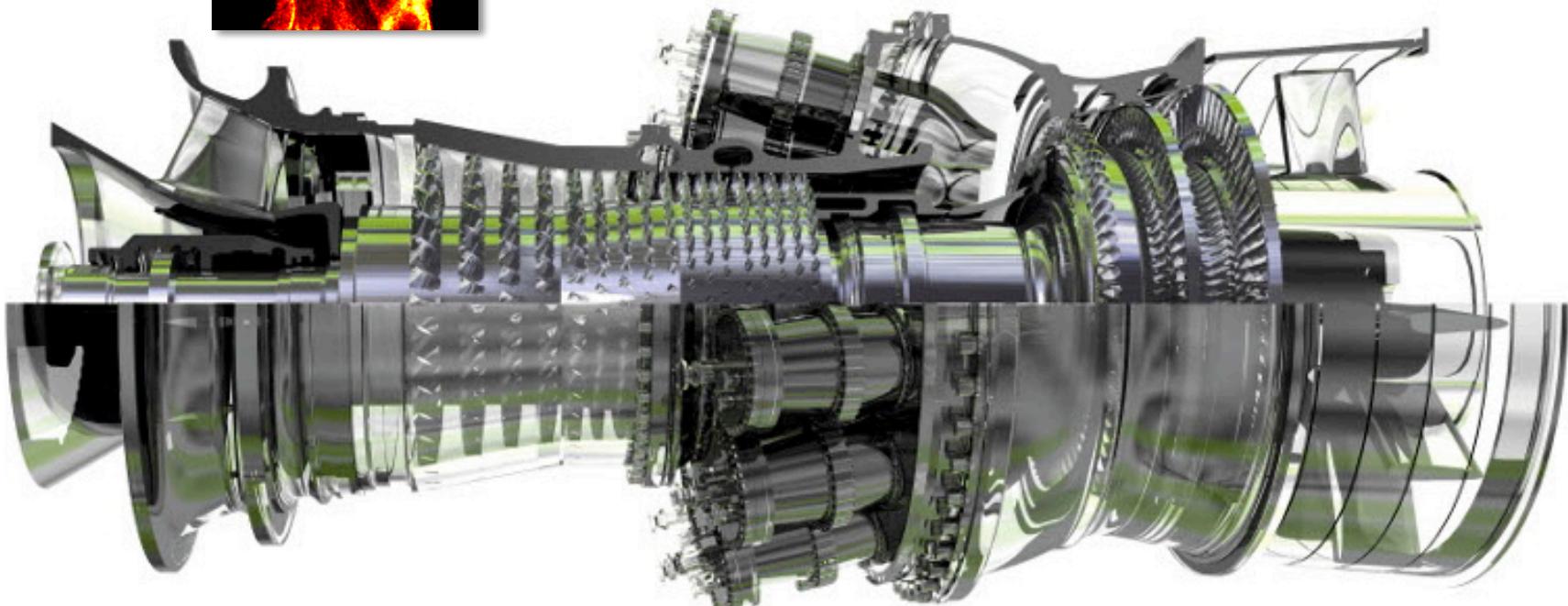




## *Diagnostics to Go*

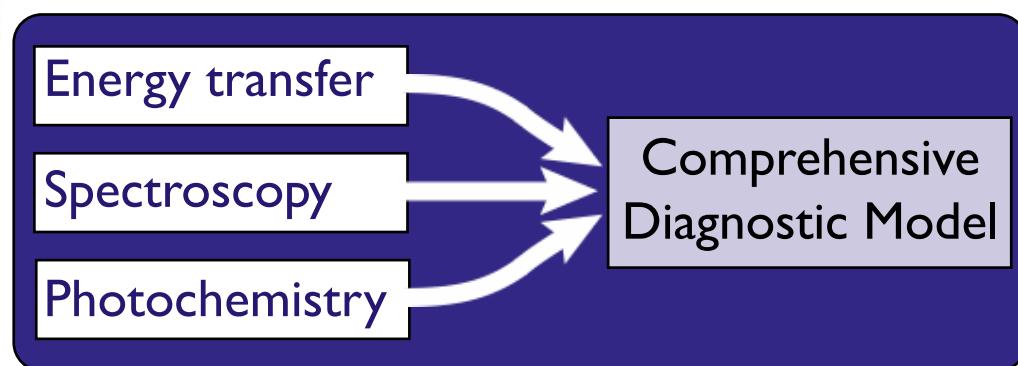
Andy McIlroy  
Senior Manager





# CRF Diagnostics Ecosystem

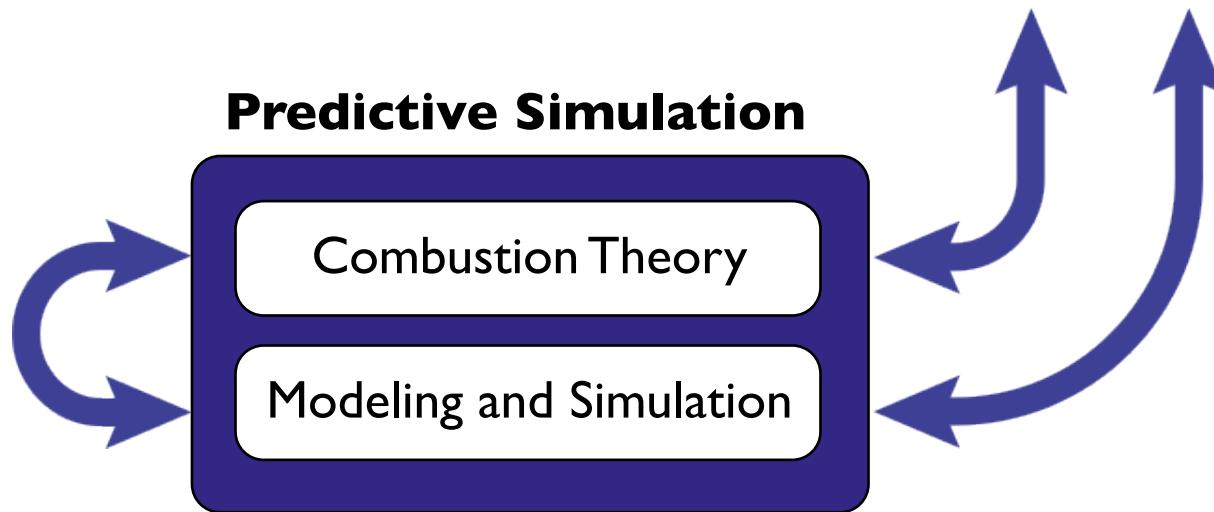
## Combustion Diagnostics Research



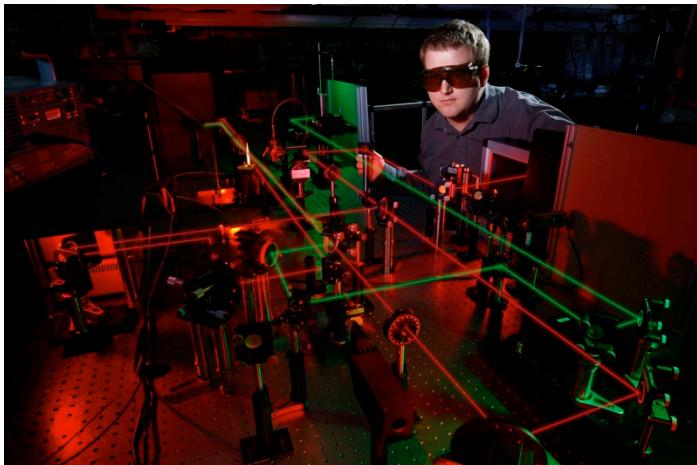
## Experimental Combustion Research

Combustion Kinetics  
