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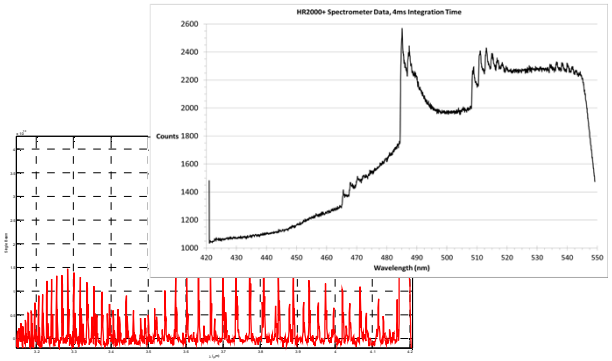

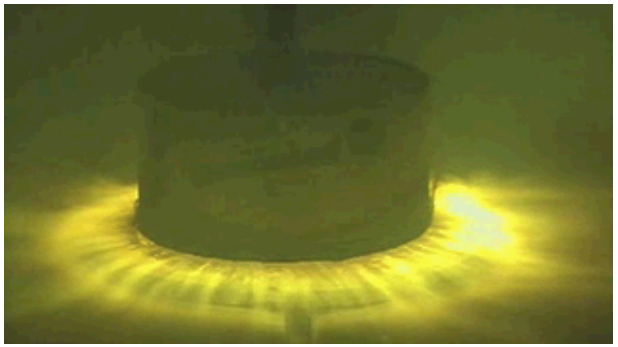

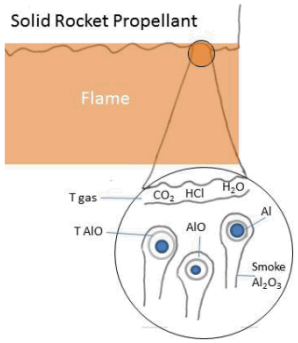

Measurement of solid rocket propellant exhaust gas temperatures using molecular spectroscopic methods

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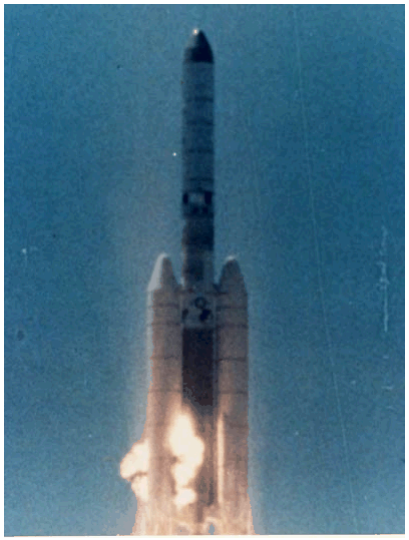
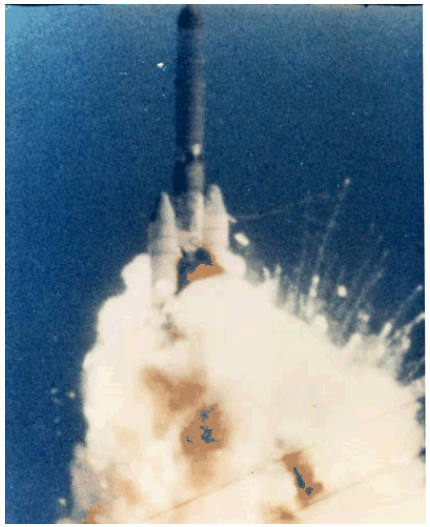
Introduction

Program objectives

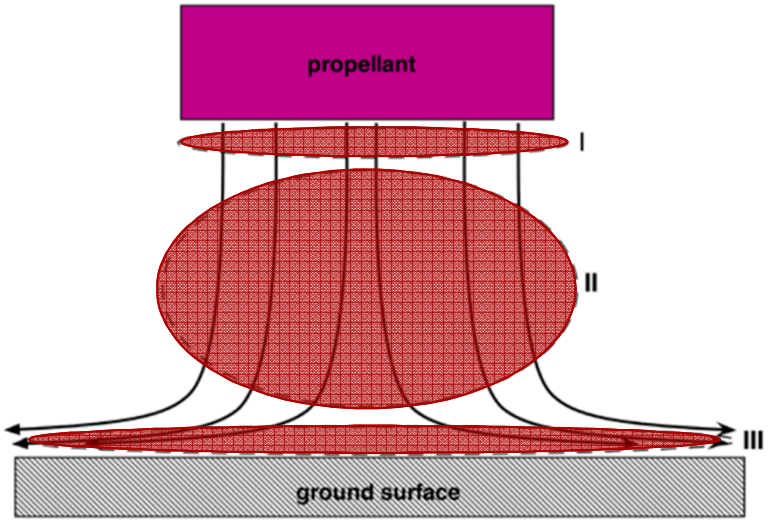
- Define the **thermal-chemical-physical** environment in and around a plume formed from a burning fragment of solid rocket fuel at atmospheric pressure.
- Use the specification to quantify the risk associated with a launch pad abort involving solid fueled rocket motors and high hazard payloads (e.g., deep space power source).





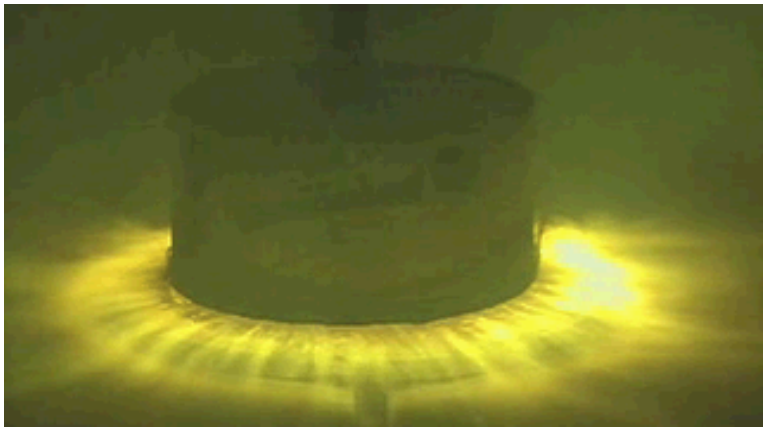
Titan 34D-9 accident sequence, 1986

Regions of Analysis



- Region I: combustion of Al + ammonium perchlorate (+ binder, etc.)
- Region II: populated by hot, emitting gases (HCl, CO_2, H_2O) and particles (AlO, Al_2O_3, etc.)
- Region III: interaction with hazardous payload; possible feedback to Region II (e.g., re-radiation)

- Physico-chemical behavior of burning Al strongly correlated to the environment, *i.e.*, properly functioning motor at high pressure/well defined geometry *versus* off-normal occurrence.
- ***Major concern***: vaporization of hazardous payload material in Region III, condensation on available particulate and transport to the environment.



Test Case – March 12, 2014

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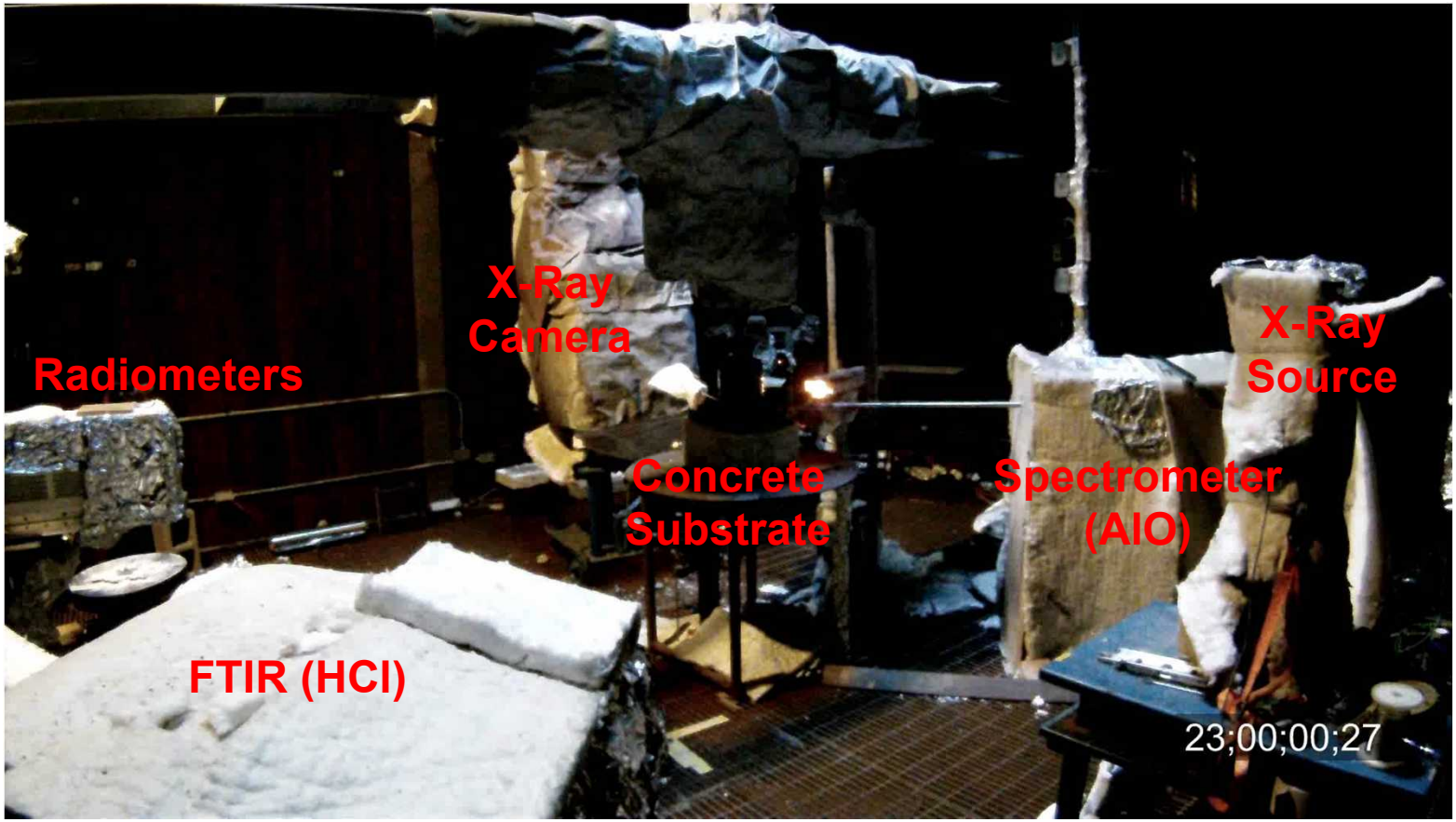
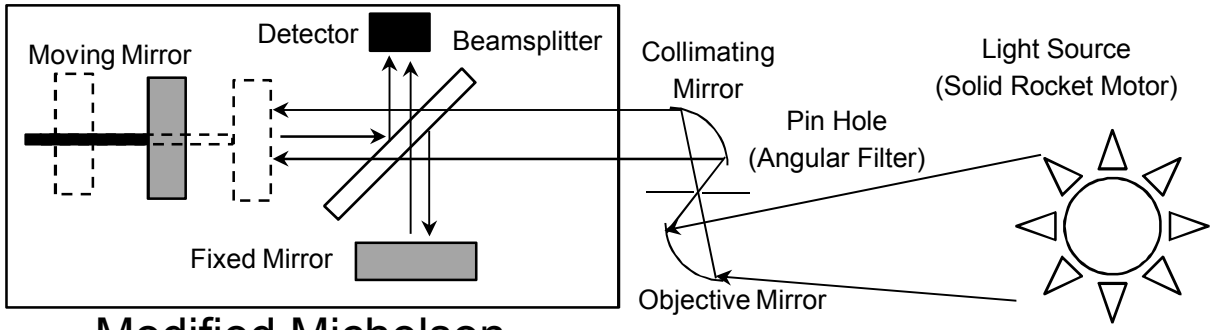


Plume from burning propellant is complex:

- highly emitting
- multiple chemical species and temperature-regions
- particulates / smoke
- substrate degradation / interaction

HCl Measurements

Fourier Transform IR Interferometry

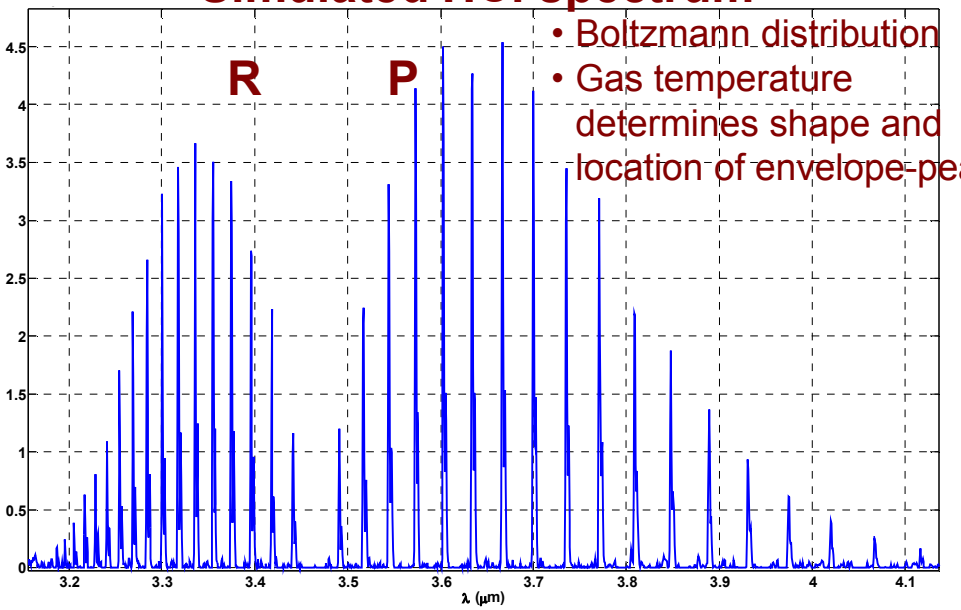


Modified Michelson Interferometer

HCl considered target of opportunity to measure gas temperature

- ✓ High S/N for the HCl spectra
- ✓ Spectral regions with minimal overlap
- × Noisy data captured on loss of sight of the flame due to:
  - Propellant inhibitor failure
  - Extremely small gaps
  - High particle-density

