Fundamental Mechanisms, Predictive Modeling, and Novel Aerospace Applications of Plasma Assisted Combustion

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PAC MURI 4-year milestone: Overview of goals and approaches

Goals

• Obtain quantitative, time- and space-resolved data in well-characterized plasma assisted combustion experiments: temperature, species number densities, vibrational state populations, electric field, electron density

• Quantify the effect of plasma generated species – radicals and excited states – on fuel oxidation, ignition, combustion, and flameholding

• Elucidate detailed kinetic mechanisms, develop predictive kinetic models of nonequilibrium plasma assisted combustion processes, assess and validate the models

Approaches

• Experimental Platform I. Plane-to-plane, high repetition rate nsec pulse discharge: large-volume, premixed plasma chemical fuel oxidation and ignition at near-0-D conditions.

• Experimental Platform II. 1-D low-pressure premixed flame: effect of nonequilibrium plasmas on premixed combustion chemistry

• Experimental Platform III. Point-to-point, single-pulse nsec pulse discharge: kinetics of energy transfer among excited species (electronic and vibrational) and radicals at high energy loadings per molecule

• Kinetic modeling. Integrated model of electric discharge, plasma kinetics / chemistry, and “conventional” hydrogen / hydrocarbon chemistry mechanism
PAC MURI overarching end-of-project goal: development of predictive kinetics, realistic geometry plasma model

Overview of MURI thrusts (which we observe to merge gradually)

• Studies of nonequilibrium air-fuel plasma kinetics (Thrust 1) and fundamental nonequilibrium discharge processes (Thrust 3) using advanced non-intrusive diagnostics and predictive kinetic modeling (Thrust 2)

Kinetic model expectations

Technical

• Integrating / coupling of electric discharge model, plasma kinetics / chemistry in discharge and “early” afterglow, and “conventional” hydrogen / hydrocarbon chemistry in “late” afterglow

• Simple “canonical”, but realistic, discharge geometry (including filaments)

• Expected use: prediction of ignition delay time and temperature, flame speed, combustion products composition, based on easy-to-measure discharge parameters (voltage and current waveforms, initial composition, pressure and temperature)

Practical

• Minimal changes of the model / code between different discharge configurations; minimal turnaround time

• Accessibility to different MURI research groups; ability to model multiple PAC problems

• Thorough and extensive documentation
Example of insight given by predictive modeling

Interpretation based on experimental data alone

Interpretation using insight from non-empirical modeling
Previous Results (Year 3), Experimental Platform I:
mildly preheated $\text{H}_2$-air, $\text{CH}_4$-air, $\text{C}_2\text{H}_4$-air, and $\text{C}_3\text{H}_8$-air

- Discharge dimensions 1 cm x 2 cm x 6 cm
- Right angle quartz prism 6 cm long provides optical access to discharge

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<th>Pressure (torr)</th>
<th>$\text{H}_2$-air, pulse #10</th>
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- $\text{H}_2$-air, $\text{C}_2\text{H}_4$-air, $\text{CH}_4$-air, and $\text{C}_3\text{H}_8$-air at $T_0 = 100-300^\circ \text{C}$, $P = 50-500$ torr, $\phi = 0.03-1.2$
- Pulse repetition rate (20-25 kV peak, ~10-50 nsec), $v = 10-40$ kHz
- Diffuse, volume filling, mildly preheated plasmas at pressures up to hundreds of Torr
- Ample optical access (LIF, TALIF, CARS) for species and temperature measurements
- OH LIF absolute calibration: adiabatic burner in Hencken burner, more recently Rayleigh scattering
[OH] on centerline after a 50-pulse burst, $T_0=500$ K, $P=100$ torr: comparison with 0-D kinetic modeling (A. Konnov mechanism)

Agreement becomes worse for more complex hydrocarbons.
[OH] (LIF) and psec CARS (T, T_v (N_2)) measurements during plasma assisted ignition of H_2-air

- Threshold ignition temperature T_f ~ 700 K
- N_2 vibrational temperature remains quite low
- Not enough energy loading per molecule, per pulse
- Use pin-to-pin discharge (Platform III) to enhance it
- This provides far more stringent test of the model

T_0=500 K, P=92 torr, \phi=0.4, \nu=10 kHz, 120 pulses

- [OH], T by OH LIF (Proc. Comb. Symp. 2013)
  - 0-D model: good agreement with measured [OH] at the end of the burst, during ignition

