

Prismatic Cavity Ring-Down Spectroscopy with Multi-Species Measurement Capability

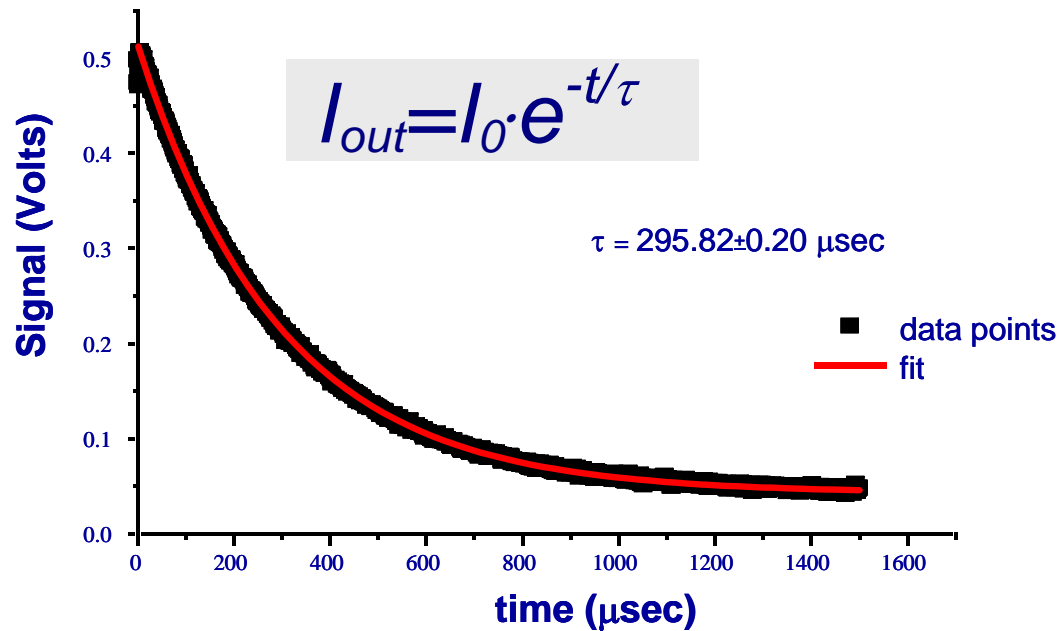
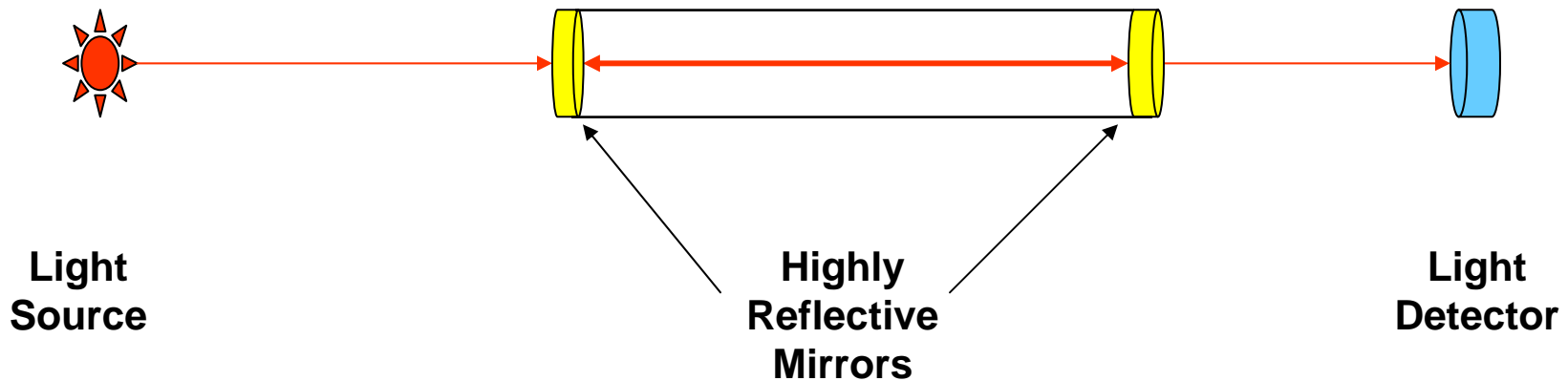
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Tiger Optics, LLC

Overview

- **Introduction to Continuous-Wave Cavity Ring-Down Spectroscopy (CW-CRDS)**
- **Prismatic: Prism Cavity Implementation of CW-CRDS**
- **H2 Fuel Cell Quality Measurement Application**
- **Summary**

Mirror-Based CW-CRDS*: *How It Works*



*CRDS involving CW lasers is a patented technique proprietary to Princeton University and exclusively licensed to Tiger Optics, LLC.

CW-CRDS: *Principles*

First Measurement:

$$\tau_{\text{empty}} = \frac{d}{c(1-R)}$$

Second Measurement:

$$\tau(\nu) = \frac{d}{c(1-R + \sigma(\nu) N d)}$$

Calculate Concentration:

$$N = \frac{1}{c \sigma(\nu)} \left(\frac{1}{\tau(\nu)} - \frac{1}{\tau_{\text{empty}}} \right)$$

c-speed of light

d-cell length

R-reflectivity of mirror

N-molecular density (concentration)

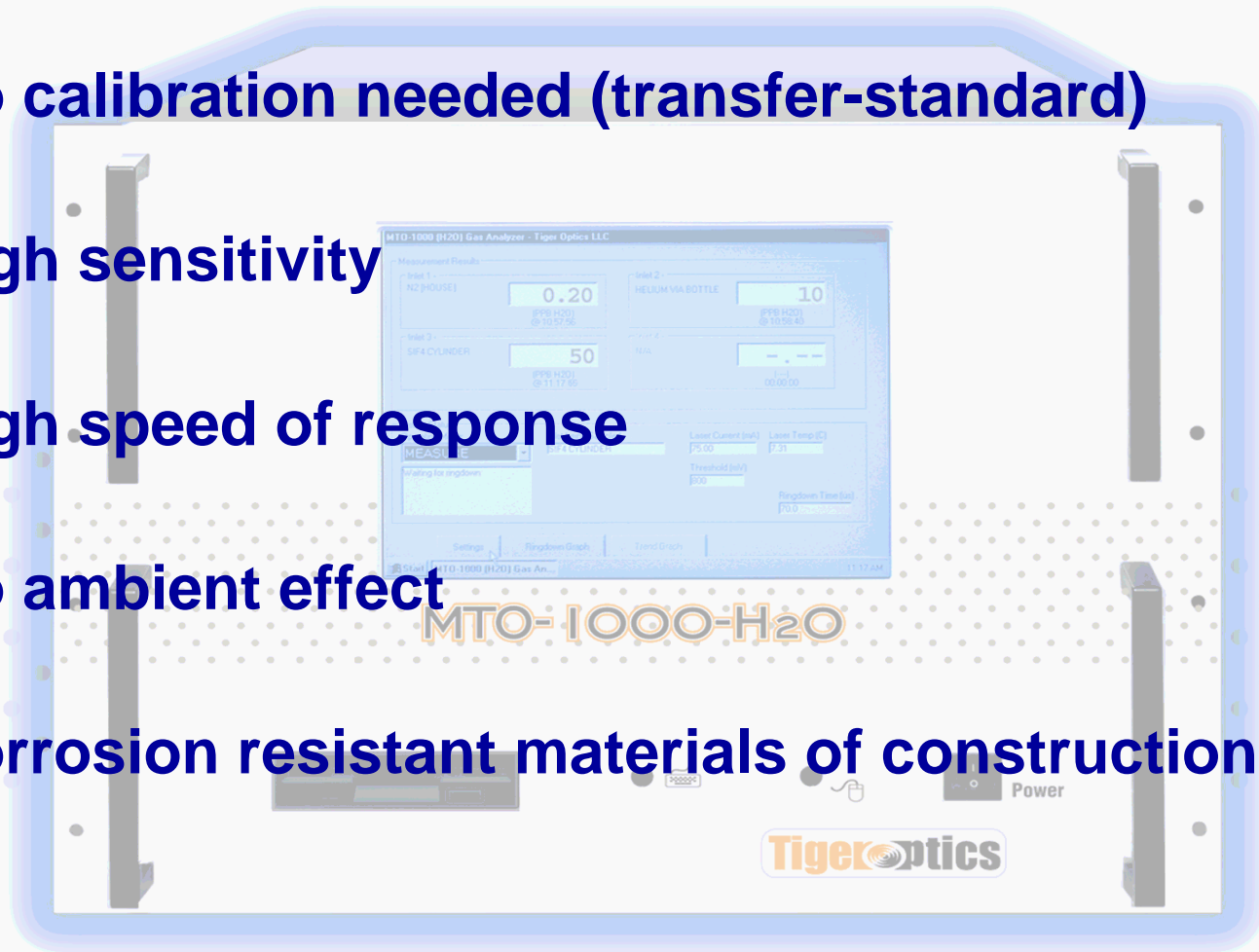
σ -absorption cross section

τ - ring-down time

ν -laser frequency

CW-CRDS: *Unique Advantages*

- **No calibration needed (transfer-standard)**
- **High sensitivity**
- **High speed of response**
- **No ambient effect**
- **Corrosion resistant materials of construction**



CW-CRDS: *Expanding Applications*

- H₂O analysis covers numerous matrices:
 - Inert and passive: N₂, Ar, He, H₂, Xe, Ne, Kr
 - Oxygenated gases: O₂, CDA, CO, CO₂, N₂O, NO
 - Corrosives: HCl, HBr, Cl₂
 - Hydrides: NH₃, PH₃, AsH₃
 - Fluorides: SF₆, NF₃, C_xF_y Series (CF₄, C₂F₆, C₃F₈, C₄F₆, C₄F₈, C₅F₈)
- Higher range H₂O units: 100 ppm, 500 ppm, 1000 ppm, etc
- Beyond moisture – growing list of analytes:

Analyzers shipped O₂, CH₄, C₂H₂, NH₃, HCN, HCHO, HF, etc

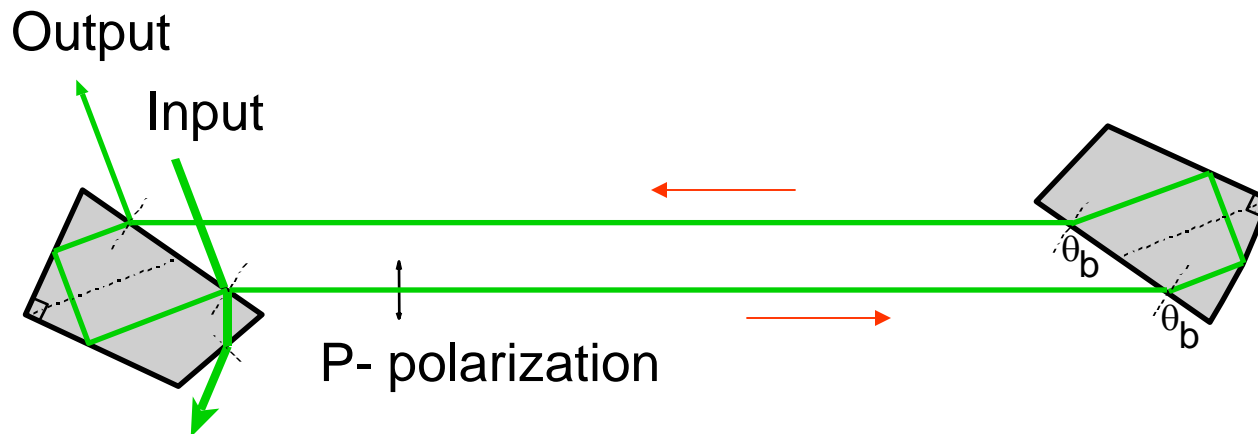
CW-CRDS: *Expanding Applications*

- **Industrial Process Analytical Control**
- **Fixed Bulk Gas Continuous Monitoring**
- **Portable Mobile Analytical Carts**
- **Air Separation**
- **Gas Cylinder QC**
- **OEM Tools**
- **Pre-Purifier**
- **LCD/LED Manufacturing**
- **Clean room ambient monitoring**
- **Labs**



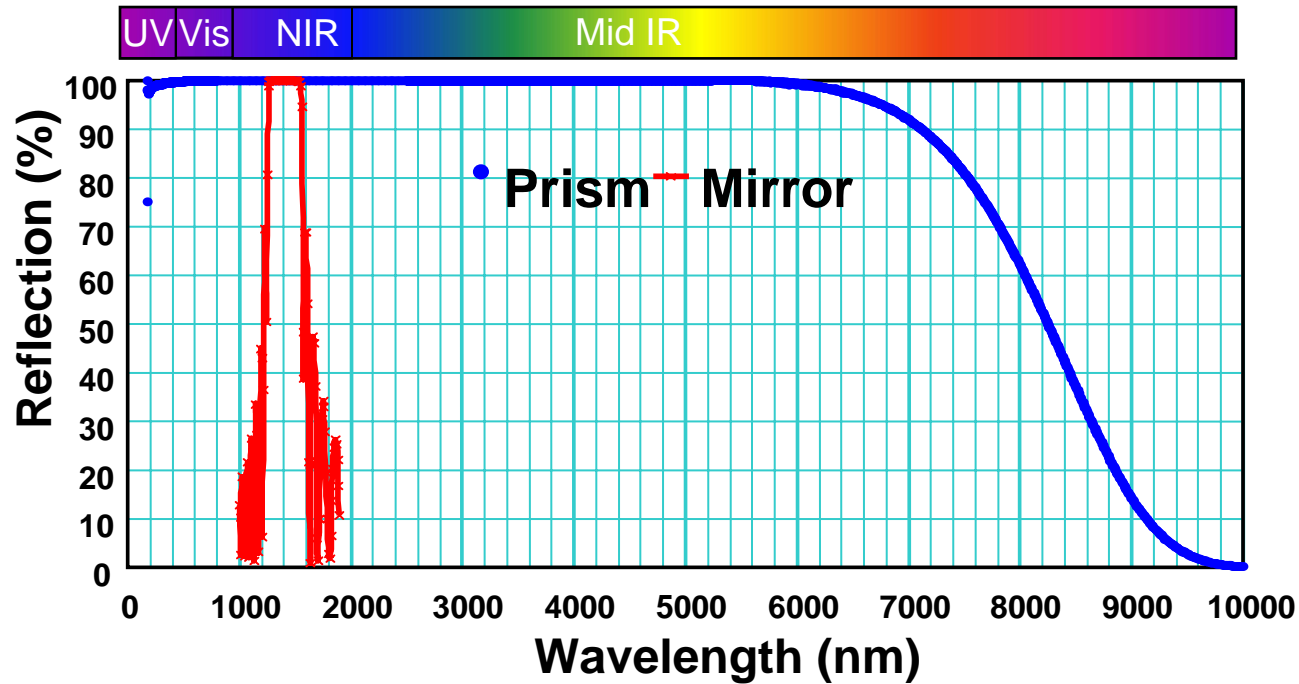
Prism Implementation of CW-CRDS

- **Mirror-Based CW-CRDS:**
Bandwidth $\sim 5\% \lambda_0$; Generally one species per cavity
- **Broadband Prism Cavity:**
*Brewster's Angle Prism Retro-Reflectors**
 - *Total internal reflection (TIR)*
 - *Brewster angle minimizes Fresnel reflection*
 - *High finesse optical resonator over wide λ range*



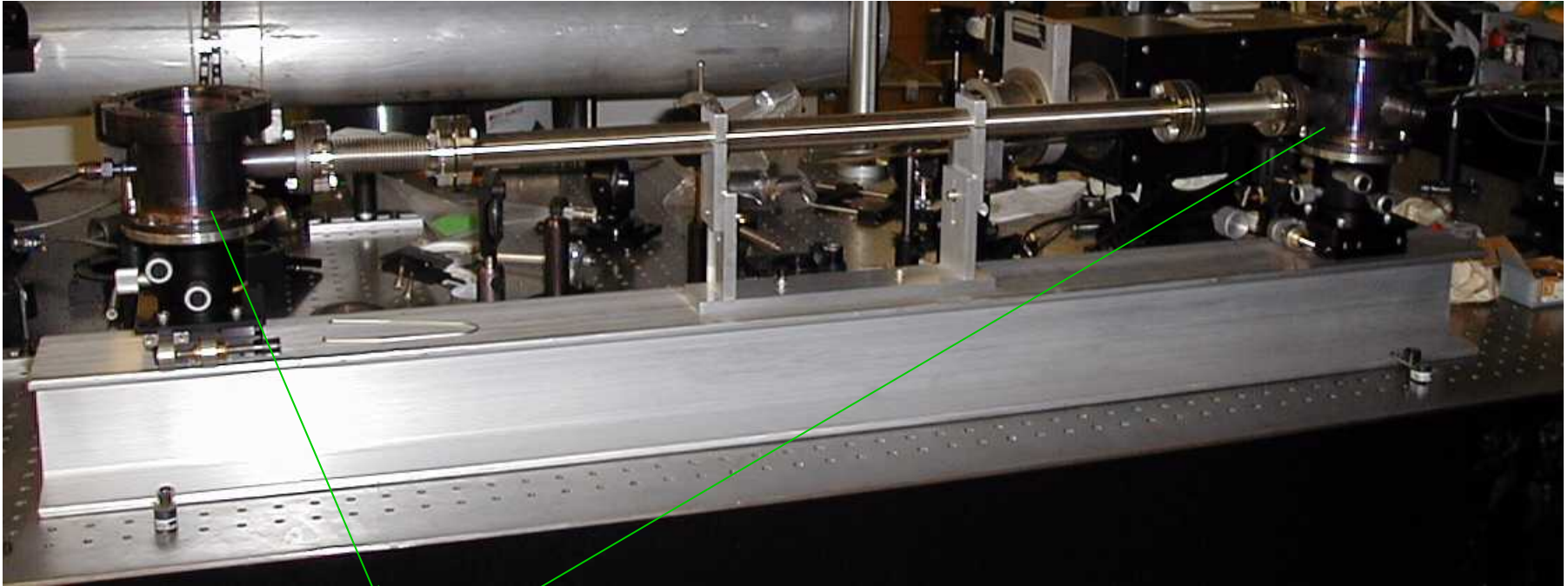
*Prism-based CW-CRDS is a patented technique proprietary to Princeton University and exclusively licensed to Tiger Optics, LLC.

Prismatic Cavity: *The Broadband Advantage*

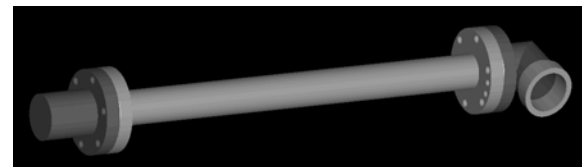
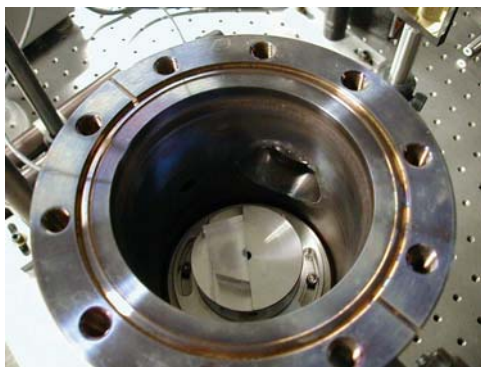


- High Reflectivity Range: Total Internal Reflection vs. Dielectric Layers
- NSF STTR Award Phase I and Phase II

Prism Cavity: *Phase I vs. Phase II*

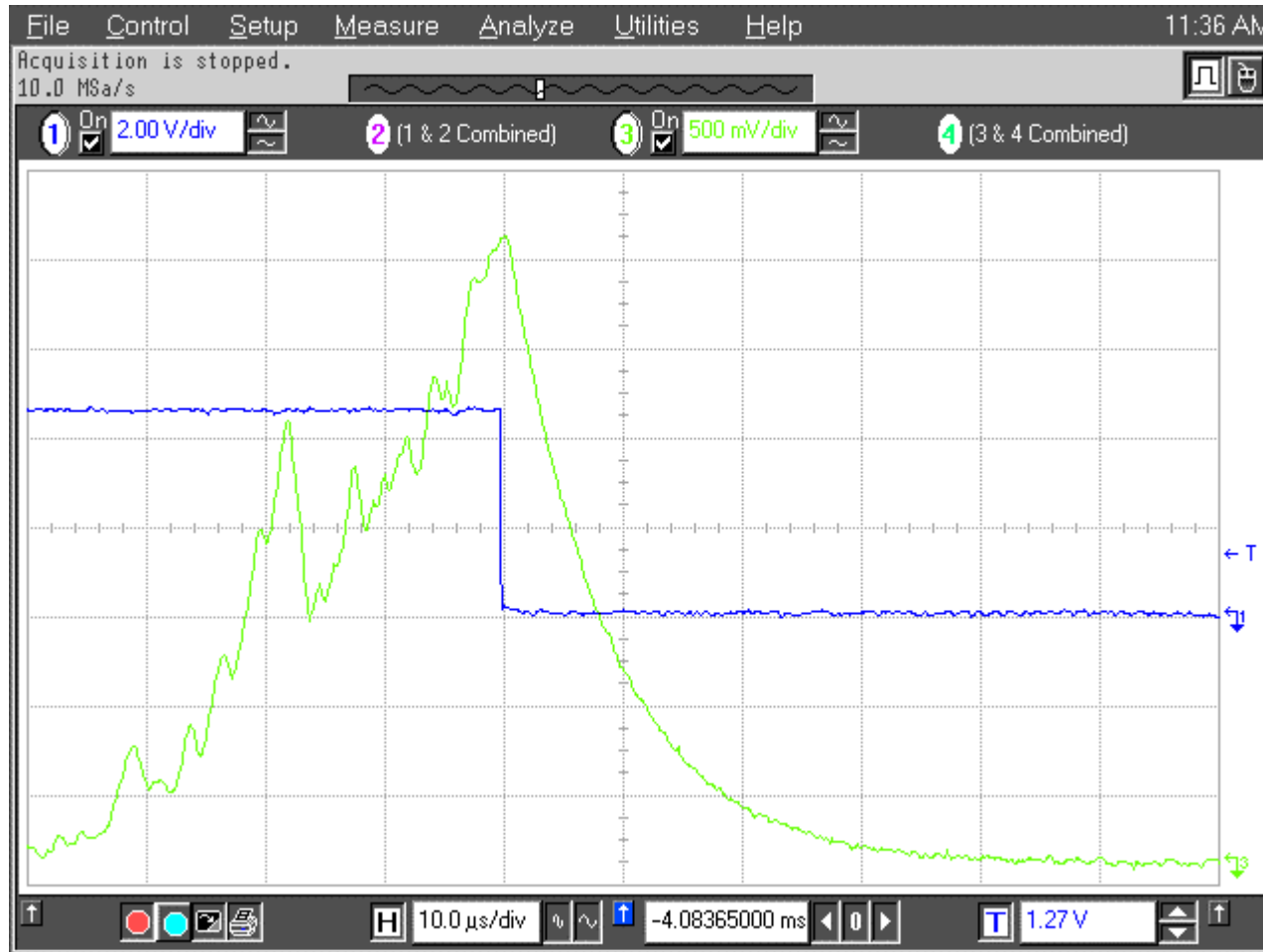


prism
chamber



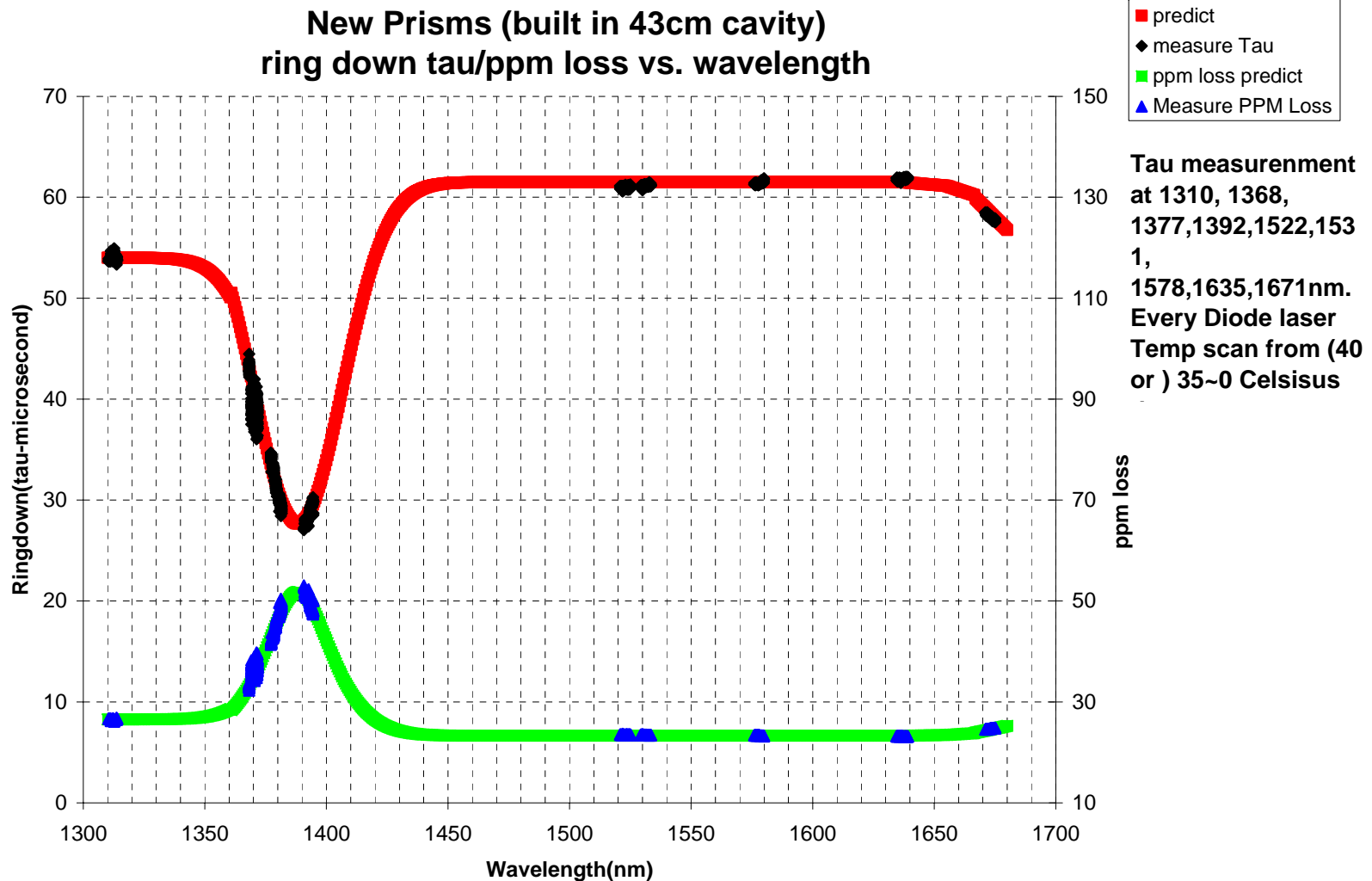
The new cell today

Prism Cavity: *Ring-Down Transient*

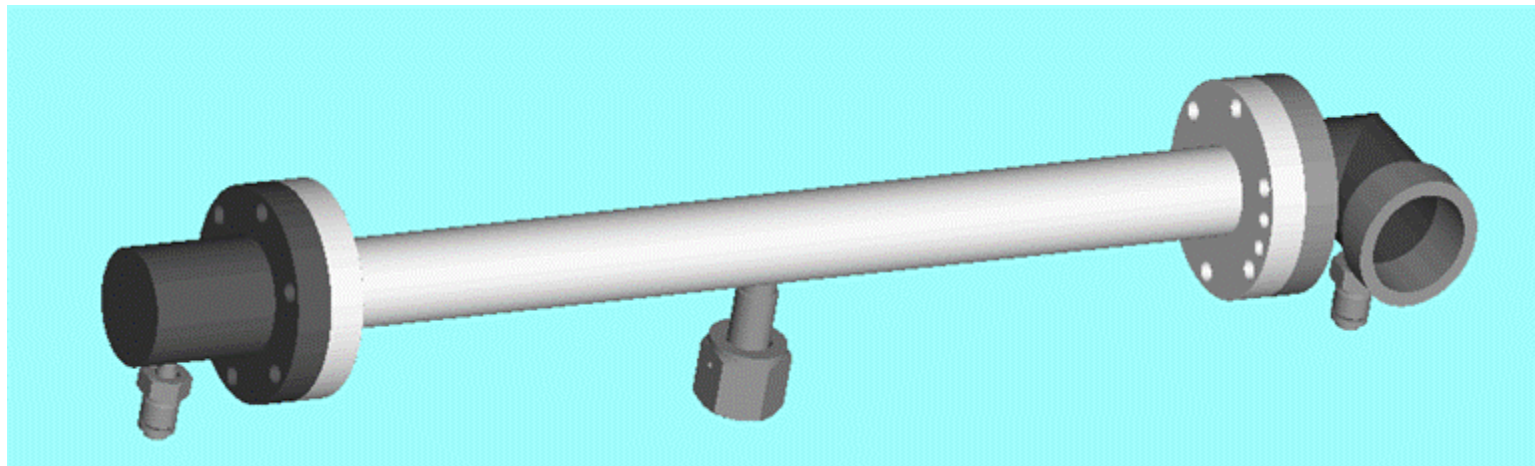
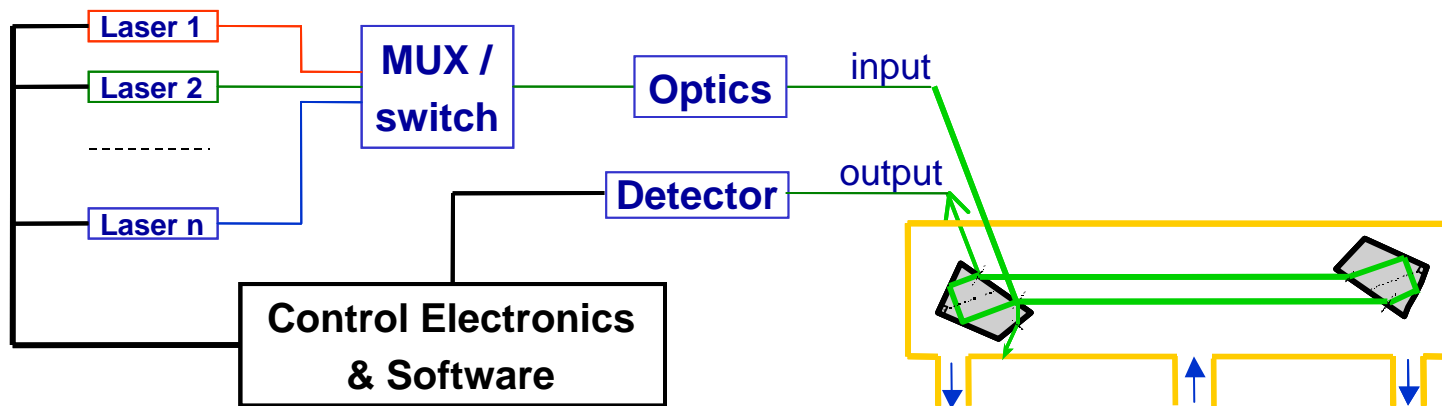


- $\tau = 30 \mu\text{s}$; $L_{\text{total}} = \sim 50 \text{ ppm}$

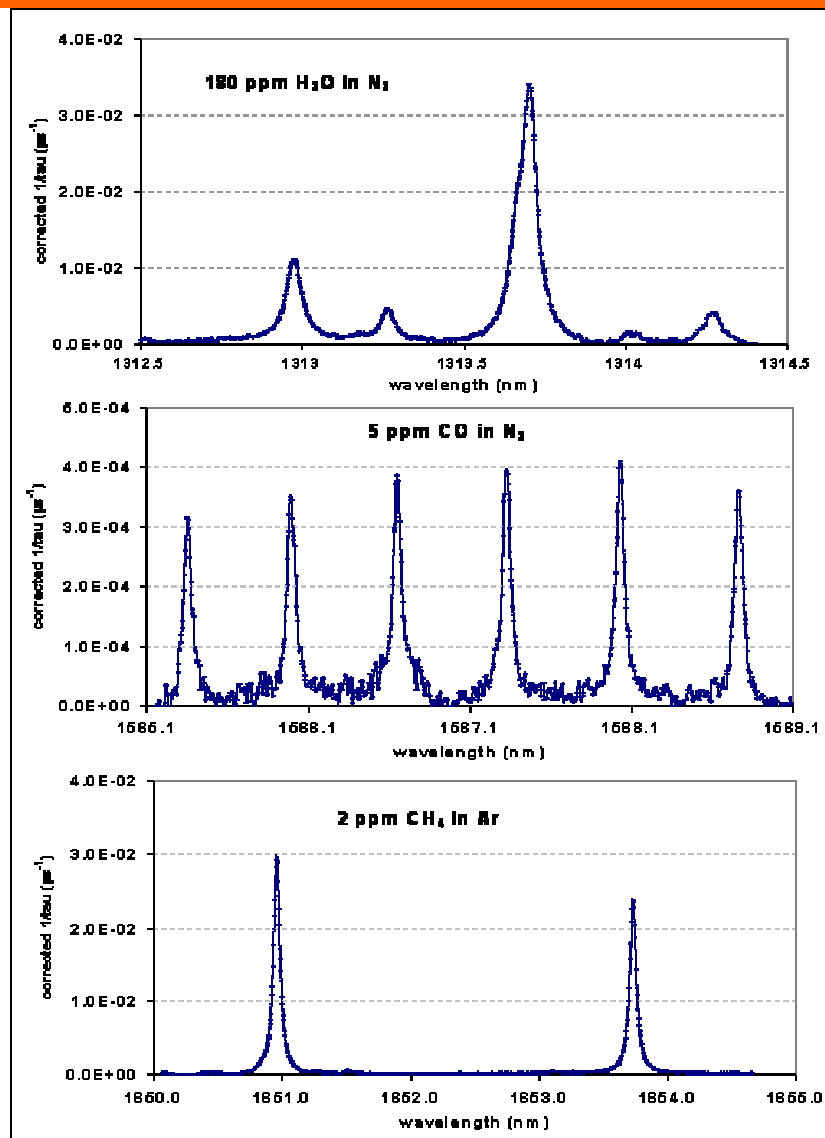
Prism Cavity: Wavelength Dependence



Prismatic: *Instrument Schematics*



Prismatic: *Selected Scan Data*



Prismatic: *H2 Fuel Cell Application*

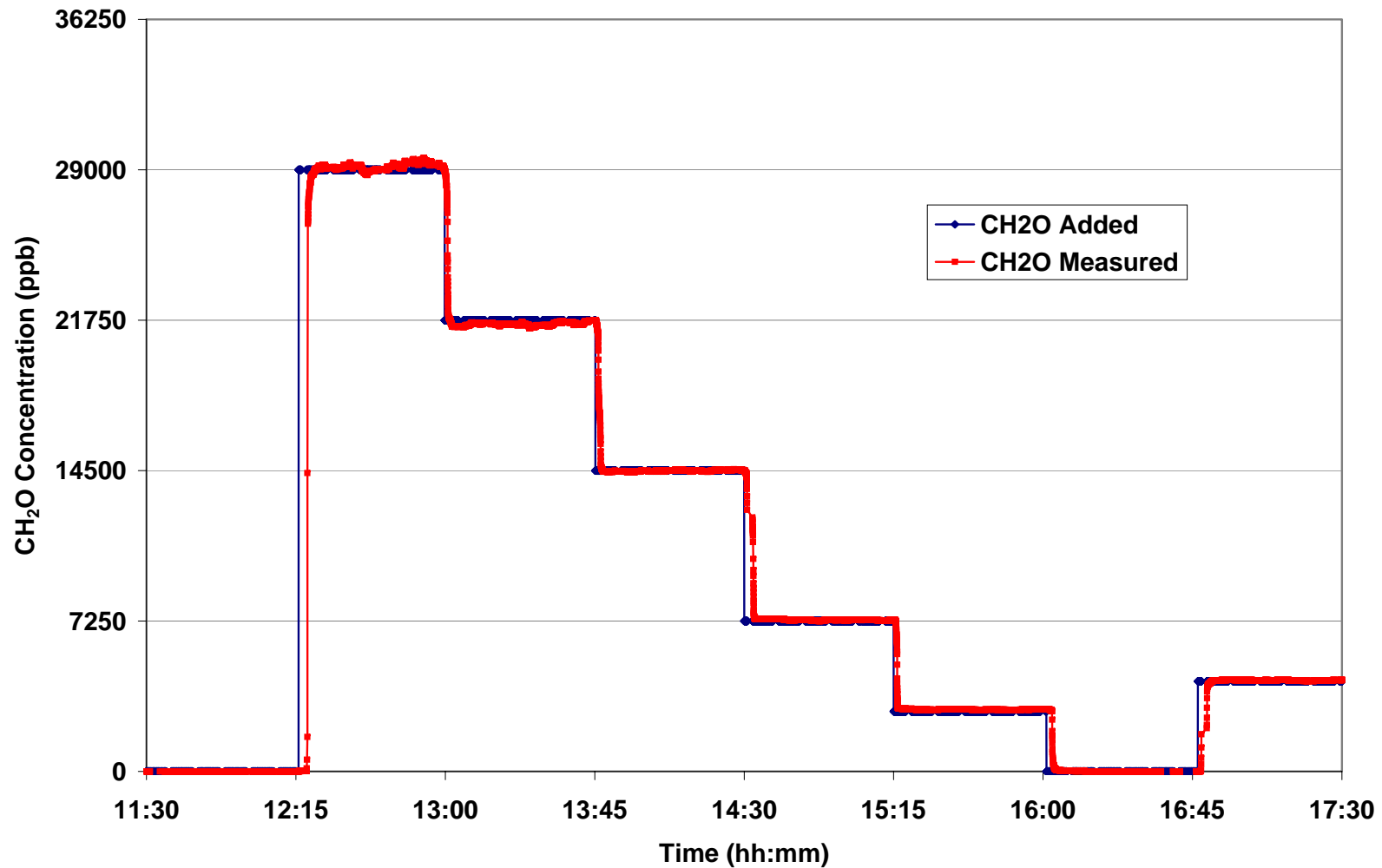
Impurity	Max Spec* Level (ppb)	Prismatic/LaserTrace Analysis Range (ppb)*
Water (H2O)	5,000	20 – 200,000
Total hydrocarbons (C1 basis)	2,000	2 – 8,000 (CH4)
Carbon Dioxide (CO2)	2,000	400 – 1500,000
Carbon Monoxide (CO)	200	250 – 1000,000
Formaldehyde (HCHO)	10	7 – 100,000
Ammonia (NH3)	100	0.7 – 4,000
Total Halogenated Compounds	50	0.5 – 5,000 (HCl)

*ISO/TS 14687-2:2008(E) Contaminant Specifications for Fuel Cell H2 Type I and II Grade D

**Custom ranges also available

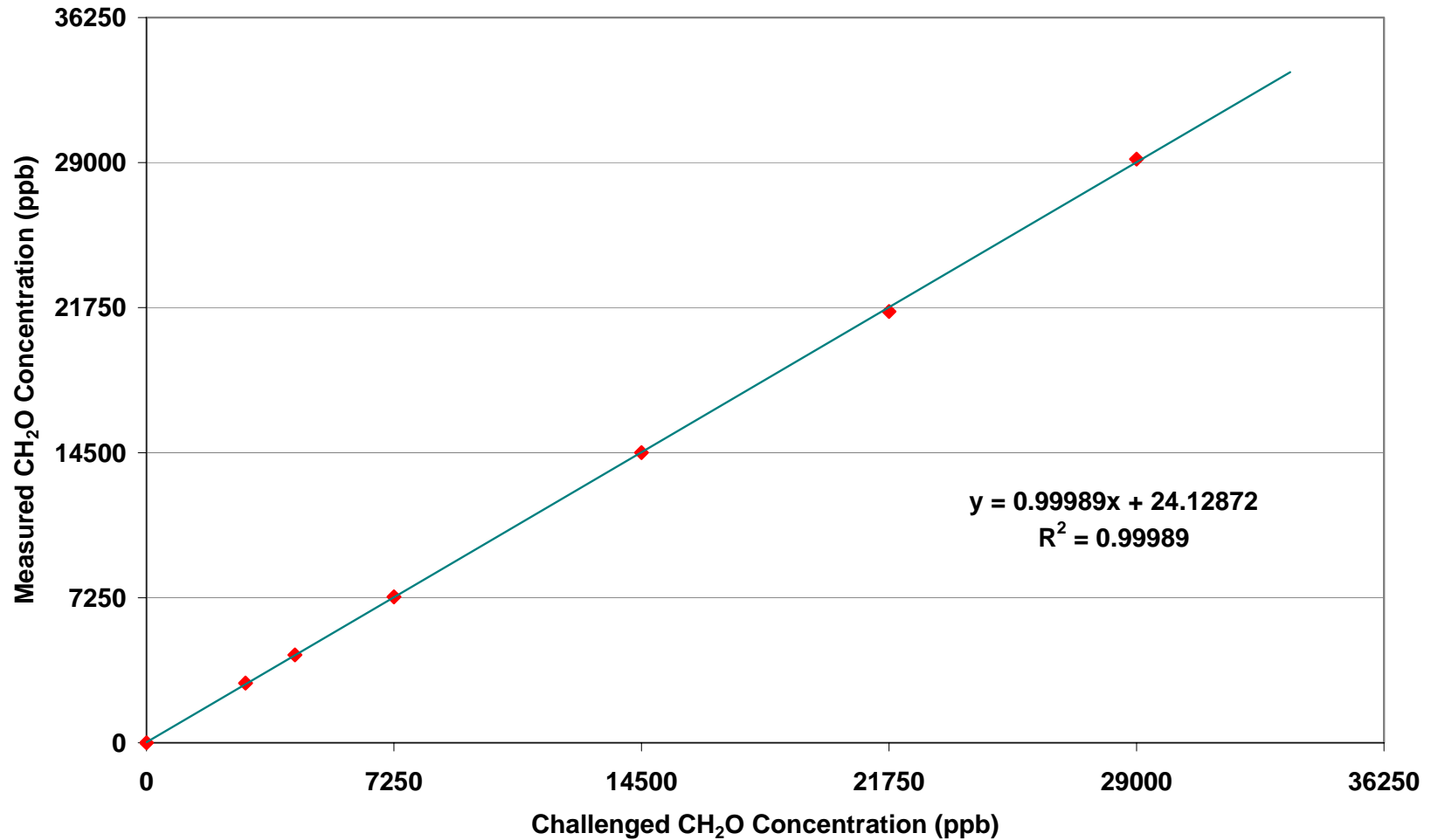
CW-CRDS: *Formaldehyde Measurement Data*

Step Challenge of Formaldehyde in Balance N₂ on LaserTrace-CH₂O

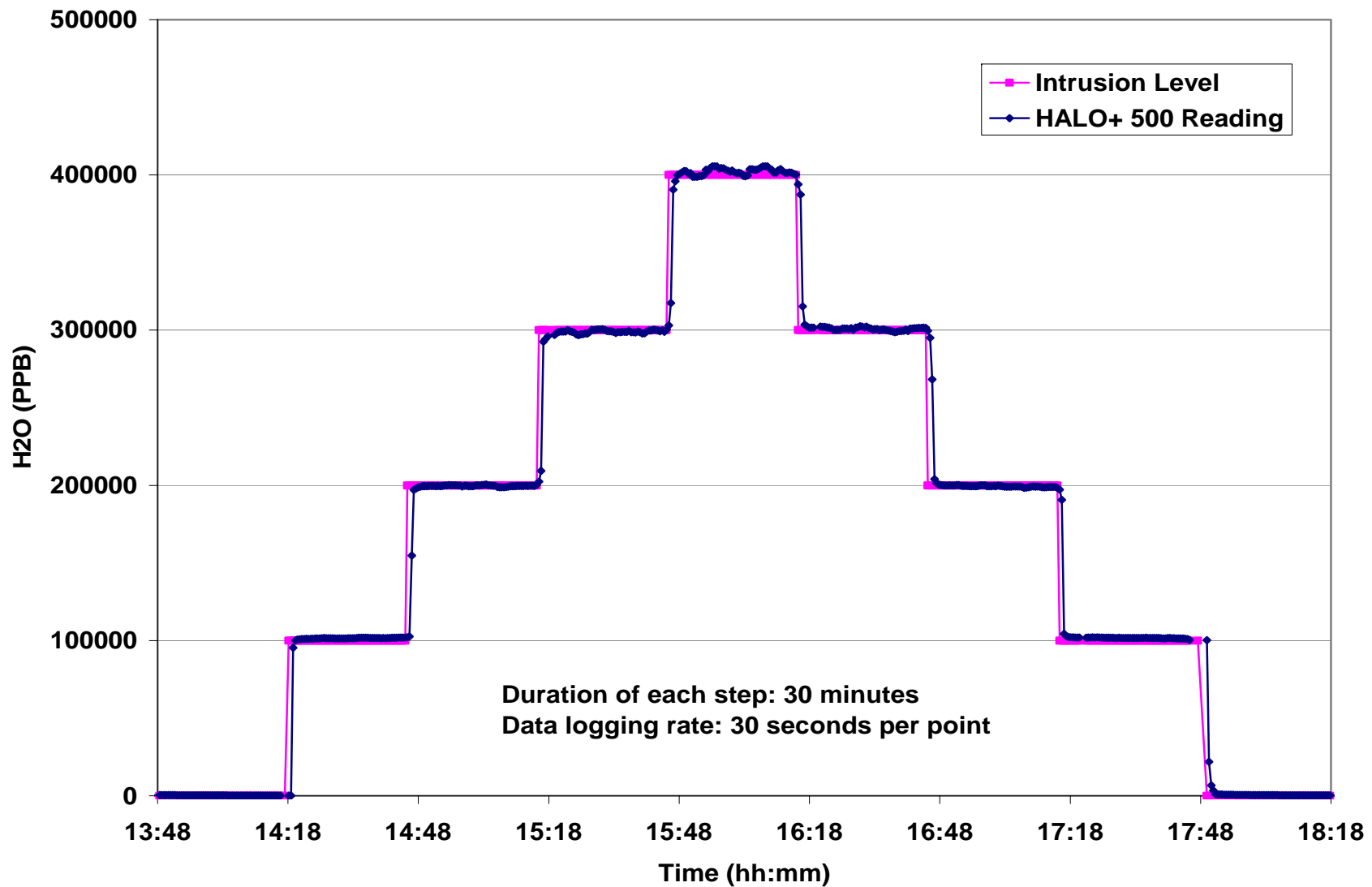


CW-CRDS: *Formaldehyde Measurement Data*

Linearity Plot of Formaldehyde Step Challenge on LaserTrace CH₂O

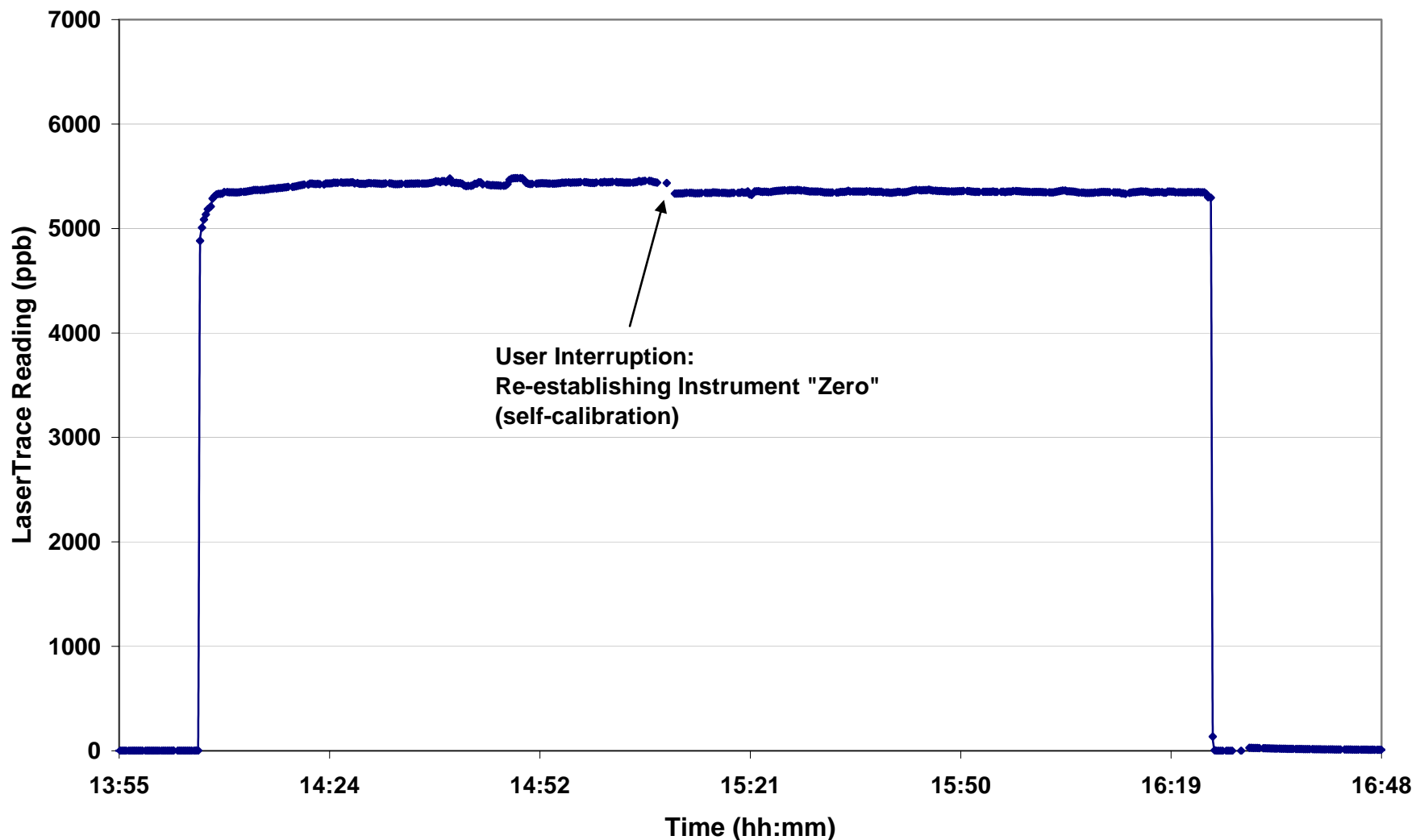


CW-CRDS: High Level H₂O Data



CW-CRDS: *Ammonia Measurement Data*

5300 ppb NH₃ in Air Challenge from a Standard Mixture Gas Cylinder



Summary

- CW-CRDS demonstrates strong detection capabilities
- The prism cavity achieves performance equivalent to the mirror cavity but with broadband advantage
- The Prismatic Multi-Gas Analyzer has great potential in H₂ quality measurement applications in fuel cell research



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and counting!!