Flame Chemistry  
Turbulent Flames  
Applied Research

## Predictive Simulation



# Diagnostics Investment at the CRF

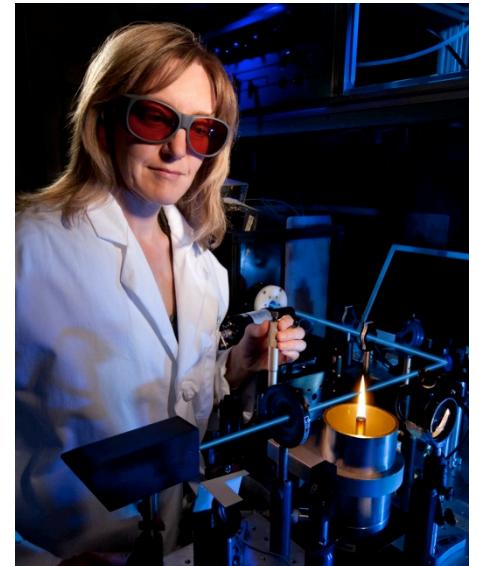


## Diagnostic Development

- 4 Laboratories
- 3 Staff Scientists
- 3 Postdocs
- 3 Technologists

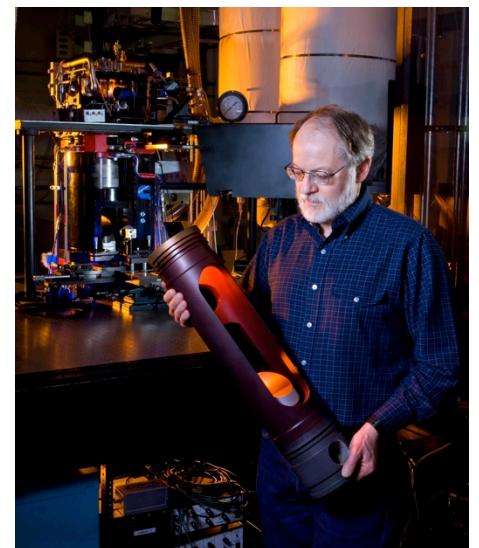
## Fundamental Combustion

- 6 Laboratories
- 7 Staff Scientists