- T, T_v (N_2) by psec CARS (Comb. Flame 2013)
  - Measured temperature in excellent agreement with 0-D model predictions from previously published work
Predictive kinetic modeling of nonequilibrium fuel-air plasmas: model overview

- Nonequilibrium plasma model / code used as a starting point: non-PDPSIM (developed by M. Kushner, U. Michigan), widely used in low-temperature plasma community, well-documented

- Quasi-1-D and 2-D (plane, axisymmetric) geometries

- Poisson equation for the electric field: predict electric field in plasma, cathode voltage fall

- Boltzmann equation for EEDF (experimental cross sections): predict rates of electron impact excitation, dissociation, and ionization processes

- Charged species equations (ionization, recombination, attachment, detachment processes, ion-molecule reactions): predict electron density in plasma

- Excited neutral species equations (electron impact excitation, non-reactive and reactive quenching): predict contribution to radical species formation

- Master equation for N₂ (X,v) populations; vibration-translation (V-T), vibration-vibration (V-V) processes, vibrational-chemistry (V-Chem) enhancement of reaction rates

- Neutral species reactions: fuel-air air chemistry, enhanced by radical production in plasma

- Coupling between chemistry, transport processes (diffusion, conduction), and flow

* Synergy with

AFOSR BRI “Nonequilibrium Molecular Energy Coupling and Conversion Mechanisms for Efficient Control of High-Speed Flow Fields” (M. Berman)

DOE Plasma Science Center “Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems”
Gaining confidence in model predictions (validation):
I. Electric field and electron density

Key plasma parameters controlling coupled energy and its partition among different channels (elastic, vibrational, electronic, dissociation, ionization):

• Electric field
• Electron density
• Electron temperature

The model has to predict them accurately, given the applied voltage waveform.

Model validation requires experimental data on electric field (4-wave mixing), electron density, and electron temperature (Thomson scattering)
Experimental and measured electric field in a plane-to-plane nsec pulse discharge in N\textsubscript{2}

- Experiment (Ruhr Universität Bochum, Germany, nsec pulse 4-wave mixing): N\textsubscript{2}, P=0.25 bar, 1.2 mm gap, pulse repetition rate 2 kHz
- Field in plasma before breakdown follows applied voltage, \( E=U/d \)
- Field in plasma after breakdown is significantly lower, significant cathode voltage fall
- Model predictions for time-resolved E-field, pulse current: good agreement with experiment
E/N in the plasma in a plane-to-plane nsec pulse discharge in N₂

- E/N in plasma after breakdown is reduced considerably due to the cathode fall.
- Significant effect on energy partition among N₂ energy modes (lower E/N favors vibrational excitation instead of electronic excitation, dissociation).
- Predicted cathode fall ($U_c \approx 300$ V) at steady-state is close to normal cathode fall: steady-state current density is fairly low, $j \approx j_n \approx 10$ A/cm².
- Cathode fall increases significantly with current density (point-to-point discharge, $j \sim 10^3$ A/cm²).
Sub-Nsec Resolution Electric Field Measurement by CARS-like Four Wave Mixing

Energy Level Diagram for E-Field CARS

$\omega_p$ $\omega_S$ $\omega_{AS}$

IR CARS

$E_{IR} = \chi_{IR} E_{Pump} E_{Stokes} E_{External}$

$E_{CARS} = \chi_{CARS} E_{Pump} E_{Stokes} E_{Pump}$

$E_{IR} = \left( \frac{\chi_{IR}}{\chi_{CARS}} \right) * \left( \frac{E_{External}}{E_{Pump}} \right)$

$E_{External} = \left( \frac{\chi_{CARS}}{\chi_{IR}} \right) \sqrt{\left( \frac{I_{IR} I_{Pump}}{I_{CARS}} \right)}$

• “E-Field CARS” is a 4-wave mixing process

• CARS probe beam is replaced by an external electric field, which is at essentially zero frequency. This creates an IR “CARS” signal at the vibrational frequency.

