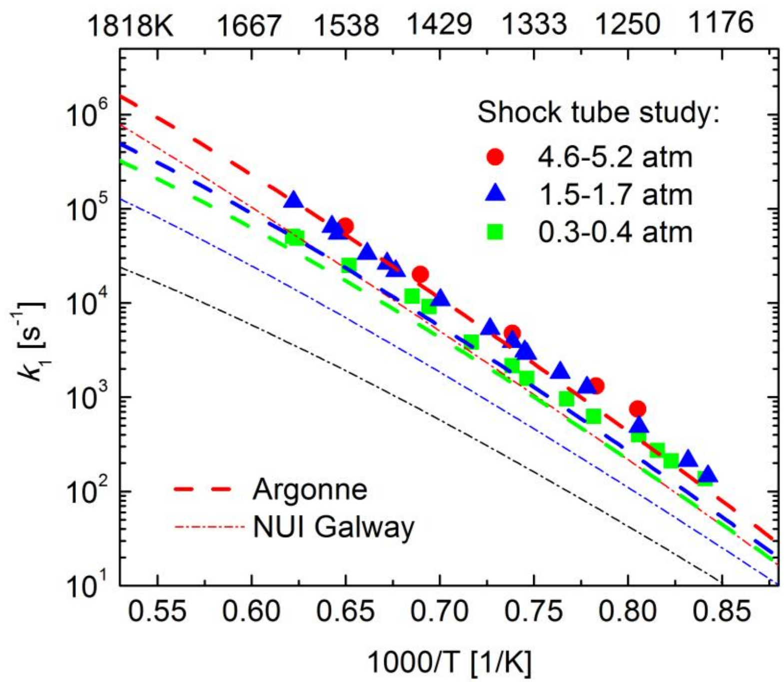
- 基元反应速率常数测量

CO absorption near 4.6 μm



Best-fit simulation obtained by adjusting k_1= 5.3x10^3 s^{-1}

Pressure Effect on *k*

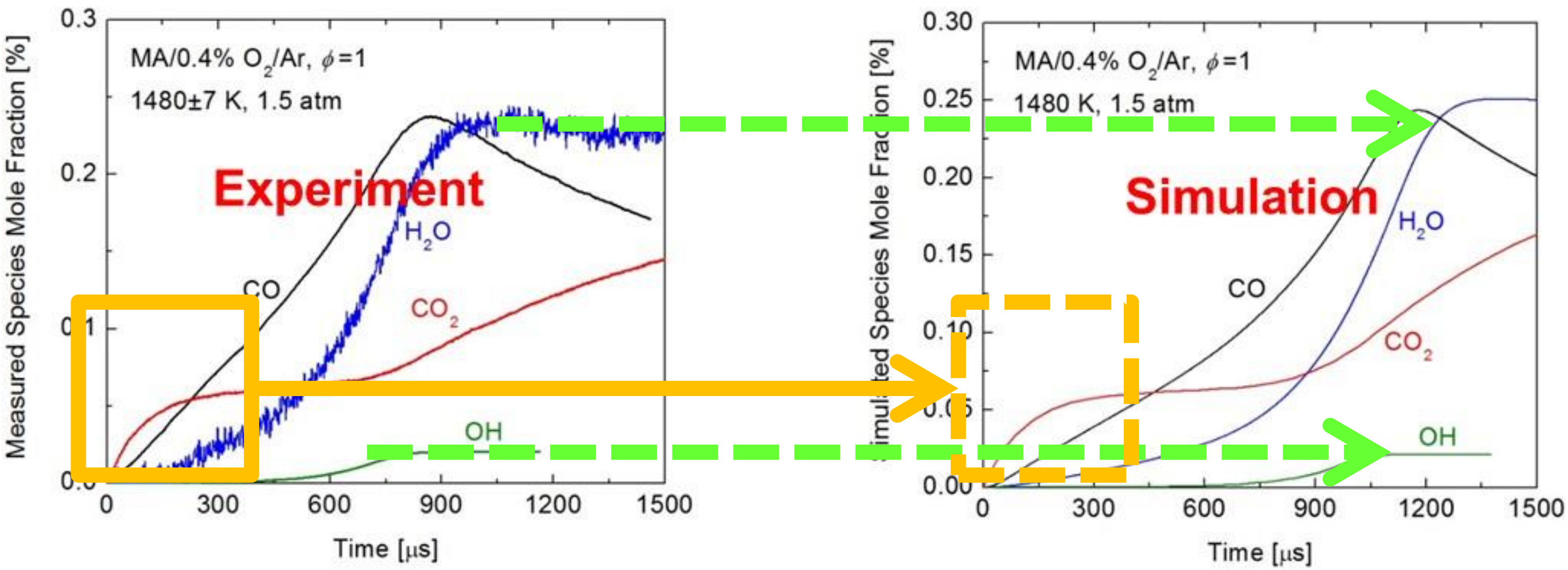


Agreement with calculation (weak pressure dependence with P>1.5 atm)

- *W. Ren, et al., Proceedings of Combustion Institute 34, 453-461 (2013).*
- *W. Ren, et al., Combustion and Flame, 12, 2669-2679 (2013).*

激波管化学反应动力学

- 多组元浓度-时间曲线测量及机理验证



Laser absorption measurements: methyl acetate oxidation (unpublished)

CHEMKIN simulation: Princeton methyl ester mechanism (Yang et al. PoCI, 2015)

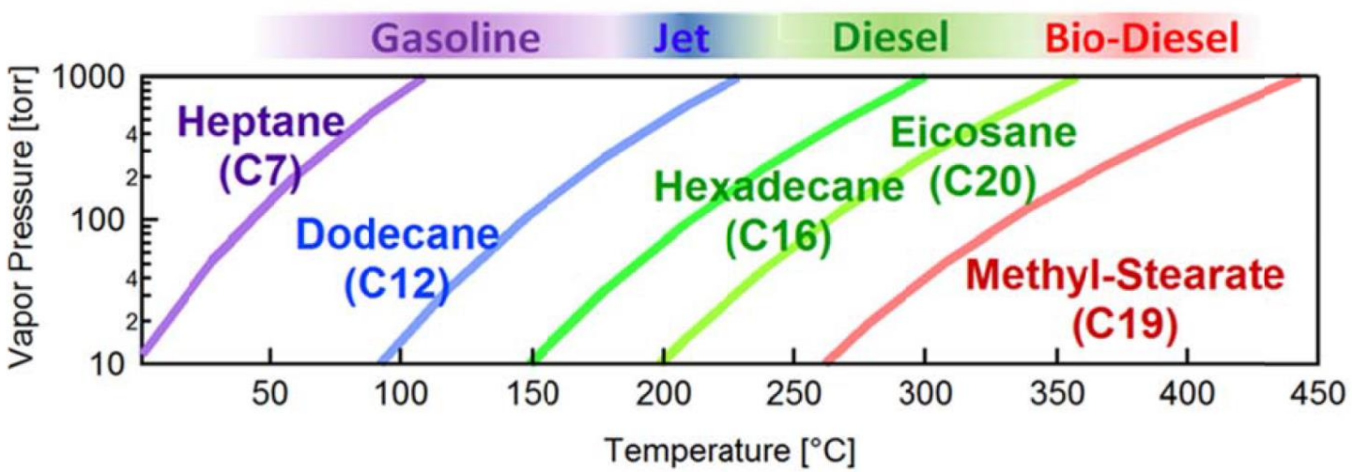
- *W. Ren, R. M. Spearrin, D. F. Davidson, and R. K. Hanson, J. Phys. Chem. A, 118(10), 1785-1798 (2014).*
- *K.-Y. Lam, W. Ren, S. H. Pyun, A. Farooq, et al., Proc. Combust. Inst., 34(1), 607-615 (2013).*
- *S. H. Pyun, W. Ren, K.-Y. Lam, D. F. Davidson, et al., Combust. Flame, 160(4), 747-754 (2013).*
- *A. Farooq, W. Ren, K.-Y. Lam, D. F. Davidson, et al., Combust. Flame, 159(11), 3235–3241 (2012).*