- 8 Postdocs
- 4 Technologists



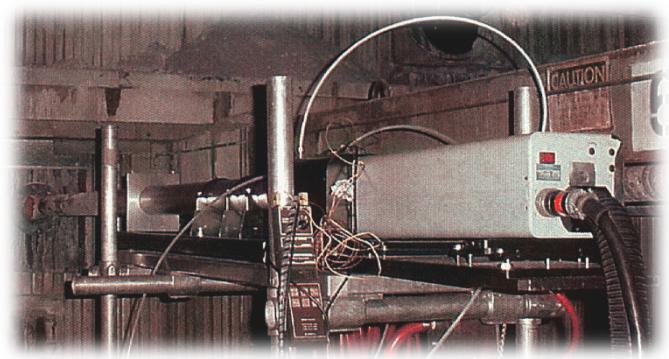
## Applied Combustion

- 10 Laboratories
- 8 Staff Scientists
- 8 Postdocs
- 5 Technologists



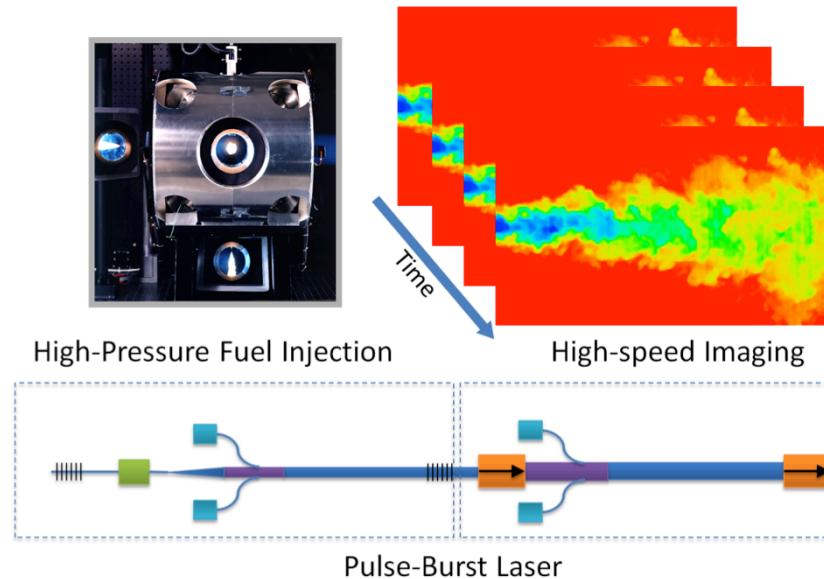
# Past CRF Fielded Diagnostics

- Steel Furnace
- Glass Furnace
- Boilers
- Pool Fires
- Cloud LIDAR
- Microfluidic detection
- Gas leak detection

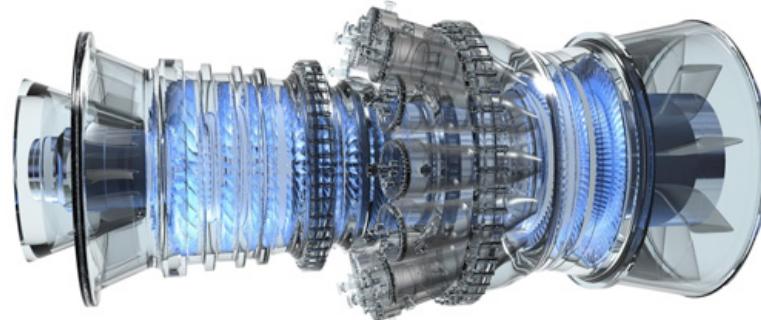


# New Opportunities

- Developing cutting edge, portable high speed imaging capability



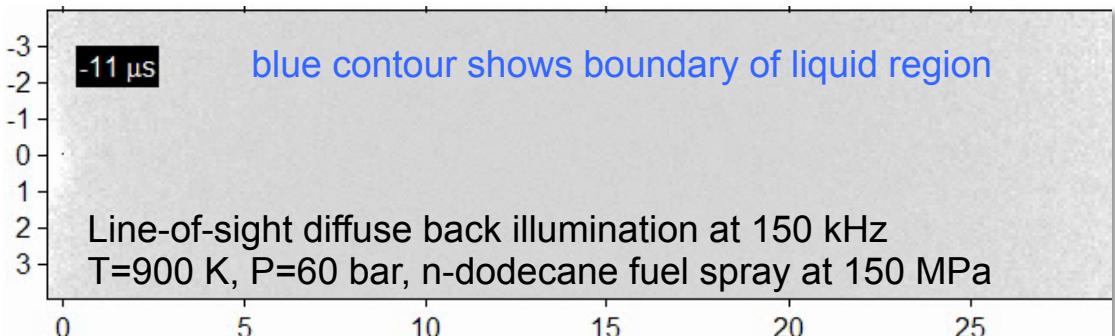
- Developing and applying targeted diagnostics for partners



# Quantitative Imaging of Turbulent Mixing Dynamics in High-Pressure Fuel Injection

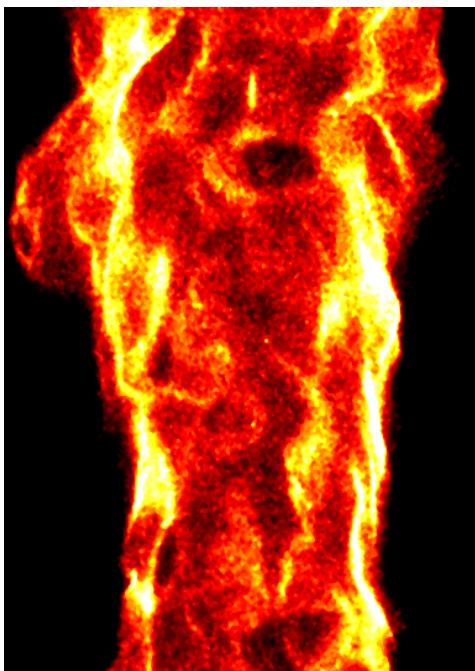
## Jonathan Frank, Lyle Pickett, Sean Moore, Scott Bisson

- Project Purpose: Develop quantitative high-speed imaging capability to provide new understanding of high-pressure fuel injection dynamics, enabling predictive simulations of engine combustion
- R&D Goals & Milestones
  - Develop pulse-burst laser system: 100 KHz, 5 ms, 30 mJ/pulse @ 355nm
  - Staged construction of fiber laser, amplifiers, harmonic generation
  - Prepare high-pressure diagnostics & spray chamber
  - Study dynamics of fuel injection and effects on combustion
  - High-speed velocity and scalar imaging of fuel vapor mixing, ignition, and flame stabilization
- Duration: FY13-15
- Total Budget: \$2.3M
  - LDRD funded

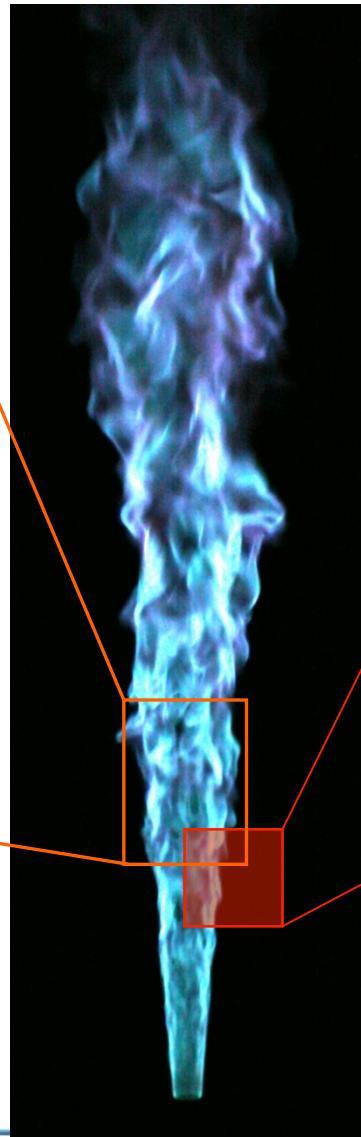


# Extend Capability from Line-of-sight to Spatially Resolved Measurements

Line-of-sight Measurement



Flame luminosity at 15 kHz

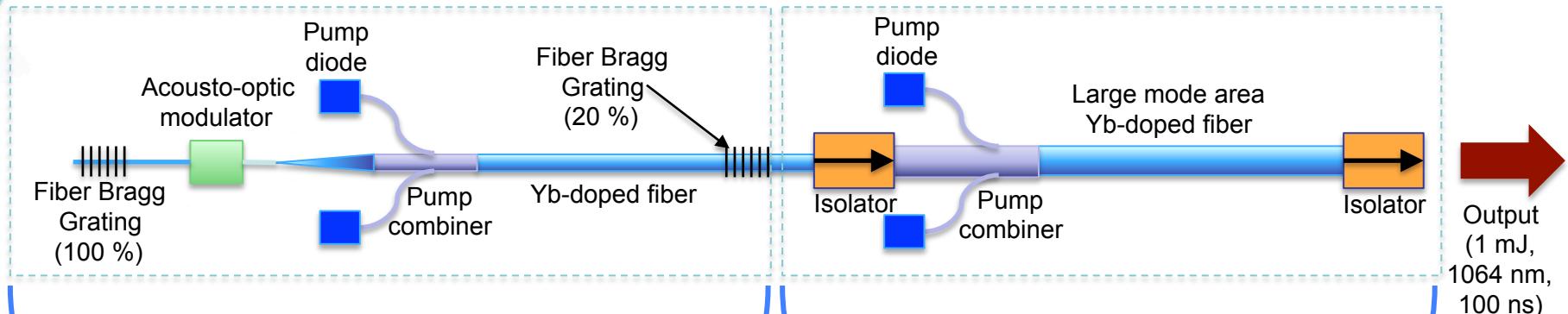


Planar Imaging Measurement

OH LIF Imaging at 10 kHz

# Fiber- and Diode-Based System Promises High Power and Rep. Rate in Compact Package

## Master Oscillator



## Fiber Power Amplifier

Master Oscillator  
(Actively Q-switched fiber laser)

0.1 mJ  
1064 nm

Fiber Amplifier  
(Double-clad Yb-doped fiber amplifier)

1 mJ  
1064 nm

Commercial Amplifier  
(diode pumped Nd:YAG)

15 ns, 100 kHz burst lasting ~5 ms

## Full Laser System Architecture

30 mJ  
355 nm

Sum-frequency Mixing (LBO)

1064 nm  
532 nm  
50 mJ

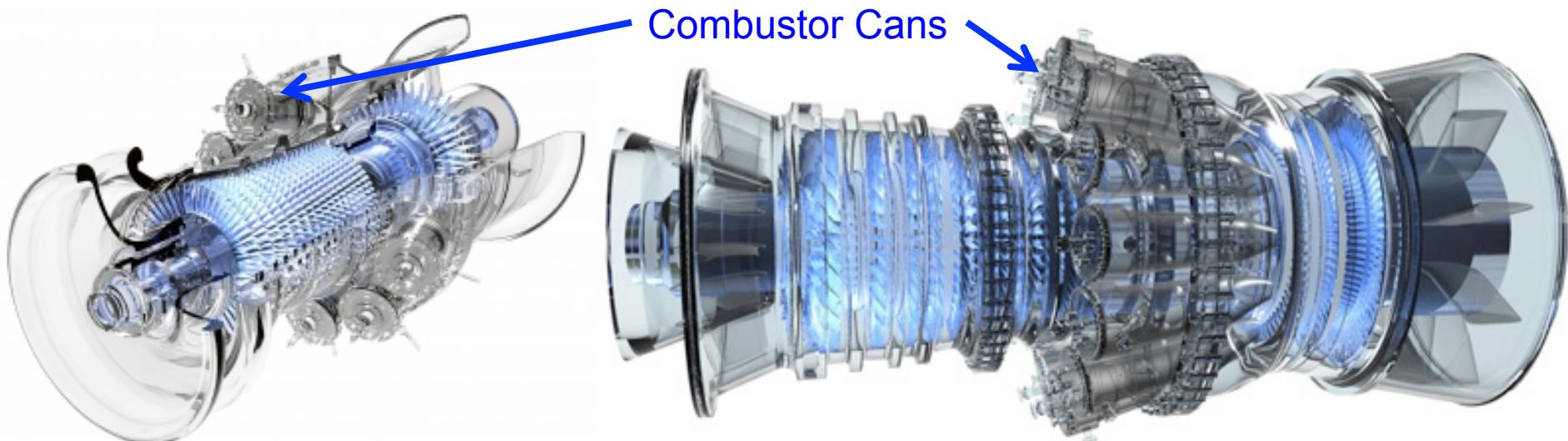
Frequency Doubling (LBO Phase-Matched)

100 mJ  
1064 nm

Pair of Custom-Developed Amplifier Modules (diode pumped Nd:YAG)

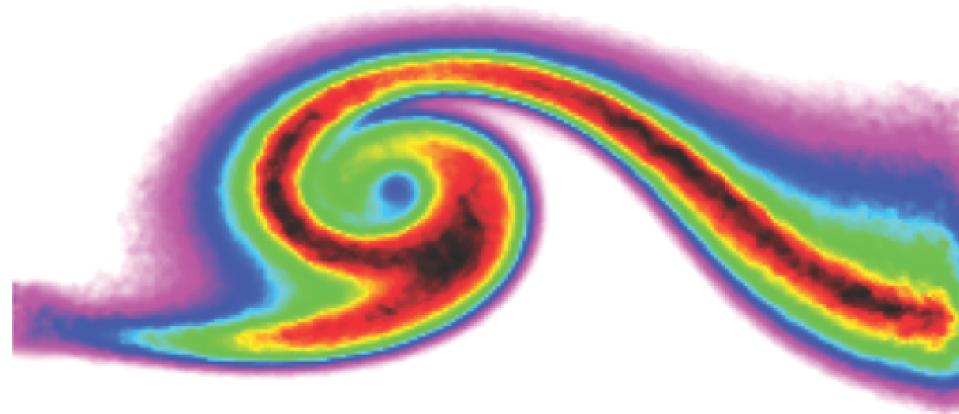
# Field Application of CO Diagnostic for Turbine Combustors

- Gas turbine generators provide reliable base load power
- Integration with intermittent renewables would be enhanced by enhanced 'turn down' capability – operating at less than the full rated power, preferably as low as 40%
- Existing systems exceed permitted CO emissions below ~80%
- Efforts to date have failed to identify CO formation mechanism
- Strong desire to measure spatial distribution of CO in a turbine combustor at low load

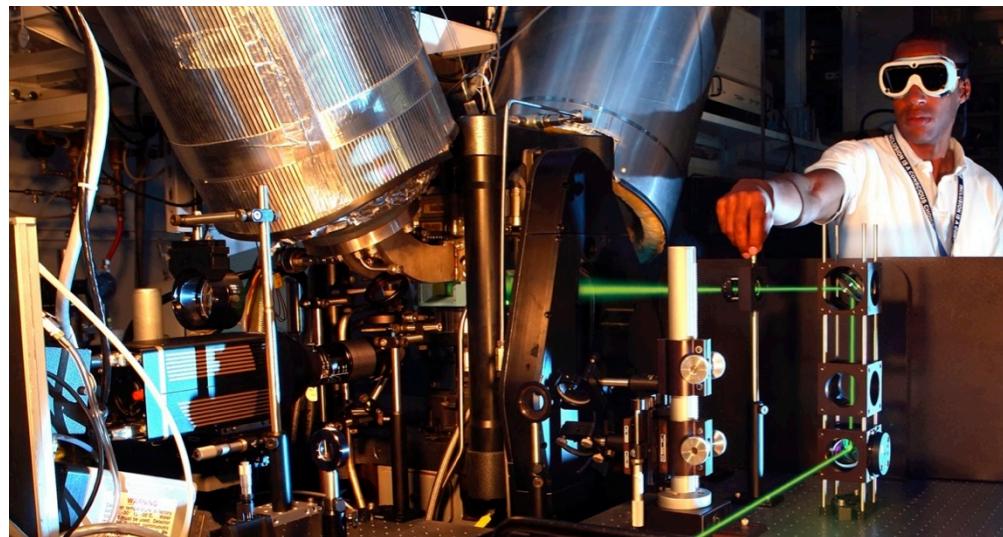


# Why the CRF for CO Diagnostics?

- Tom Settersten: World expert in CO spectroscopy

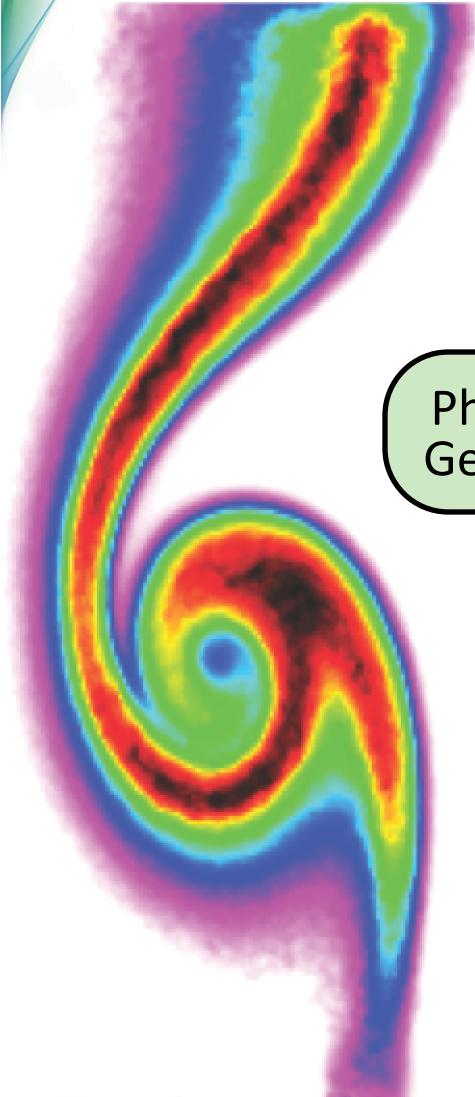


- Paul Miles and Isaac Ekoto: World experts in applying CO diagnostic



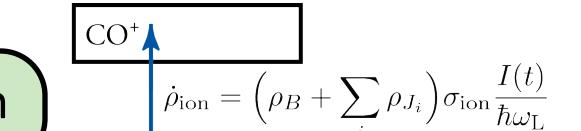
# Challenges of Quantitative CO Imaging

## Detailed spectroscopic investigations inform predictive models



Photoionization

Photolytic Generation



High-Res. Spectroscopy

$$\dot{\rho}_{J'} = +\Omega_J \beta_J - \rho_{J'} \Gamma_{J'} + \sum_i \rho_{J'_i} R_{J'_i J'}$$

Predictive Quenching

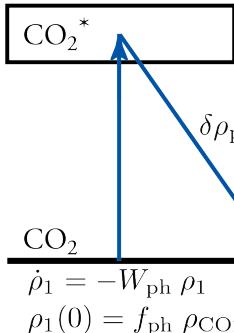
$$\dot{\rho}_B = -\rho_B \Gamma_B + \sum_i \rho_{J'_i} R_{J'_i B}$$

Two-photon Absorption

$$\dot{\rho}_{\text{lost}} = \left( \rho_B + \sum_i \rho_{J_i} \right) (Q + A)$$

$$\begin{aligned} \dot{\alpha}_J &= -\Delta \beta_J - (\gamma_J + \gamma_L) \alpha_J \\ \dot{\beta}_J &= +\Delta \alpha_J - (\gamma_J + \gamma_L) \beta_J + \Omega_J (\rho_J - \rho_{J'})/2 \end{aligned}$$

Pressure Broadening



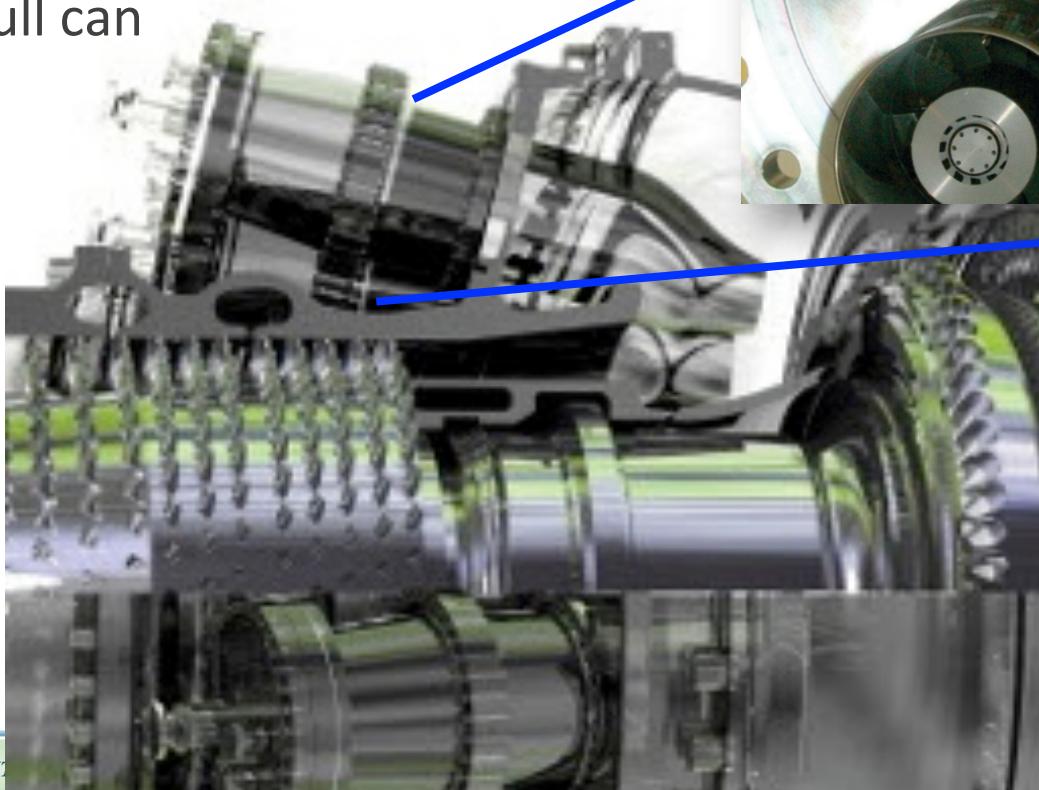
$$\dot{\rho}_{J_i} = \delta \rho_{\text{ph}, t'} \quad \left\{ \begin{array}{c} \text{CO}_2 \\ \text{CO}_2^* \end{array} \right.$$

Molecular Energy Transfer

$$\begin{aligned} \dot{\rho}_X &= -\rho_X \Gamma_X + \sum_i \rho_{J_i} R_{J_i X} \\ \dot{\rho}_J &= -\Omega_J \beta_J - \rho_J \Gamma_J + \sum_i \rho_{J_i} R_{J_i J} \end{aligned}$$

# Test Plan

- Optical engine test-bed
- Laser/materials assembly
- GE-GRC optical test rigs
- GE-GRC single injector at T&P
- GE-P&W full can



Combustor Can  
End View