• The physical origin of this signal is the dipole induced by the external field

• Phase Matching for E-Field CARS is collinear

*V.P. Gavrilenko, JETP Lett. 1992
Electric field measurements in a point-to-point nsec pulse discharge in H₂ (psec 4-wave mixing)

- H₂, P=0.21 bar, discharge between two spherical electrodes, 5 mm gap, pulse repetition rate 10 Hz
- Estimated current density much higher than in RUB experiments, j ~ 10³ A/cm²
- Time resolution 0.2 nsec (in the present experiment, 0.5 nsec “time bins” are used)
- Absolute calibration and modeling calculations are underway
Thomson scattering electron density measurements in diffuse filament, point-to-point discharge

** Acknowledgement: U. Czarnetzki, Ruhr-Universität Bochum
First test, helium: plasma images, current and voltage waveforms

Helium, 200 torr, 10 mm gap, camera gate 150 nsec
Left: single pulse; right: 100-pulse average
Absolute calibration using N\textsubscript{2} rotational Raman spectra

No discharge

Used for Thomson scattering calibration

Laser energy 500 mJ/pulse

6 minutes accumulation time
Sample Thomson scattering spectra during and after discharge pulse (t=0-250 nsec)

- Helium, 200 torr
- Peak voltage 7 kV
- Peak current 60 A
- Coupled energy ~18 mJ/pulse
- Pulse repetition rate 90 Hz
- t=0 beginning of pulse current rise
- Laser energy 500 mJ/pulse
- 6 minutes accumulation (~3200 shots)
Time evolution of Thomson scattering spectra during the discharge pulse

- Breakdown at $t=0$
- End of pulse $t \approx 100$ nsec
Experimental and predicted electron density and electron temperature in helium

- Breakdown may be not fully resolved in the experiment (time resolution ±15 nsec)
- High electron temperature (up to ~5 eV) during breakdown onset
- High peak electron density during the pulse, \( n_e \sim 3 \cdot 10^{15} \text{ cm}^{-3} \), followed by rapid decay in the afterglow
- "Residual" electron temperature in the afterglow (maintained by superelastic processes) \( T_e \sim 0.3-0.4 \text{ eV} \)
2-D contour plots of predicted electron density and electron temperature in helium

- Gate 150 nsec (entire pulse)

- Ongoing work: electron density measurements in molecular gases (H₂, N₂, air)

- Rotational Raman spectra are “in the way” (except for H₂), but ...

- High electron density, \( \sim 10^{14} \sim 10^{15} \) cm\(^{-3} \) helps inferring \( n_e \), \( T_e \) from the underlying “envelope”
Point-to-point, single-pulse nsec pulse discharge: high energy loadings per molecule (~0.1-0.5 eV/molecule), modest temperatures (from a few tens of K up to a few hundred K), fairly large dimensions (10 mm gap, 2-3 mm diameter)

- **Diagnostics:** psec CARS for $T, T_v(N_2)$
- **TALIF, LIF:** absolute N, O, NO number densities
O, NO, N LIF / TALIF experiment: Schematic and calibration

N, O, and NO Can Be Measured Without Changing the Dye

N calibrated using Kr

O calibrated using Xe

NO calibrated using 100 ppm NO/N₂

N calibrated using Kr

\[ N_O = \frac{S_O}{S_{Xe}} \cdot g_{ND} \cdot \frac{a_{21}(Xe)}{a_{21}(O)} \cdot \frac{\sigma^{(2)}(Xe)}{\sigma^{(2)}(O)} \cdot \left[ \frac{\nu_O}{\nu_{Xe}} \right]^2 \cdot \frac{1}{F_0(T)} \cdot N_{Xe} \]
Quasi-1-D discharge model in N\textsubscript{2}, P=100 torr: Electric field and electron density in the filament

- Significant cathode fall ($U_c \approx 1.5 \text{ kV}$ at $j \sim 300 \text{ A/cm}^2 \gg j_n$): fairly low electric field in plasma ($E/N \approx 30 \text{ Td}$) after breakdown

- High electron number density, $n_e \sim 10^{14} \text{ cm}^{-3}$: electron-electron collisions are important for energy partition among internal energy modes
• $N_2(v=1)$ and $T_{v01}$ rise in the afterglow due to “downward” $N_2-N_2$ V-V exchange

• Temperature rise is fairly low ($\Delta T \approx 50$ K)

• Very good agreement between the experiment and the model predictions
Vibrational excitation and temperature rise are predicted fairly accurately.

$\text{N}_2(X^1\Sigma^+_g, v) + O \rightarrow \text{NO} + N$ channel appears unlikely: $\text{N}_2(X)$ vibrational excitation (measured by CARS) is fairly weak.