目前本方向的难点问题及可能解决方案

- 极低饱和蒸气压、大分子燃料的激波管实验
- 更长的测试时间: 1ms→100ms?
- 低温点火过程Pre-ignition问题

问题一：极低饱和蒸气压、大分子燃料的激波管实验

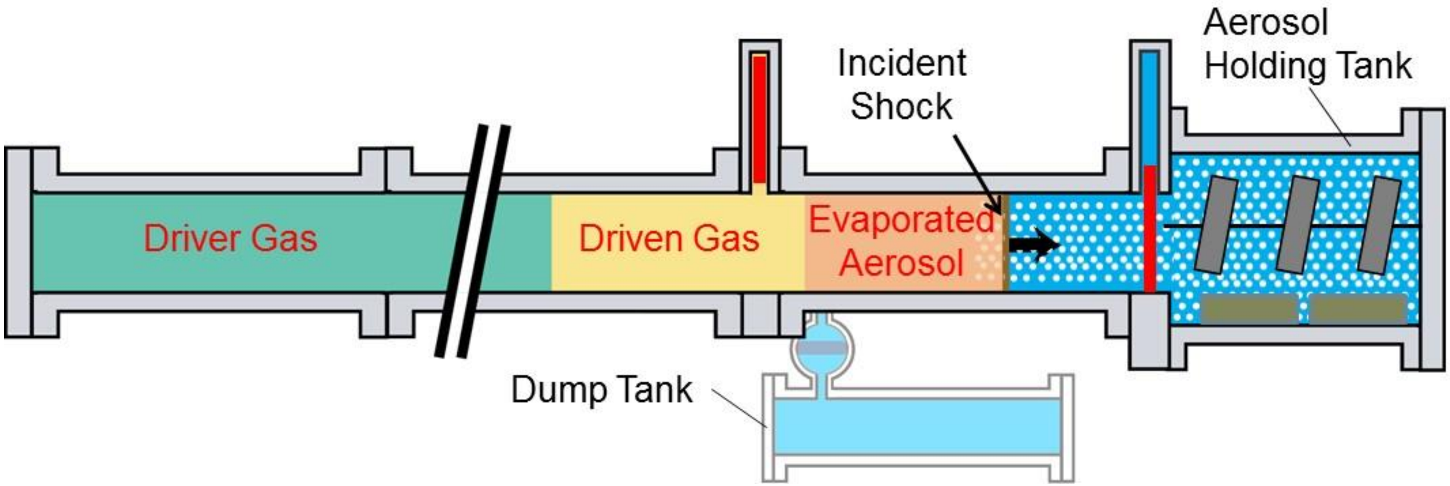
- 大分子燃料饱和蒸气压



- 激波管需要加热到几百摄氏度以便获得足够的燃料浓度，带来的问题：
  - ❑ Pre-test reaction
  - ❑ Gas/fuel leakage

问题一：极低饱和蒸气压、大分子燃料的激波管实验

- 气溶胶激波管(Aerosol shock tube): Hanson Group, Stanford University

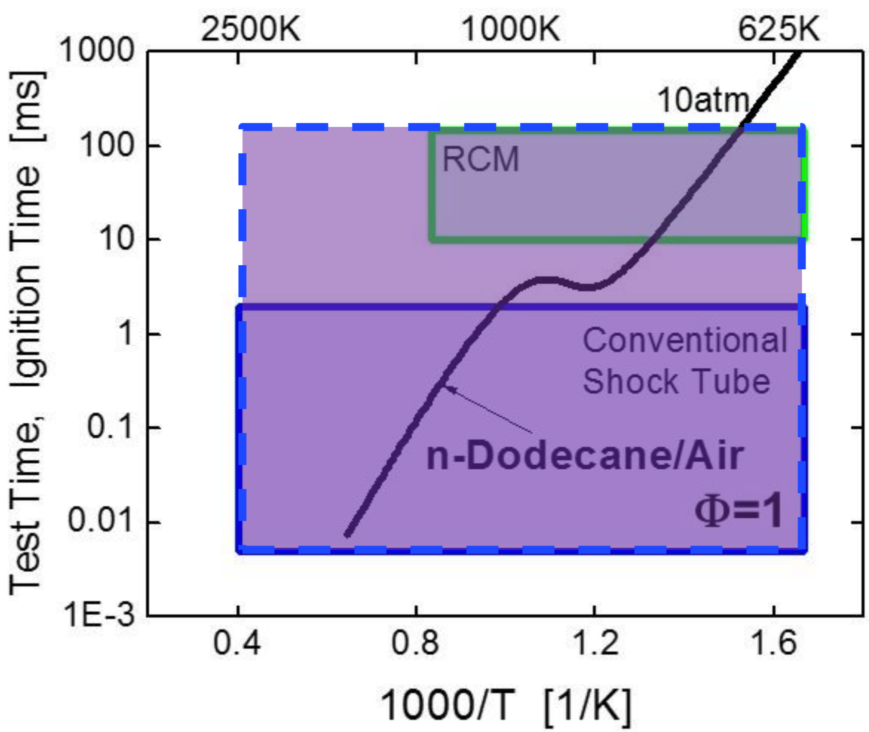


  - Incident shock rapidly evaporates the fuel

- 但是，复杂的多相流问题：激波-液滴相互作用、燃料液滴蒸发对5区的影响？

问题二：更长的测试时间(1ms→100ms?)

- 测试时间：激波管 vs. RCM

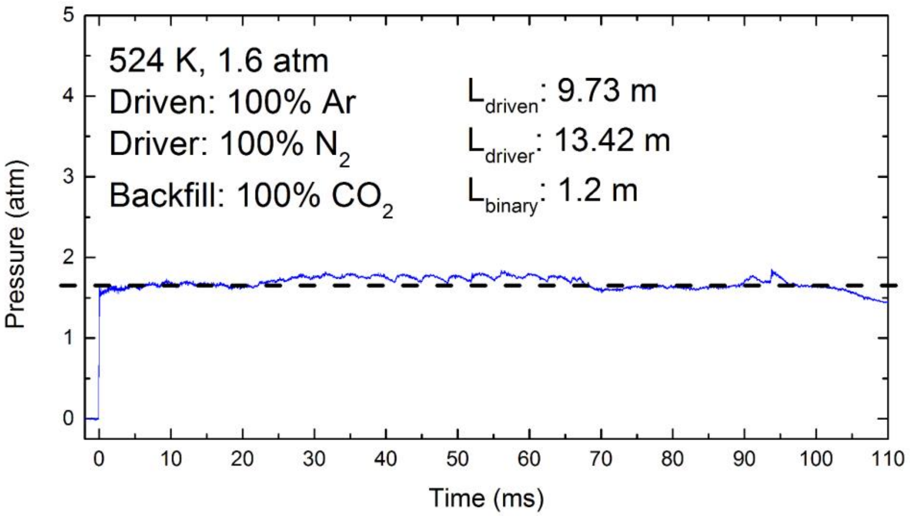


- 更重要的是，低温燃烧（LTC）需要更长、稳定、准确的测试时间。

问题二：更长的测试时间(1ms➔100ms?)

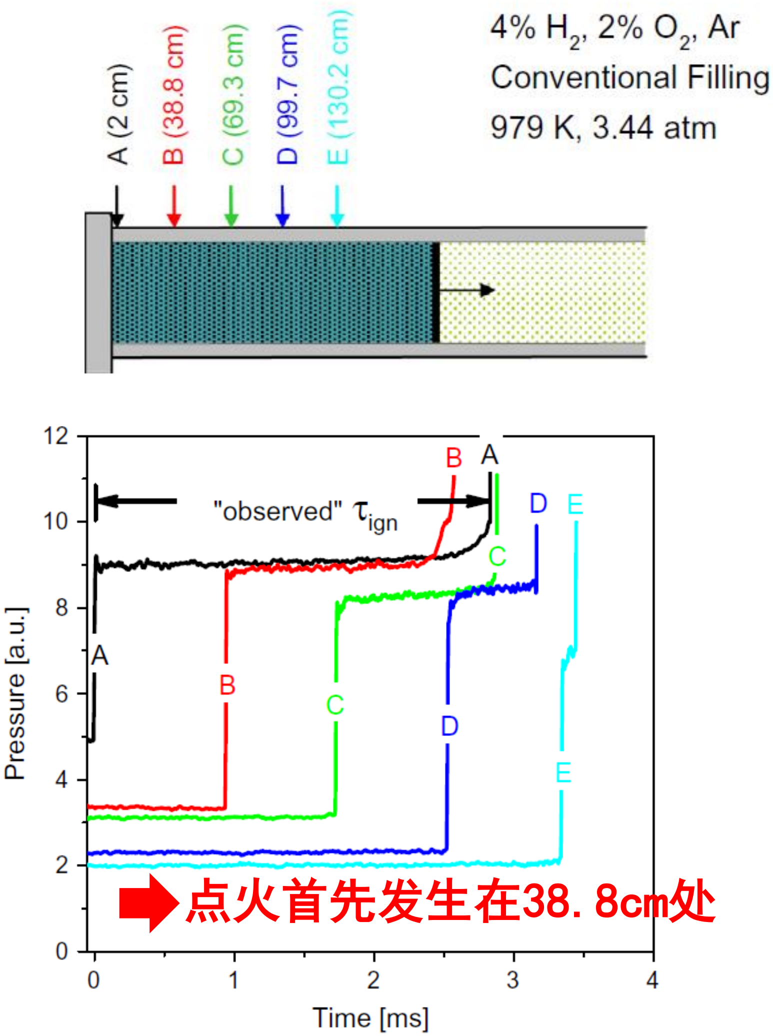
- Combination methods: driver inserts, driver gas tailoring, staged filling, and driver extensions.

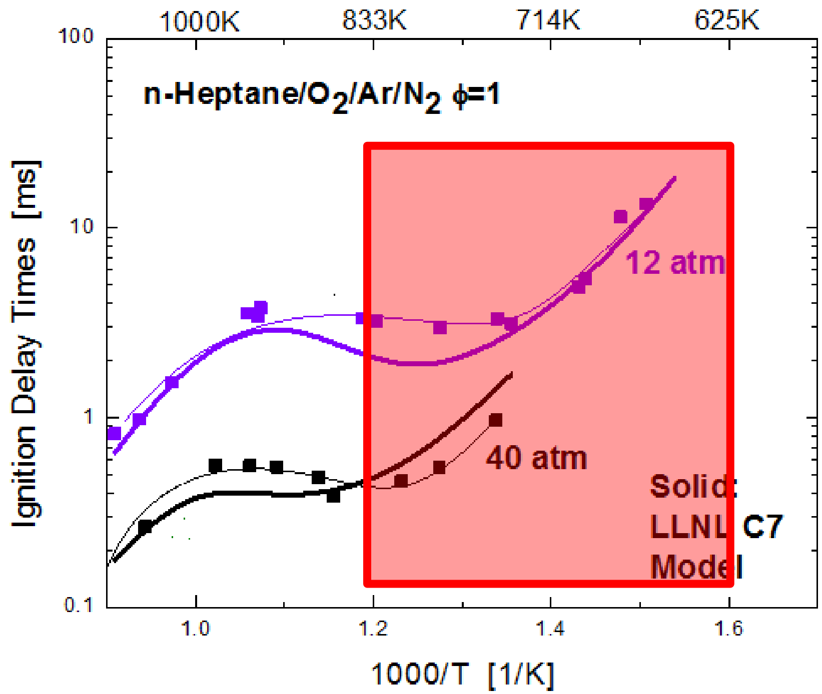
Hanson Group, Stanford University



- **Heat transfer?**
  - Numerical analysis: **not an issue** for shock tubes with **8-cm** or larger internal diameters; Frazier et al., *Shock Waves, 21, 2011*.
  - 进一步的实验验证及理论分析需要开展!

问题三：低温点火过程Pre-ignition问题





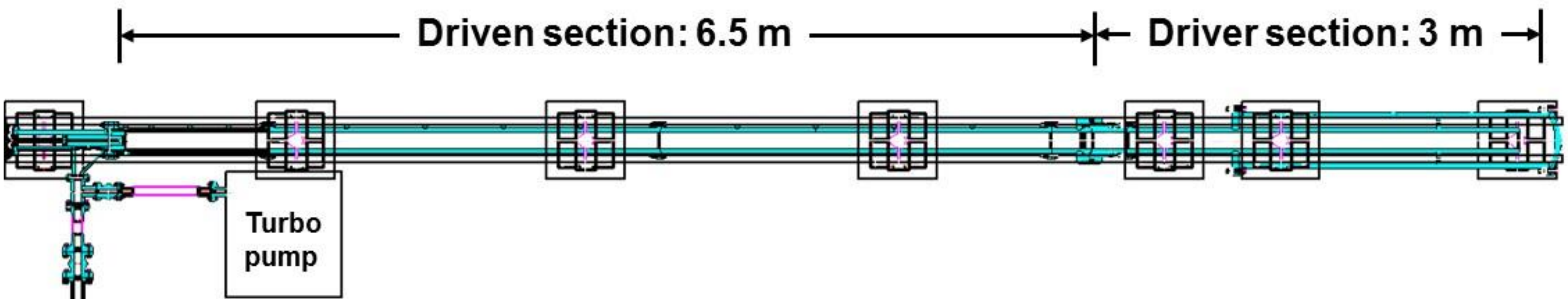
- 低温（NTC regime）点火延时测量的准确性需要特别关注！

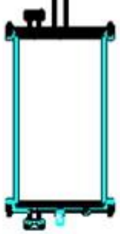
• *R. K. Hanson, et al., Combustion and Flame, 160, 1550-1558 (2013)*

未来可能的研究方向与合作

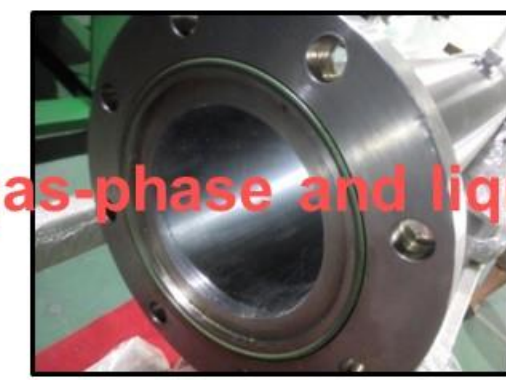
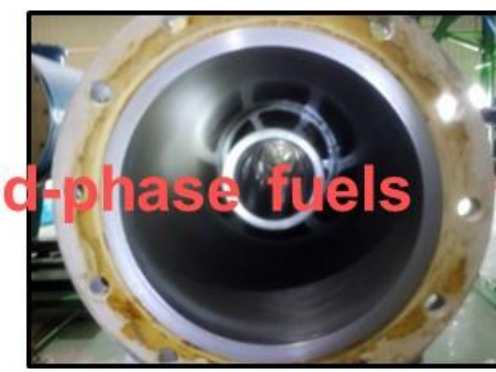
- 激波管流场特性研究
- 大分子燃料燃烧特性
- 新型燃烧诊断技术

CUHK激波管





- 内径：12cm, 总长：9.5m
- 温度、压力：500-2000K, 0.1-5MPa
- 测试时间：2-50ms
- 气/液态燃料

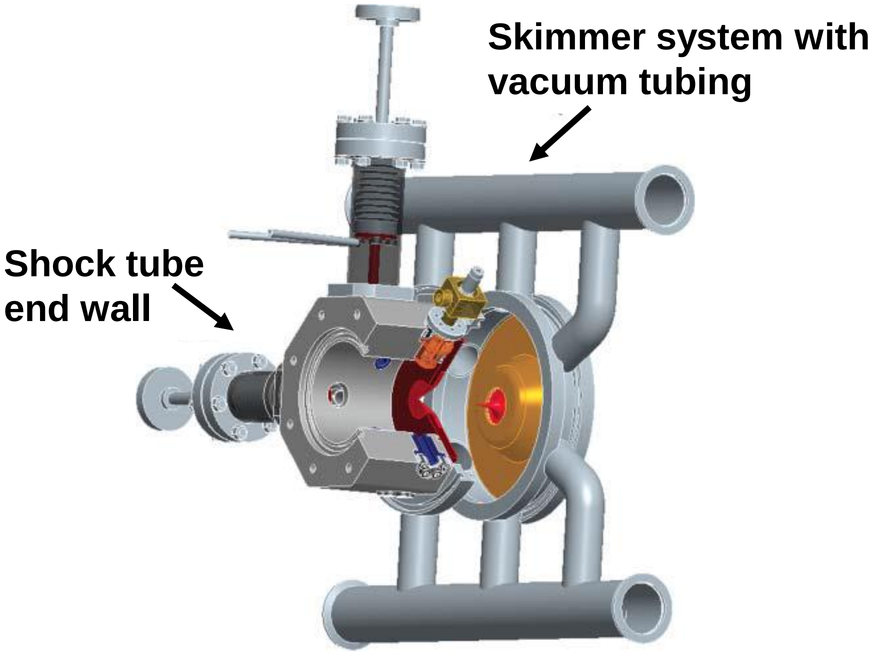
CUHK shock tube facility: polished driver and driven sections

未来可能的研究方向与合作

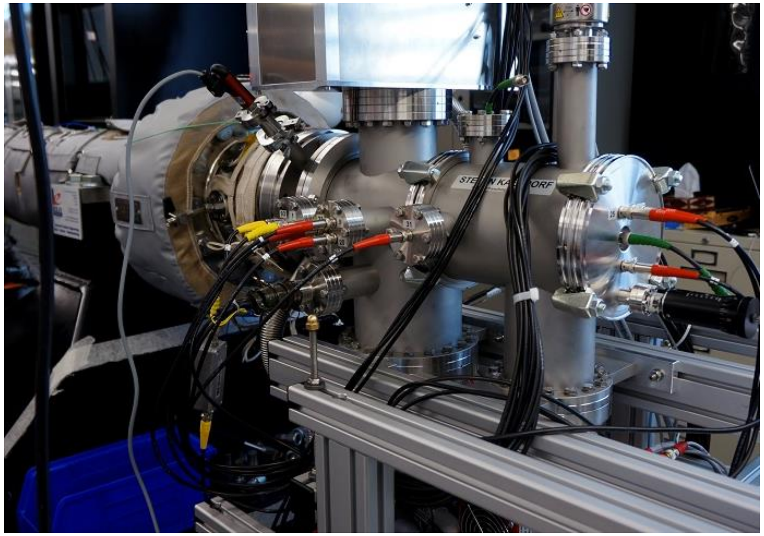
- 激波管高压、低温，以及多相流条件下的流场特性研究
  - 需要气动力学专家、流体力学专家、多相流问题的专家在这一基础科研问题上提供新思路
- C0-C4核心机理及大分子燃料激波管化学反应动力学
  - Chemical kinetic modelers: detailed/lumped/reduced mechanisms for pyrolysis and oxidation
  - Theoretical chemists: ab initio calculation, rate constant calculation
- 新型激波管燃烧诊断技术
  - Non-invasive optical diagnostics
  - Sampling strategy

反应过程中间产物的测量

- 激波管+高重复率飞行时间（TOF）质谱



S. Durrstein et al., Review of Scientific Instruments, 82, 084103 (2011).



Chemical Kinetics and Laser Sensors Lab, KAUST (http://kinetics.kaust.edu.sa/)

谢谢！

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