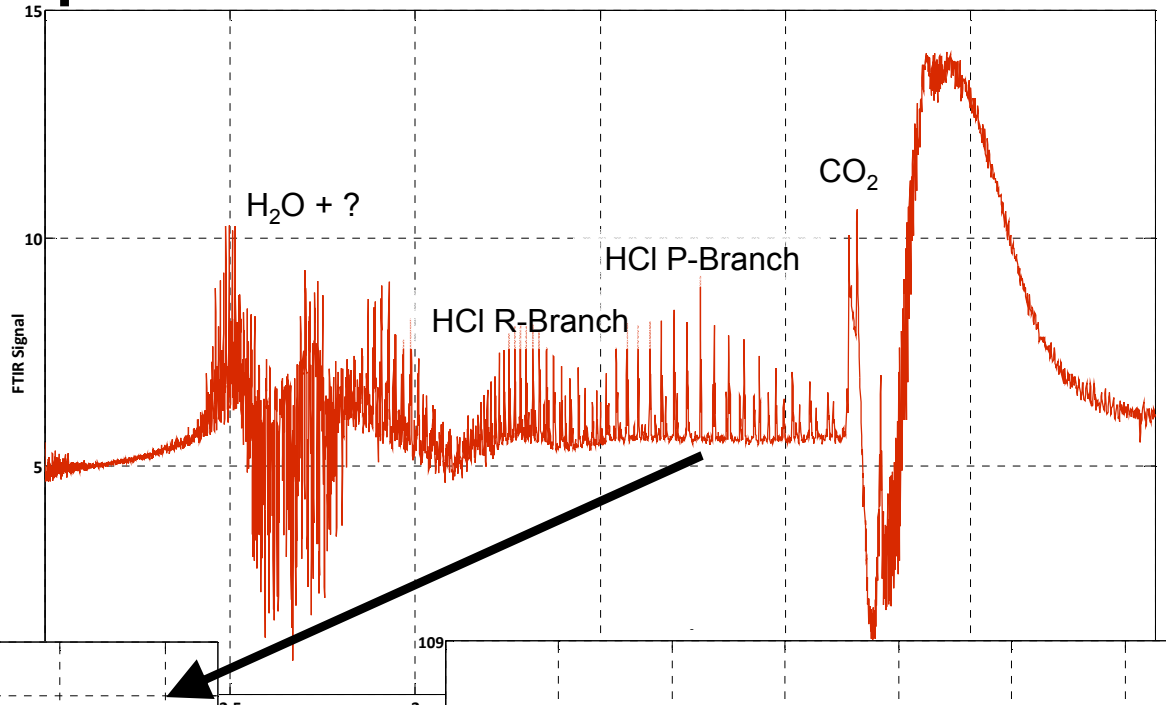
Simulated HCl spectrum

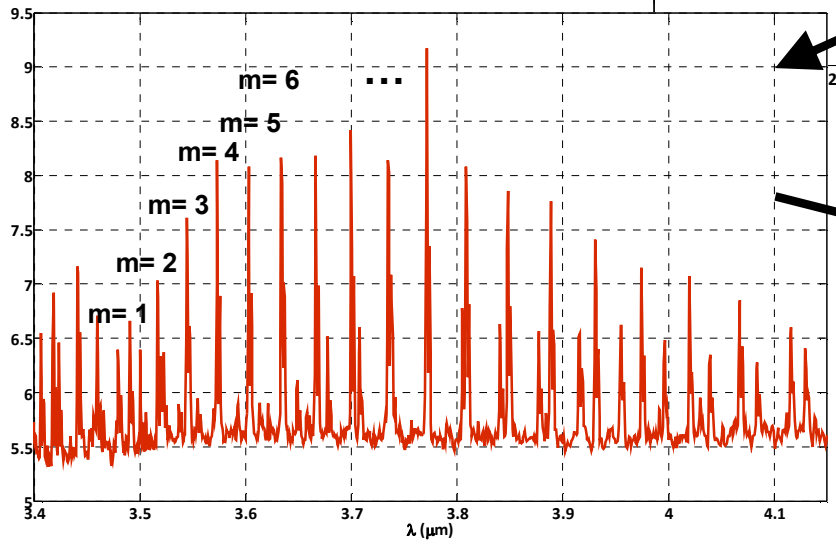


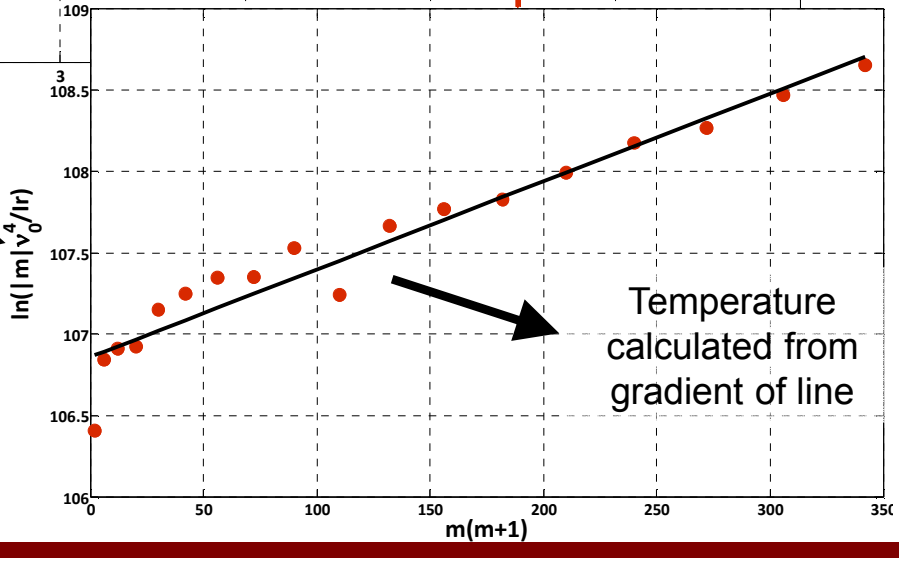
HCl Measurements

Spectrum Measured

- Devcon Inhibitor
- 6” Diameter
- 1” Gap
- Preliminary temperatures calculated using Boltzmann curves

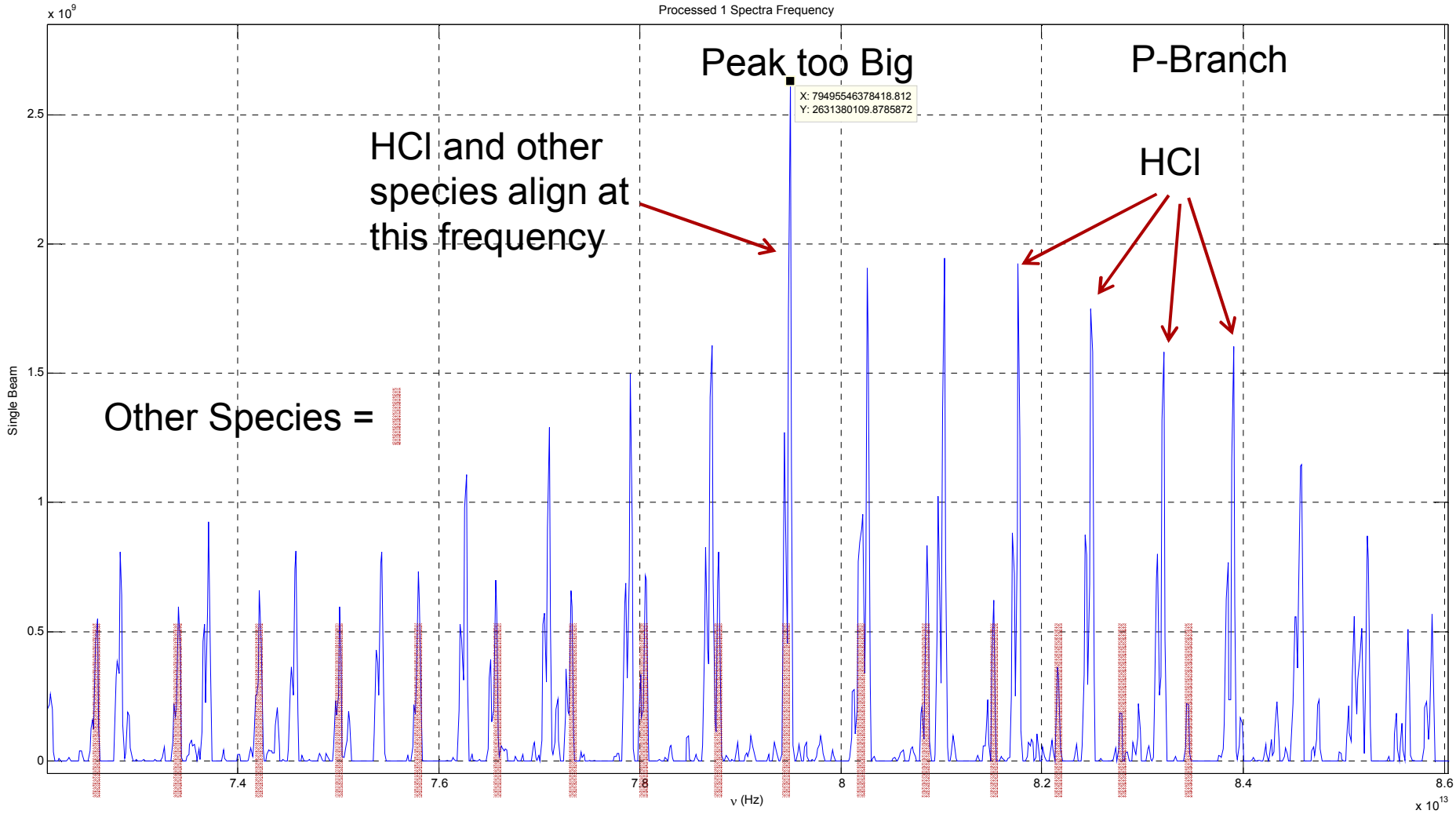


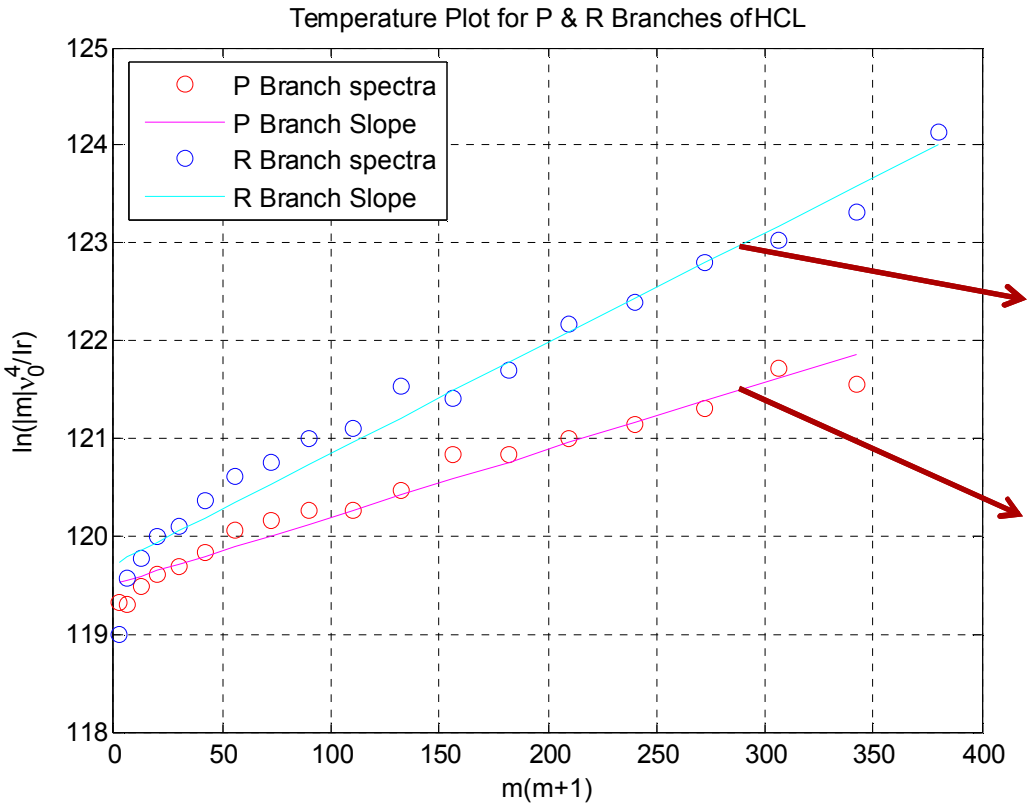




HCl Measurements

Unexpected Species, What is it?





HCl temperature ~ 1200 – 1500 K
- too low?

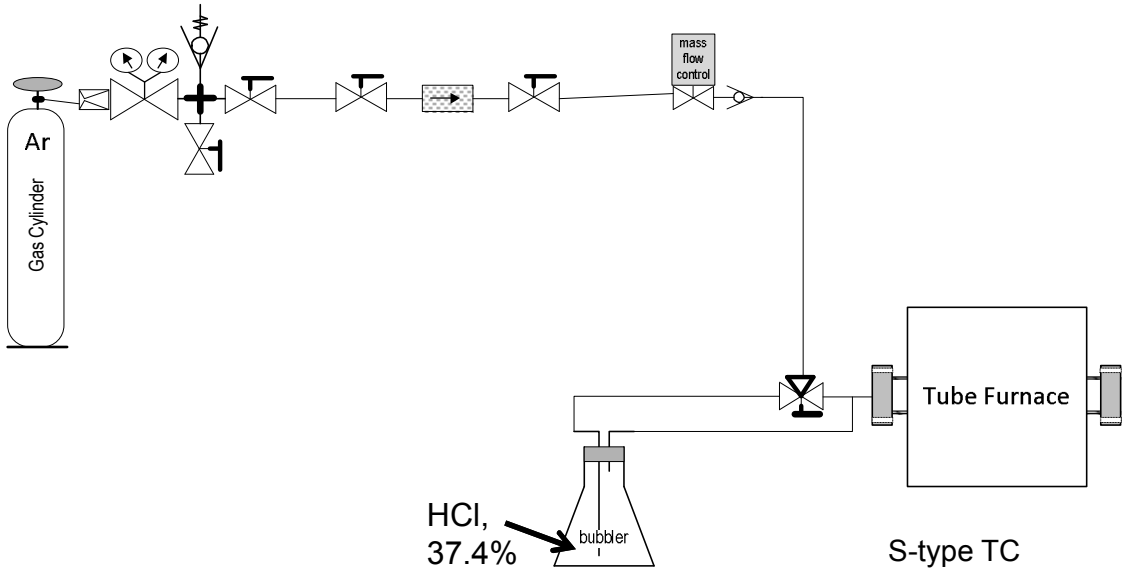
HCl temperature ~ 3000 K
- not un-reasonable

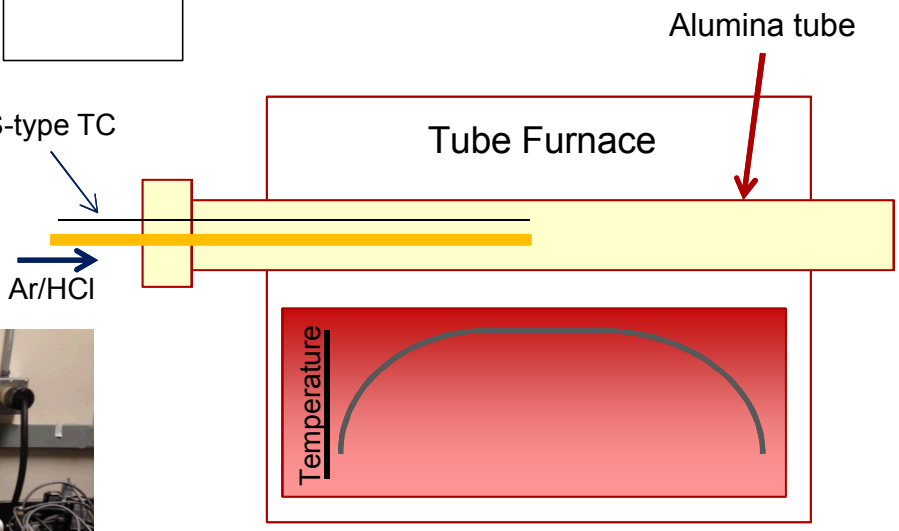
- Difference between P- and R-branch results
- Unknown secondary fingerprint

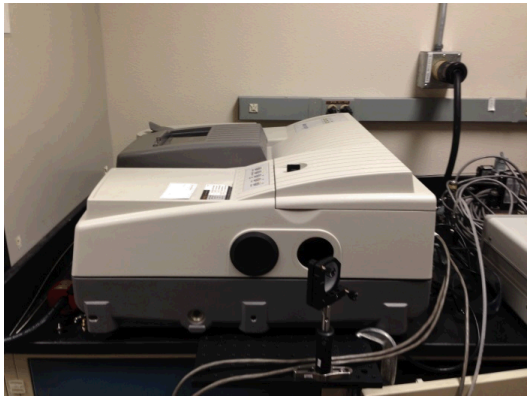
→ **Need for experiments under controlled conditions**

Calibration & Validation

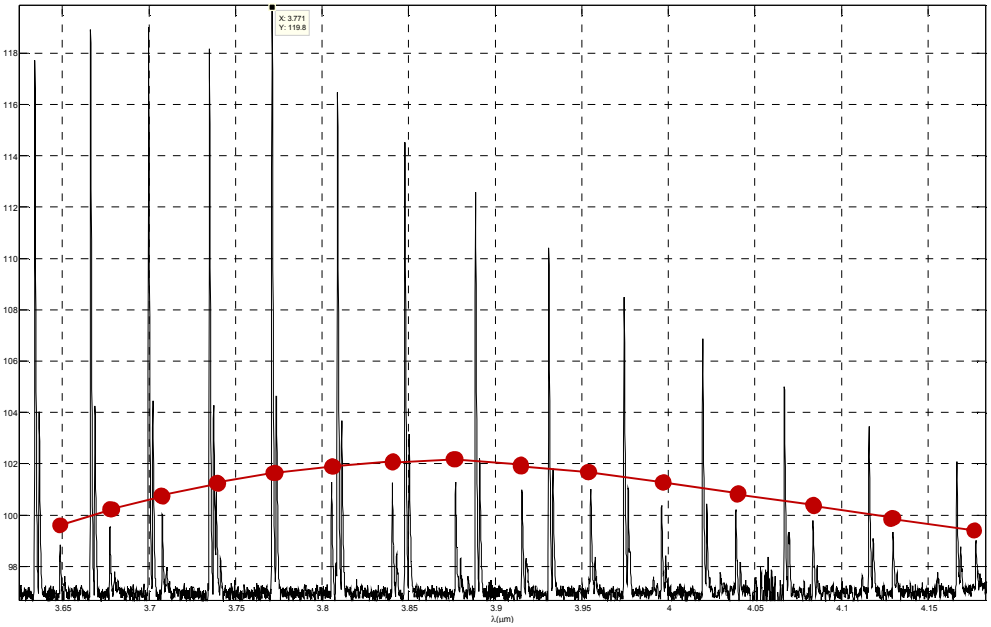
"clean" environment, controlled temperature

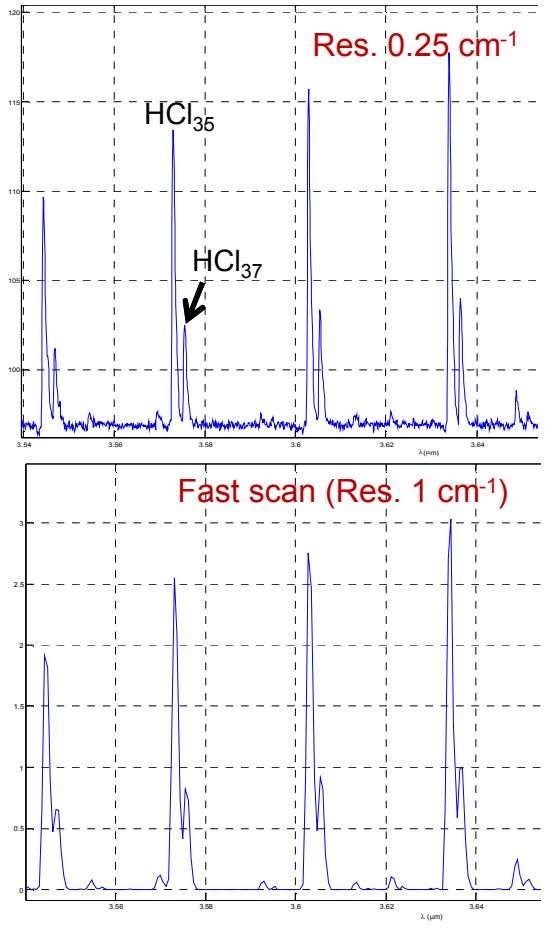




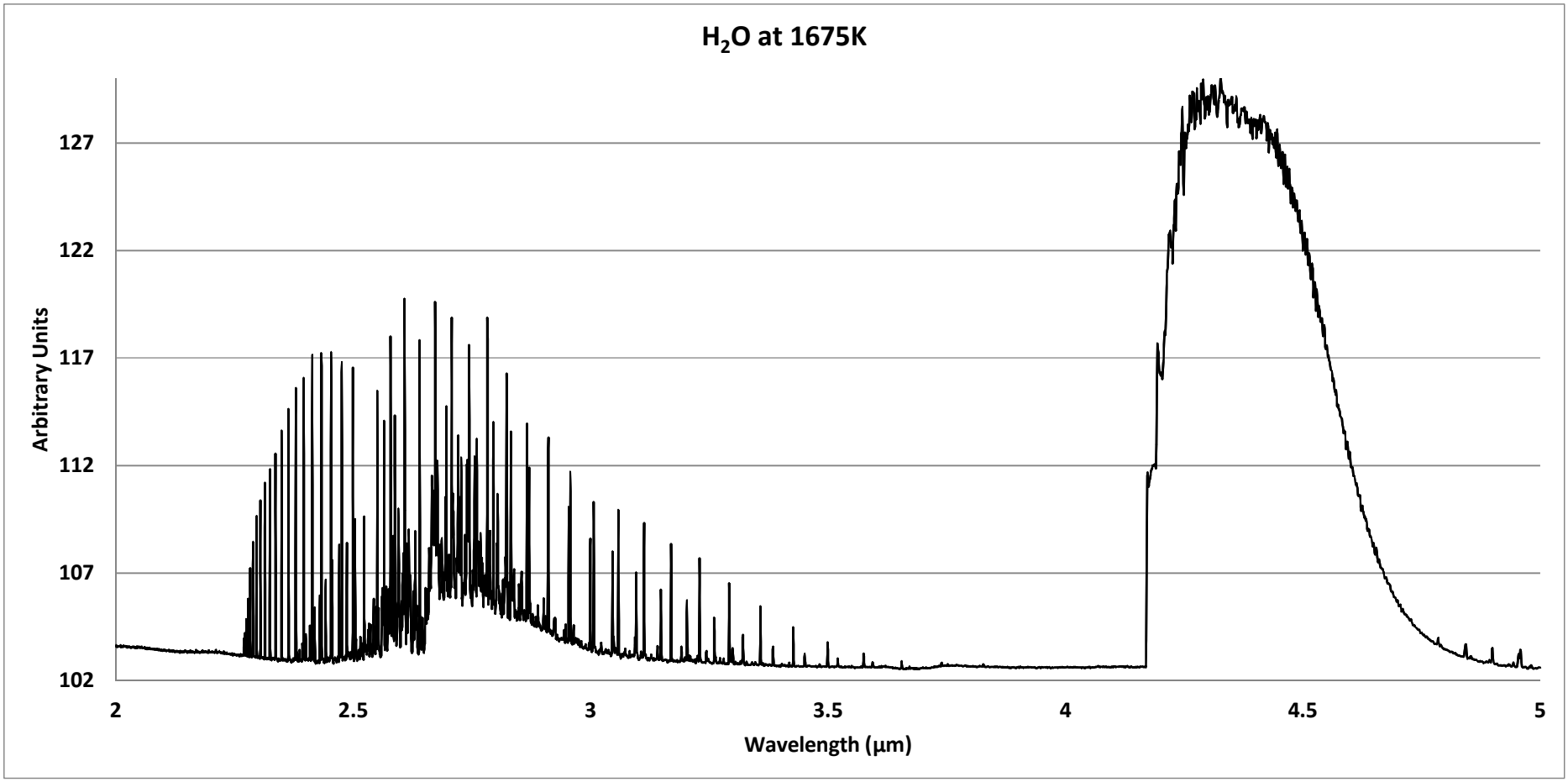


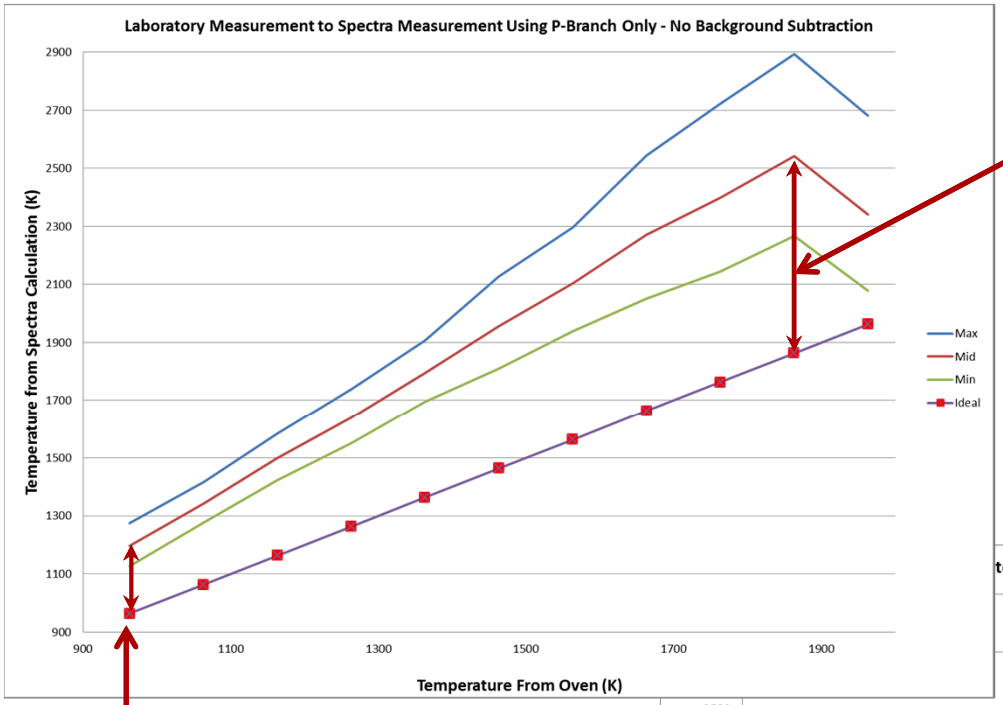
Tube furnace operations





- Even under “clean” conditions, unknown secondary pattern persists
- Isotope effect resolvable
- At higher resolution, could probably resolve overlap at 3.77 μm

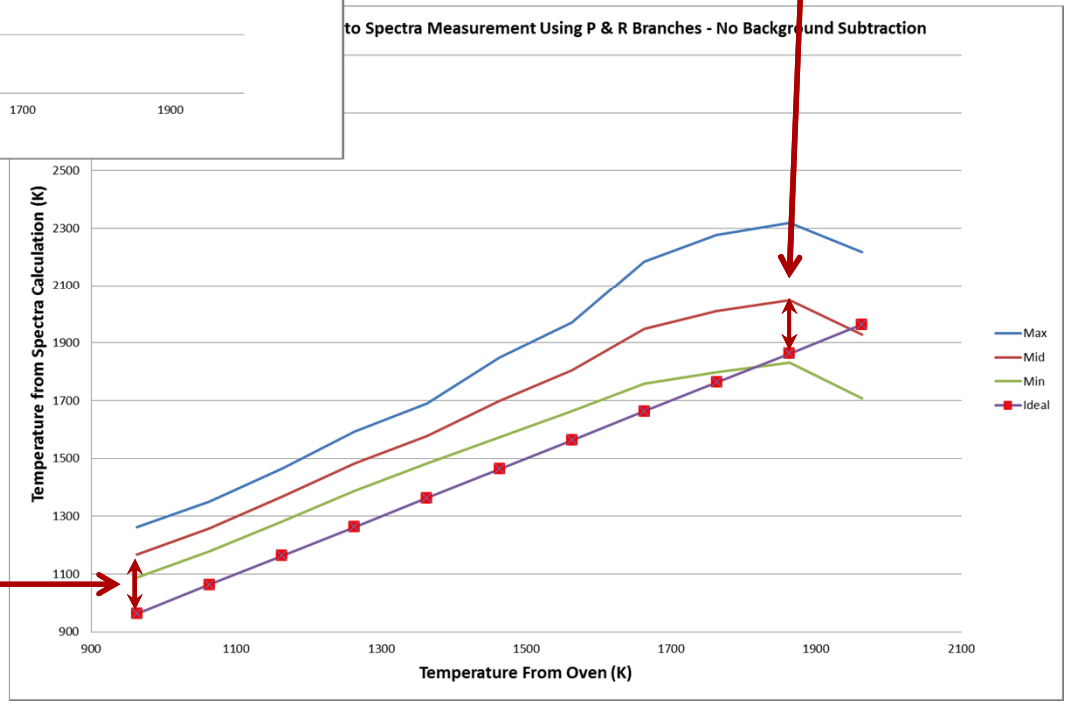

H2O at 1675K
127
122
117
112
107
102
Arbitrary Units
2
2.5
3
3.5
4
4.5
5
Wavelength (µm)



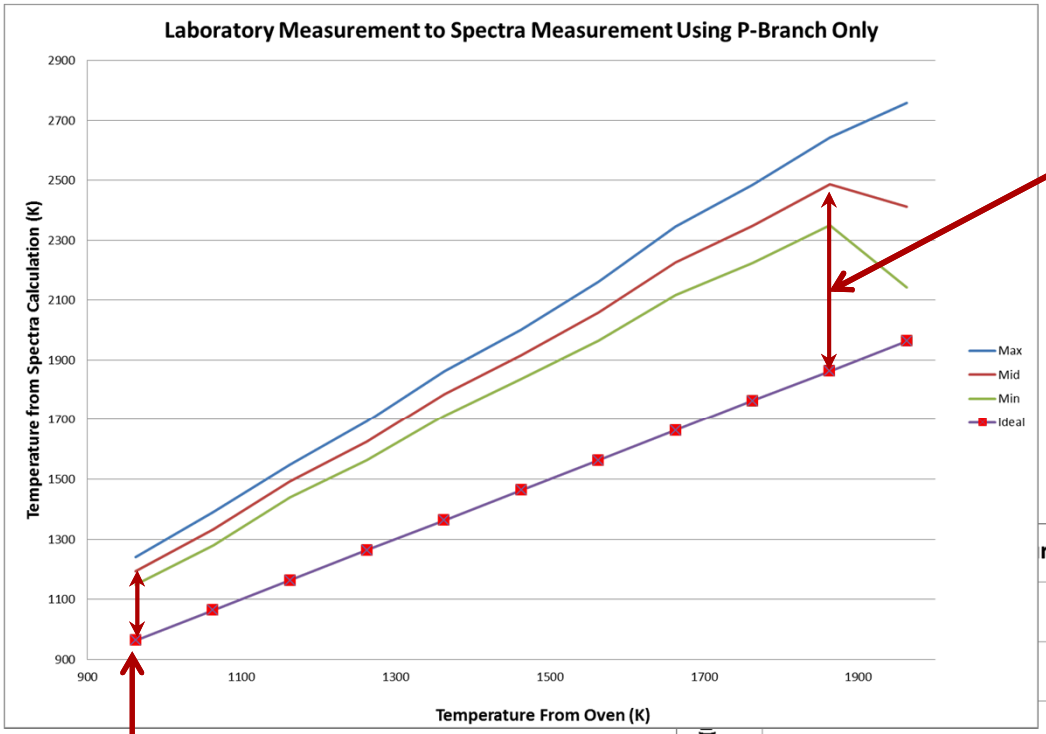
Δ = 680 K

Δ = ~200 K

Δ = 233 K



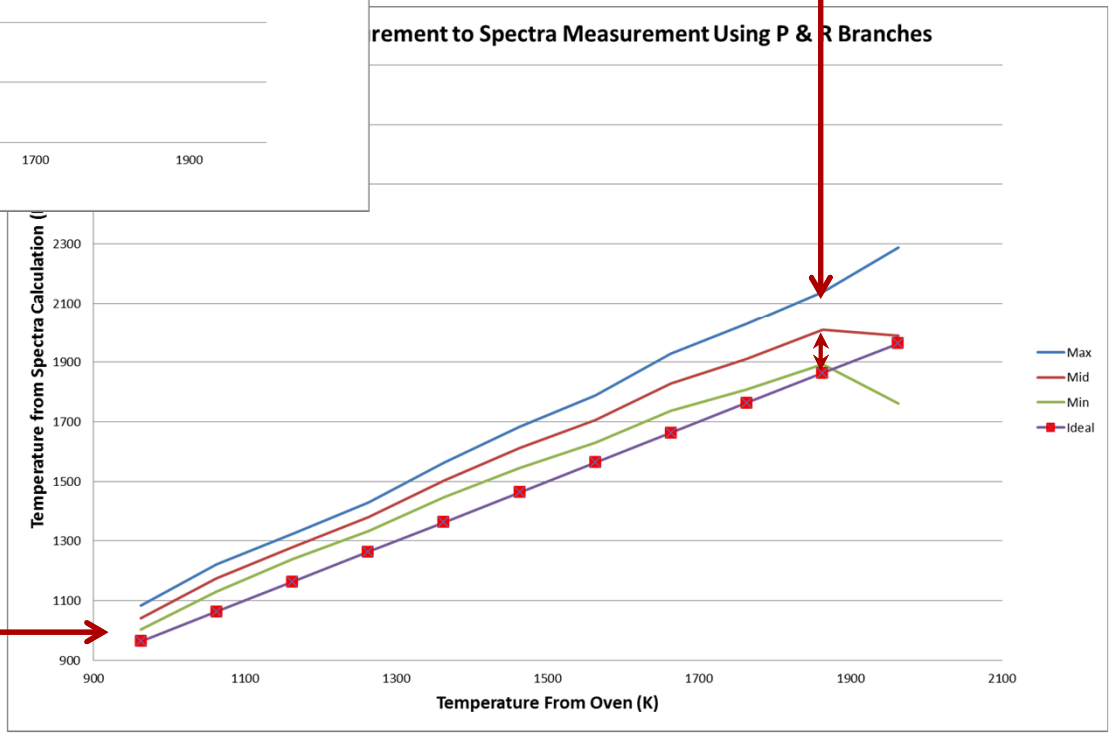
Δ = ~200 K



Δ = 630 K

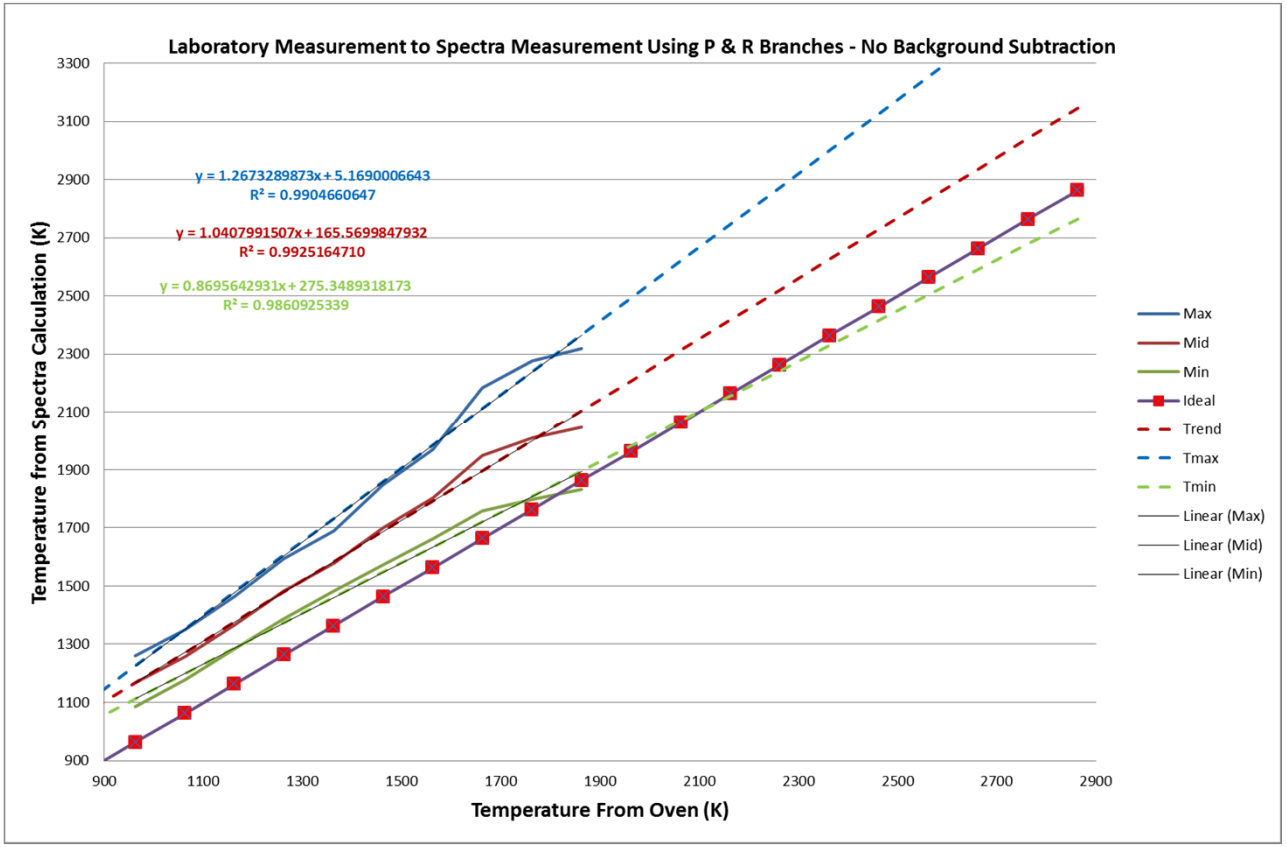
Δ = 230 K

Δ = 145 K



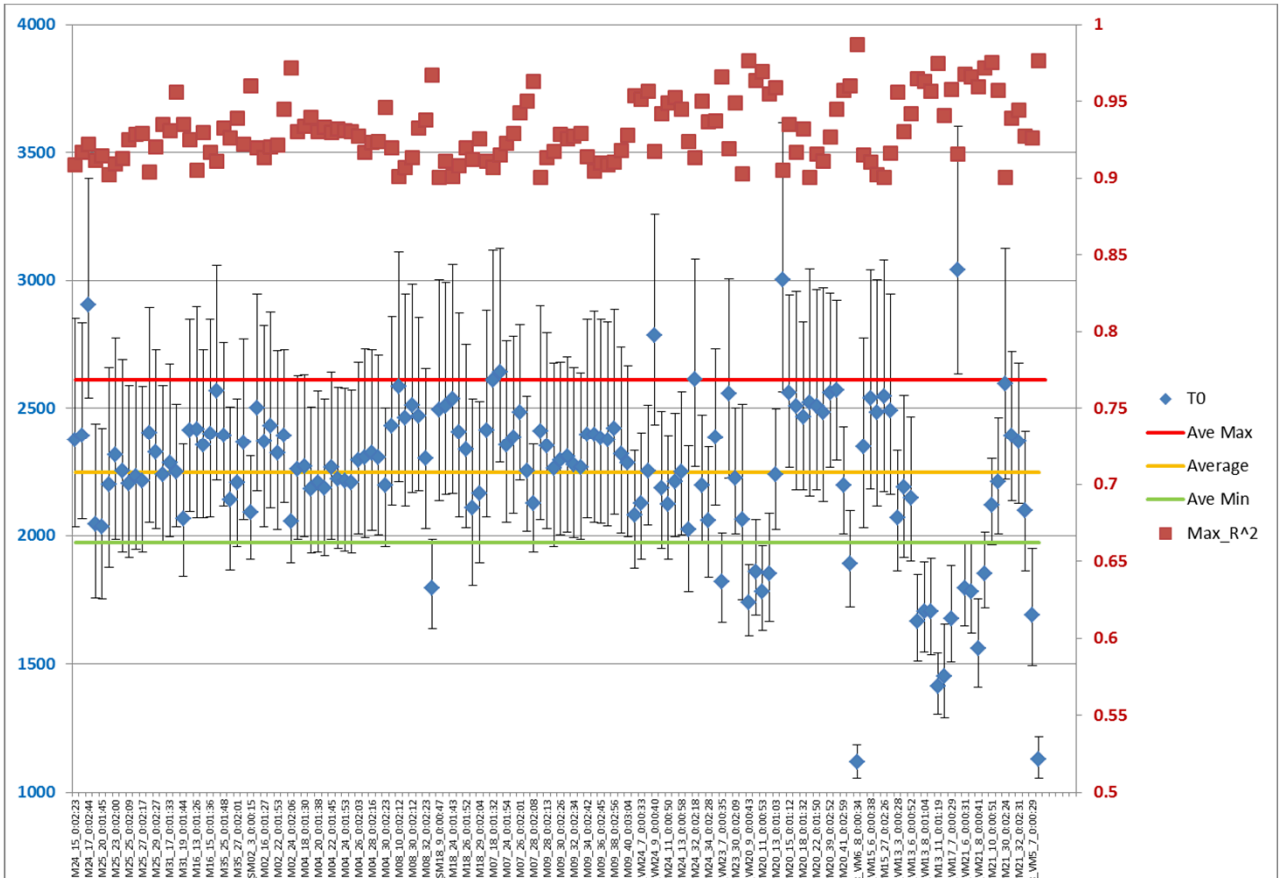
Δ = 78 K

Laboratory Experiment: Correction P & R



- Linearizing the trend (red lines) The error of average of P & R branches is **176K to 282K** for calculated temperatures with HCl spectrum of **263K to 2863K**

$$T_{HCl_{Final}} = T_{HCL} - AT_{HCL} - B, where\ A$$=0.0391998309 and B=159.0796693885



Temperature for tests on two different types of propellants (blue diamonds – left ordinate). The reported temperatures have coefficient of determination (r^2 – red squares – right ordinate) larger than 0.9. The temperatures were calculated using an approximation to the Boltzmann equation from the R & P branches.

HCl Measurements
Summary

HCl is an opportunistic target for temperature measurement in propellant fires

- component of propellant plume
- strong optical emission
- relatively free from spectral overlap
- simple FTIR setup works fine

Still work to be done to refine model, based on tube furnace tests

Gas temperature in typical propellant plume between 2000 and 2600 K

Thank You

Sandia National Laboratories

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