$[\text{NO}]$ reproduced only when formation processes via multiple $\text{N}_2$ excited electronic states, $\text{N}_2^* + O \rightarrow \text{NO} + N$, are incorporated.

$[\text{NO}]$ reduction is nearly the same as initial $[\text{N}]$, $\sim 10^{15}$ cm$^{-3}$: 
$\text{NO} + N \rightarrow \text{N}_2(v) + O$ reaction.

Air, P=100 torr:
“Full set” of data ($T$, $[\text{N}_2(v)]$, $[\text{N}]$, $[\text{O}]$, $[\text{NO}]$, NO PLIF)
N, O, and NO predictions: incorporating an extended set of $N_2^*$ excited electronic states is critical

\[
N_2^* + O \rightarrow NO + N
\]

\[
k[A^3Σ] = 7 \cdot 10^{-12} \text{ cm}^3/\text{s},
\]

\[
k[\text{other states}] = 3 \cdot 10^{-10} \text{ cm}^3/\text{s}
\]

N loss due to reverse Zel’dovich reaction

Drop in [NO] is close to initial [N]

NO measurements shortly after the pulse (~1 μs) are desirable
Adding H\textsubscript{2} increases NO decay time by a factor of \(\sim 100\), reduces N atoms
NO in air, C₂H₄-air: 
P=40 Torr, high energy loading (~0.5 eV/molecule)

Similar effect:
Adding fuel C₂H₄ increases NO decay time by a factor of ~10, reduces N atoms
NO in air and $\text{H}_2$-air: comparison of data and modeling calculations

Air
$\phi = 0.14$
$\phi = 0.41$

Longer NO decay primarily due to “3rd Zel’dovich” reaction, $\text{N} + \text{OH} \rightarrow \text{NO} + \text{H}$

Peak NO, decay rate in air overpredicted
Time evolution of electron density distribution during breakdown.

$N_2$, 100 Torr, 4 mJ/pulse, $V_{\text{peak}}=12$ kV, $I_{\text{peak}}=10$ A, $\tau=200$ nsec, $(n_e)_{\text{peak}} = 0.5 \cdot 10^{15}$ cm$^{-3}$
2-D Poisson equation / Boltzmann equation / master equation model development: $N_2(v)$ populations

Time evolution of $N_2(v=0-8)$ level populations on the centerline after the discharge pulse
Gaining confidence in model predictions (validation): III. H$_2$-O$_2$-Ar plasma chemistry, point-to-point discharge

500-pulse accumulation

Electrode gap: 11.7 mm, laser beam 4.7 mm from high voltage electrode
H atom TALIF during and after 50-pulse burst
2% $\text{H}_2$ – Ar, $P=40$ torr

During the burst (5 µs after each pulse)

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After the burst

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<th>50 µs</th>
<th>200 µs</th>
<th>500 µs</th>
<th>1 ms</th>
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Flow
H atom TALIF and OH LIF during 50-pulse burst, 2\% H_2 - 20\% O_2 - Ar, P=40 torr
H atom TALIF and OH LIF after 50-pulse burst, 2% H₂ - 20% O₂ – Ar, P=40 torr
OH PLIF image
2% H₂ - 20% O₂ - Ar

5th pulse

HV

GND

2 mm
OH PLIF image
2% H₂ - 20% O₂ - Ar

50th pulse

HV

GND

2 mm
OH PLIF image
2% H₂ - 20% O₂ - Ar

500 µs after
Temperature measurements by Rayleigh scattering at 205 nm:
(a) 2% H₂ – Ar, (b) 20% O₂ – Ar, (c) 2% H₂ – 20% O₂ – Ar

Much lower temperature when O₂ is added:
Significant energy storage in O atoms

Higher temperature over a large volume in presence of H₂ and O₂:
Energy release during oxidation
Centerline temperatures:
(a) 2% $\text{H}_2$ – Ar, (b) 20% $\text{O}_2$ – Ar, (c) 2% $\text{H}_2$ – 20% $\text{O}_2$ – Ar

During the burst

Much lower $T$ when $\text{O}_2$ is added:
Significant energy storage in O atoms

After the burst

Higher centerline $T$, wider hot region
in presence of $\text{H}_2$ and $\text{O}_2$:
Energy release during oxidation
2\% \text{H}_2 - 20\% \text{O}_2 - \text{Ar}, \textbf{during} 50\text{-pulse burst}

Absolute $[\text{H}]$

Nearly complete $\text{H}_2$ dissociation by the end of the burst: $[\text{H}]_{\text{max}} = 3 \cdot 10^{16} \text{ cm}^{-3}$ at $T=500 \text{ K}$

Relative $[\text{OH}]$
2% H₂ - 20% O₂ – Ar, after 50-pulse burst

Absolute [H]

Nearly complete H₂ dissociation by the end of the burst: \([H]_{\text{max}} = 3 \cdot 10^{16} \text{ cm}^{-3} \) at T=500 K

Relative [OH]
Radial profiles of temperature and relative [H], [OH]
2% H\textsubscript{2} - 20% O\textsubscript{2} - Ar

50\textsuperscript{th} pulse

500 µs after

Loss of H atoms, OH accumulation at low temperatures in the periphery:

\[ H + O_2 + M \rightarrow HO_2 + M \]

\[ O + HO_2 \rightarrow OH + O_2 \]

“Diffuse filament” discharge: significant potential for studies of coupled kinetics and transport over a wide T, P range
Kinetic modeling calculations (in progress):

2\% H\textsubscript{2} - Ar

- Models overpredicts temperature, underpredicts [H]: a key H\textsubscript{2} dissociation channel is missing
- In the experiment, nearly all H\textsubscript{2} is dissociated by the end of the burst

Centerline, during and after burst

Dominant processes:
- Ar + e → Ar\textsuperscript{*} + e
- H\textsubscript{2} + e → H + H + e
- H\textsubscript{2} + Ar\textsuperscript{*} → H + H + Ar
- H + H + M → H\textsubscript{2} + M

Radial diffusion

Radial distributions 500 \( \mu \)s after burst
Effect of Non-Equilibrium Plasmas on Premixed Combustion Chemistry

Goal: Examine the effects of non-equilibrium plasma on radical species concentrations in a 1D low-pressure flame/plasma chamber

- McKenna burner; Low-pressure 1D flame (20-30 Torr)
- Temperature and species vary with distance above burner
- Porous HV electrode (40 mm above burner) – no flow field disturbance (burner is ground)

- Peak voltage = 3 kV
- Duration (FWHM) = 170 ns
- Coupled energy ~ 1 mJ/pulse

- Peak voltage = -14 kV
- Duration (FWHM) = 7 ns
- Coupled energy ~ 3 mJ/pulse
Experimental Facility
OH Laser-Induced Fluorescence Measurements

Plasma On
(200 or 800 Pulses)

\[ \Delta t_{PL} \approx 8 \text{ us} \]

Laser Pulse

\[ \Delta t_p \approx 100 \text{ ms} \]

\[ \Delta t_L \approx 100 \text{ ms} \]
CH$_4$/O$_2$/N$_2$ FLAME CH$^*$ EMISSION ($\phi = 0.62$)

- PLASMA OFF
- PLASMA ON (FID; 40 kHz, 200 pulses)

Burner Surface: 2 mm
Temperature Measurements

Spatially-resolved temperature measurements using five-line OH thermometry

Discrete temperature data is fit to

\[ T = A + B[1 - \exp(C H_{AB} D)] + E H_{AB}^2 \]

\( H_{AB} = \text{Height Above Burner (mm)} \)
A-E are determined via least-squares fitting
OH Mole Fraction Measurements
Placed on quantitative scale with OH absorption measurements

Effect of Plasma on OH:
Most significant at low $\phi$

Ongoing Work:
Kinetic modeling of excess OH generation in the plasma

Future Work:
O atom Measurements
Discharge power (time-averaged, burst duty cycle 1/20): \( \approx 2.5\% \) of heat of combustion

Discharge power (during burst): \( \approx 50\% \) of heat of combustion

Both upper bound estimates (due to a large volume occupied by plasma)

Predicted temperature rise (\( \approx 150 \text{ K} \)) close to the experimental result

Modest temperature rise due to greater convection and conduction heat loss

Contribution of both Joule heating and electron impact processes into [OH] rise
PAC MURI 4-year milestone: main achievements

• Time-resolved electric field measurements in “diffuse filament” nsec pulse discharge in H₂, with sub-nsec resolution (4-wave mixing - CARS)

• Time-resolved electron density and electron temperature measurements in “diffuse filament” nsec pulse discharge in He (Thomson scattering); significant progress toward measurements in molecular gases

• Time-resolved T, N₂(v) (psec CARS), absolute [O], [N], and [NO] (TALIF / LIF) measurements in “diffuse filament” nsec pulse discharge in air, H₂-air, and C₂H₄-air; Kinetic modeling - dominant kinetic mechanism of NO formation in air and fuel-air plasmas

• Demonstration of use of a new experimental platform, well characterized “diffuse filament” transient reactor for time-resolved, spatially-resolved studies of low-T fuel-air kinetics

• Time-resolved, spatially resolved measurements of temperature (Rayleigh scattering), absolute [H] and [OH] (TALIF / LIF) in H₂-Ar and H₂-O₂-Ar; measurements in CH₄-O₂-Ar underway

• Spatially- and time-resolved temperature, absolute [OH] (LIF) measurements in lean low-pressure flames, with nsec pulse plasmas coupled directly to reaction zone: CH₄, C₂H₄, H₂ flames: quantifying effect of radicals on reaction zone location

• Considerable progress in development and validation of 2-D, nonequilibrium, reacting plasma chemistry / combustion chemistry model
PAC MURI 4-year milestone: plan for Year 5

- Stable plasma generation in preheated, high-pressure fuel-air mixtures: \( T_0 = 500-600 \text{ K}, \ P = 1 \text{ bar}, \ H_2 - \text{ air}, \ CH_4 - \text{ air}, \ C_2H_4 - \text{ air}, \ C_3H_8 - \text{ air} \) (Platforms 1 and 2)

- Time-resolved, spatially resolved temperature measurements (Rayleigh scattering), absolute [OH] measurements (OH LIF), absolute [O], [H] measurements (TALIF) in \( H_2, CH_4, C_2H_4, \text{ and } C_3H_8 \) mixtures, over a wide range of equivalence ratios (Platforms 1 and 2)

- Spatially- and time-resolved temperature absolute [O] measurements in lean low-pressure flames, with nsec pulse plasmas coupled directly to reaction zone: \( CH_4, C_2H_4, H_2 \) flames (Platforms 3)

- Time-resolved \( T, T_v(N_2), \text{ and } N_2 \) \( (X,v=0-12) \) population measurements (psec CARS, spontaneous Raman) in high energy loading nsec pulse discharges in \( H_2 - \text{ air and } C_xH_y - \text{ air} \)

- Time-resolved temperature measurements (purely rotational CARS) in air, \( H_2\text{-air, } C_2H_4\text{-air: explore possible effect of temperature on OH decay kinetics in nonequilibrium plasmas} \)

- Spatially resolved electric field measurements (4-wave mixing / CARS) in nsec pulse discharge in air, \( H_2 - \text{ air: collaboration with RUB group} \)

- Electron density measurements in reacting molecular gas mixtures (Thomson scattering)

- Further 2-D discharge / fuel-air plasma chemistry model development and validation over a range of pressures, equivalence ratios, for a larger set of fuels; reduced mechanism development
Collaboration: The whole is greater than the sum of the parts

MURI Teams

- **Penn State (Nick Tsolas and Rich Yetter):** Species concentrations measurements in a high-temperature, nonequilibrium plasma flow reactor / kinetic mechanism validation: complementary to OSU Platform I experiment

- **Georgia Tech (Sharath Nagaraja and Vigor Yang):** Kinetic modeling of repetitive nanosecond pulse discharges in air and H₂-air mixtures (OSU Platform I experiments); validation of 0-D analytic model of a plane-to-plane nsec pulse discharge

Outside MURI

- **AFRL (Cam Carter):** Absolute OH LIF calibration by Rayleigh scattering

- **Moscow State University (Nikolay Popov):** Kinetic modeling of rapid heating in high energy loading, nsec pulse discharges (OSU Platform III experiment)

- **High Temperature Institute, Russian Academy of Sciences, IVTAN (Sergey Leonov):** pulsed electric discharges for flow mixing enhancement, kinetics of vibrational energy transfer

New exciting project: Center for Exascale Modeling of Plasma Assisted Combustion (PSAAP-2, lead: U. Illinois at Urbana-Champaign)

- “Unlimited” computational firepower (1 exaFLOP = 10⁶ teraFLOPs = 10¹⁸ FLOPs)

- Great expectations: 3-D geometry, multiscale (space and time), 6-D full Boltzmann equation, non-local electron kinetics, plasma-surface interaction, complex plasma / combustion chemistry
Ohio State lead:


MURI collaborators lead:

