Laser-based diagnostics and their applications to LTP

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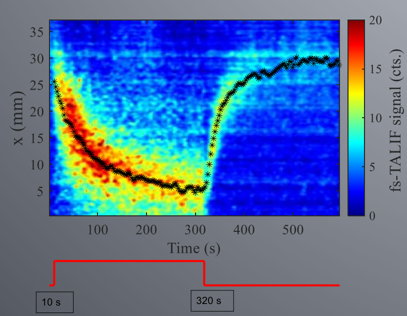
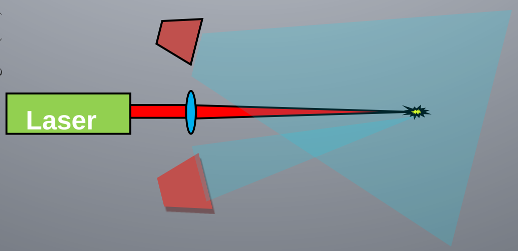
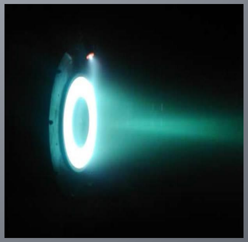
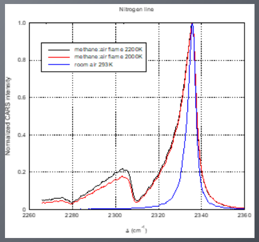
Online Low Temperature Plasma Seminar
MIPSE, August 18, 2020

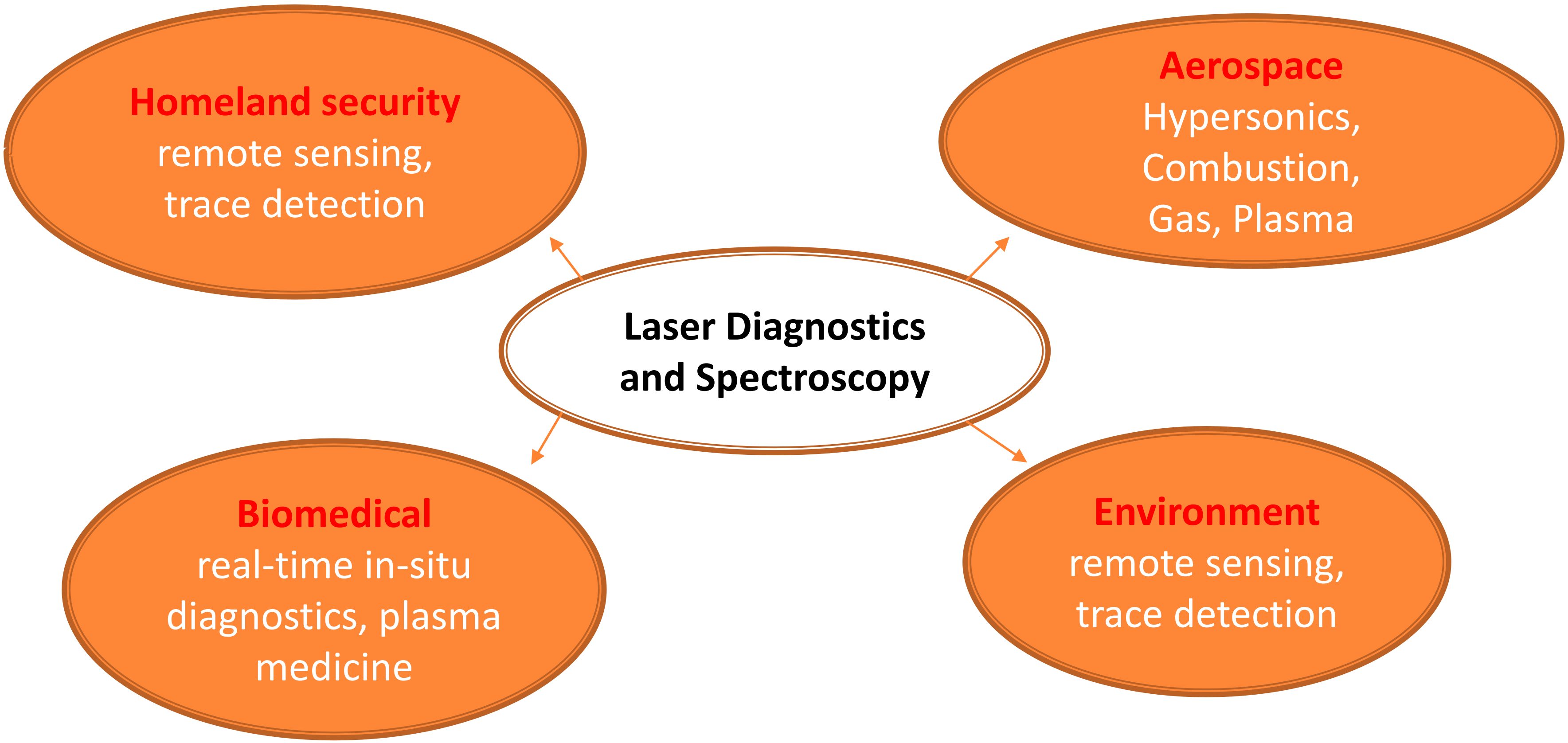








Optical diagnostics applications



Why *Optical* Diagnostics for Gases and Plasmas?

Desired properties

- Non-intrusive
- Standoff/Remote
- Single shot (real time)
- Fast repetition rate
- High temporal resolution
- High spatial resolution
- High sensitivity and specificity
- Imaging capability

Measurements

- Species
- Concentration
- Density
- Temperature
- Pressure
- Velocity
- E-, B-field

Outline: Optical Diagnostics

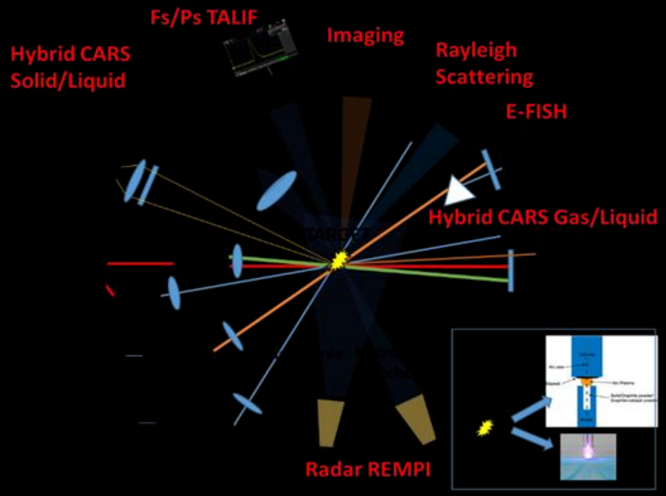
Ultrafast laser-based techniques

- **TALIF** (Two-photon absorption Laser Induced Fluorescence)

  (species, concentration, mapping, dynamics)
- Radar **REMPI** (Resonantly Enhanced Multi-Photon Ionization) – electron density, dynamics
- **FLEET** (Femtosecond Laser Electronic Excitation Tagging) – flow velocity, mapping, dynamics
- **CARS** (Coherent Anti-Stokes Raman Scattering spectroscopy) – species, concentration, temperature
- **E-FISH** (Electric field induced second harmonic generation) – electric field mapping, dynamics

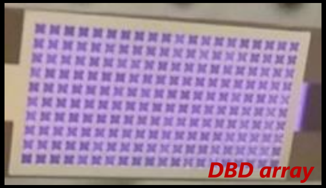
PPPL-Princeton Collaborative LTP Research Facility (PCRF)

Advanced *fs-ps-ns-cw* diagnostics of plasma species, flow, nanoparticles

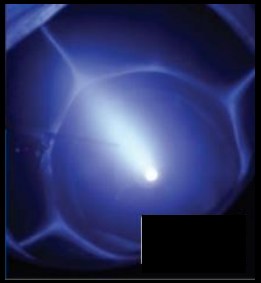


Plasma sources

- Atmospheric pressure plasma: DBD, jets, arcs

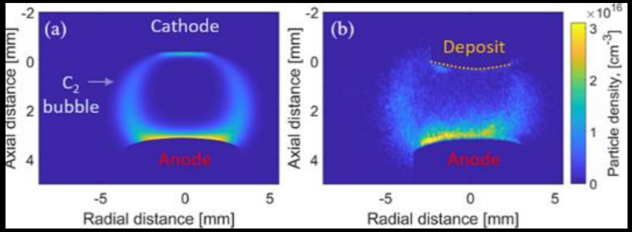


- Low pressure LTPs: magnetized, e-beam, DC/RF microscale

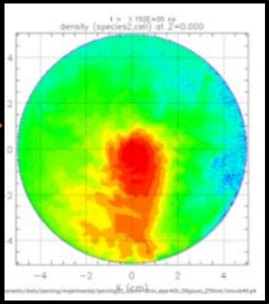


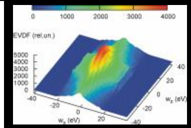
Unique measurements/simulations

- Plasmas with complex chemistry: *arc discharge* 2D CFD simulations (left) and LIF measurements (right)



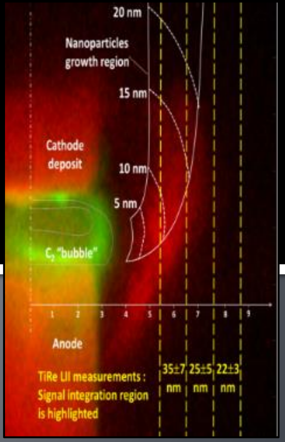
- 1D, 2D, 3D Kinetic simulations





EVDF

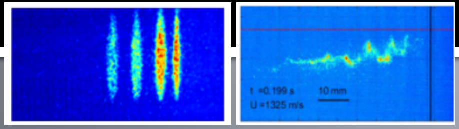
- Nanoparticles synthesis in arc: *modeling, OES and LII measurements*



PFC properties

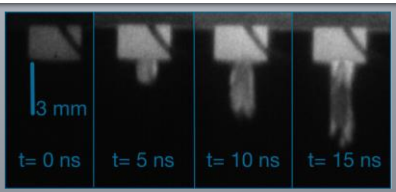
- *fs*- Laser Electronic Excitation Tagging flow measurements

Laminar flow *Turbulent flow*

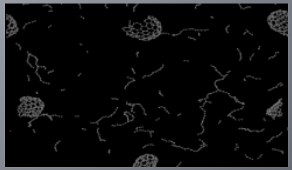


- ns-discharge in gas bubble

- Streamer in plasma jet



- Atomistic simulations

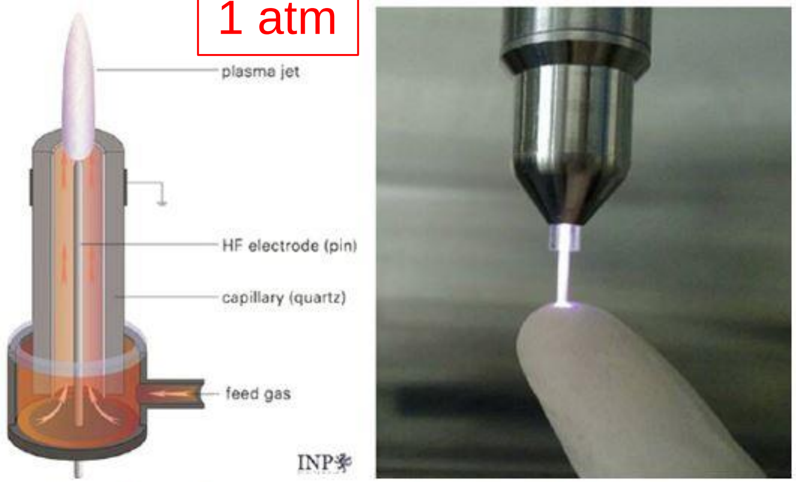


https://pcrf.pppl.gov/

https://pcrf.pppl.gov/facilities/advanced_diagnostics/index.html

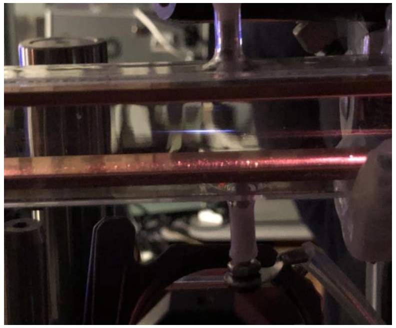
Plasma devices

1 atm



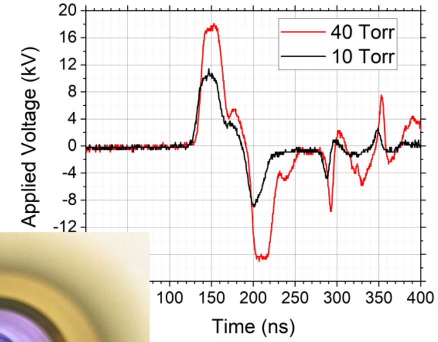
Schematic setup of the APPJ plasma source (left); original plasma jet (right) of the kINPen ® 09.

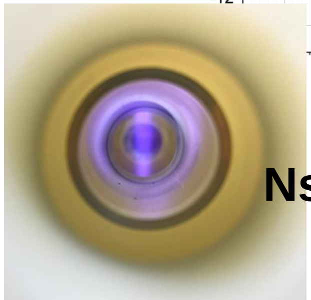
APPJ – atm pressure plasma jet



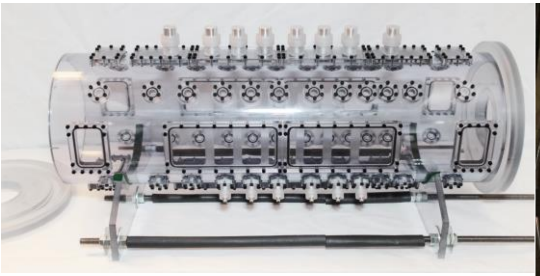
DBD – dielectric barrier discharge

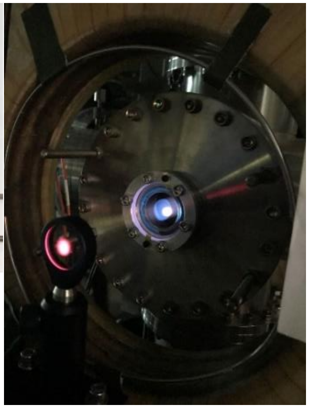
10^{-1} - 10^{-2} atm





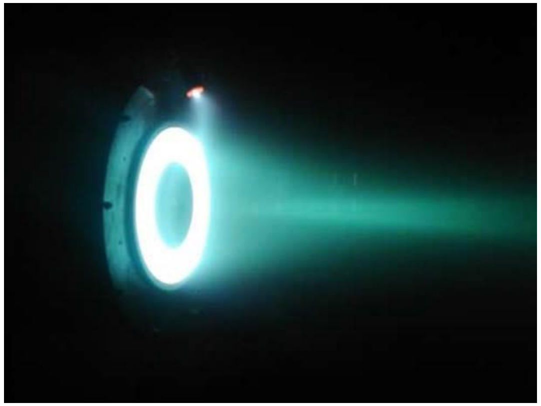
Ns discharge





Plasma mirror device

<10^{-5} atm



Hall thruster

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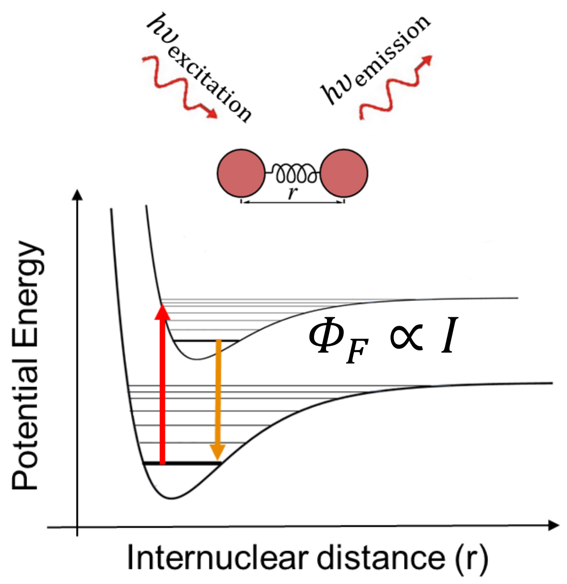
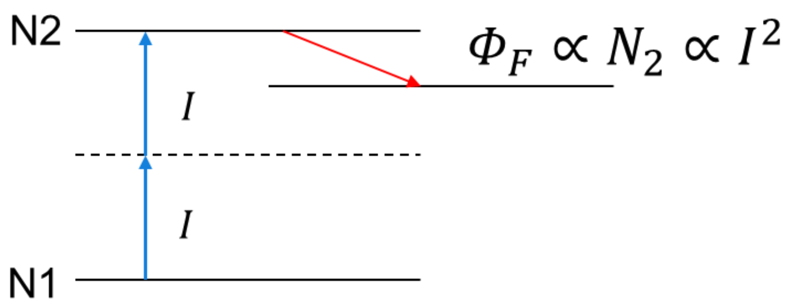
Laser Induced Fluorescence

- Spontaneous emission resulted from the **resonant** absorption of the laser radiation by atoms or molecules
- A two-step process: excitation-emission

Laser Induced Fluorescence (LIF)



Two-Photon Absorption Laser Induced Fluorescence (TALIF)



- Multiphoton transitions required for deep UV
- Two-photon transitions: easy to achieve with short pulse lasers.

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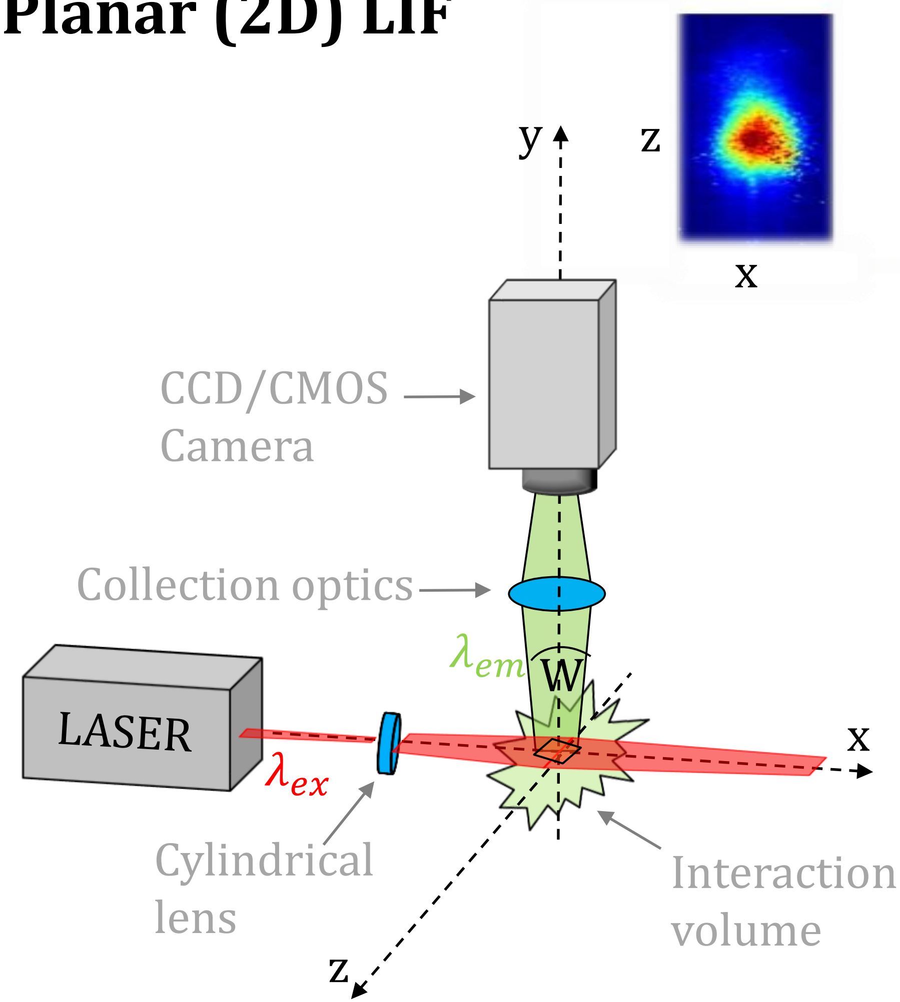
Typical Experimental Setup

Planar (2D) LIF



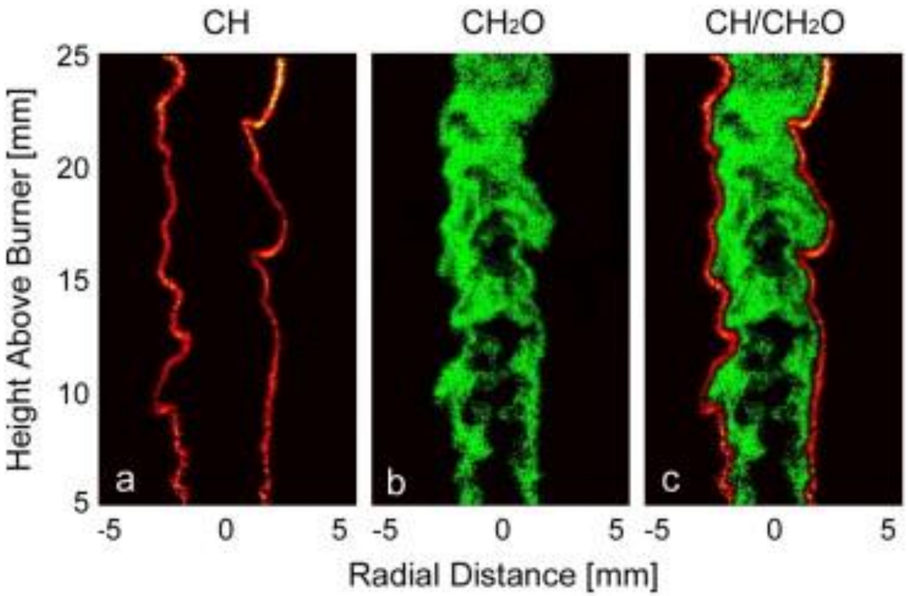
Recorded data

- Spatially resolved – 2D imaging
- Temporally resolved – gated intensifier

Measurements

- Species concentration
- Species composition
- Density
- Temperature
- Mixture fraction

Simultaneous multi-species via PLIF



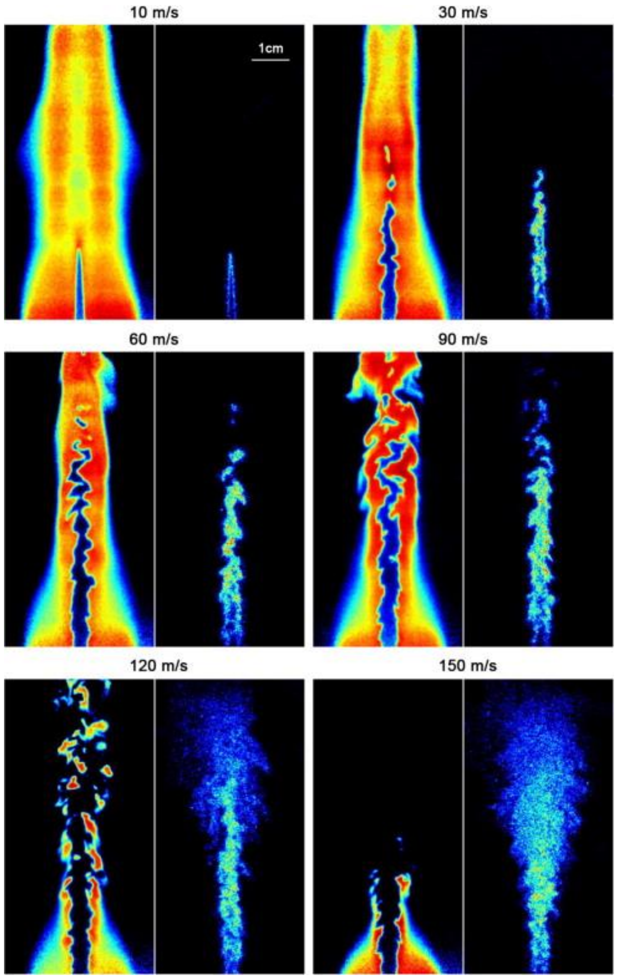
ELSEVIER

Combustion and Flame

Volume 157, Issue 6, June 2010, Pages 1087-1096

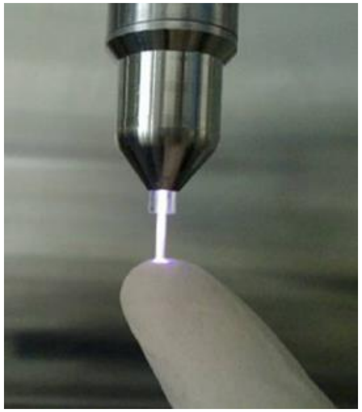
Turbulence and combustion interaction: High resolution local flame front structure visualization using simultaneous single-shot PLIF imaging of CH, OH, and CH_2O in a piloted premixed jet flame

Z.S. Li [a], B. Li [a], Z.W. Sun [a], X.S. Bai [b], M. Aldén [a]

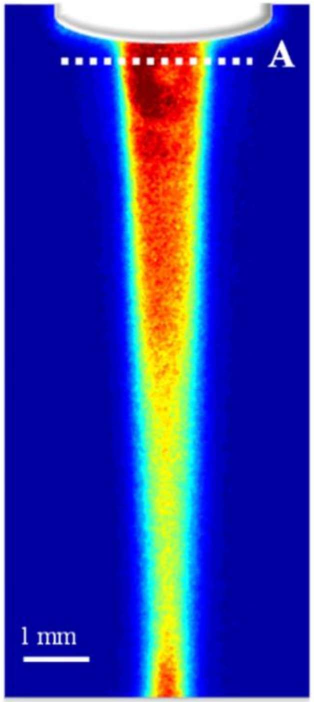


OH CH_2O

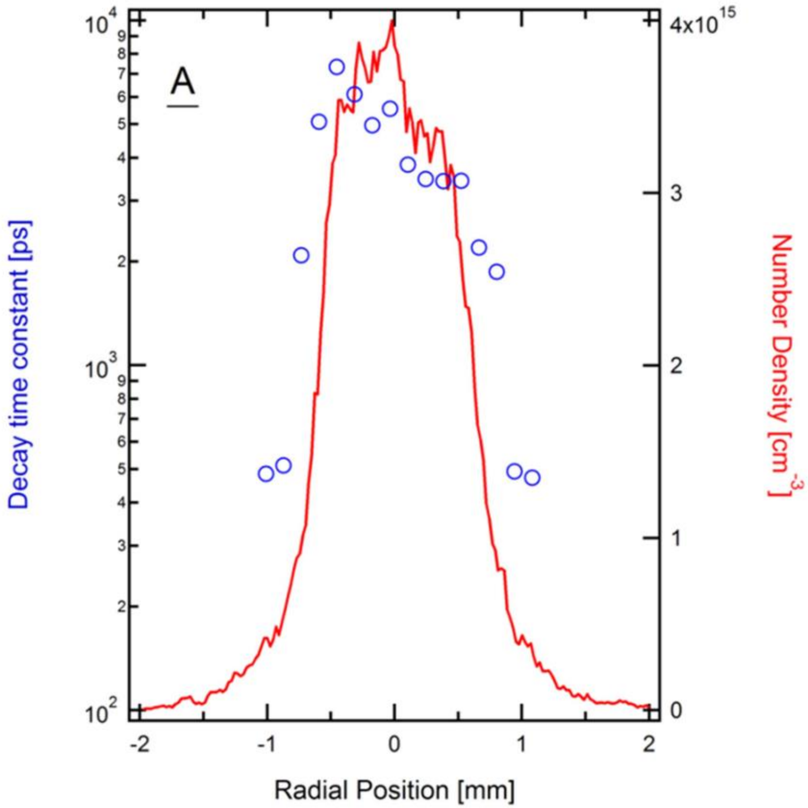
TALIF of O in an atmospheric pressure plasma jet (APPJ)



- Capillary dielectric barrier discharge
- Two-photon excitation at 226nm
- Emission at 845nm
- Calibration with Xe



O fs-TALIF
(3p $^2P_{1,2,0} \rightarrow$ 3s ^3S)



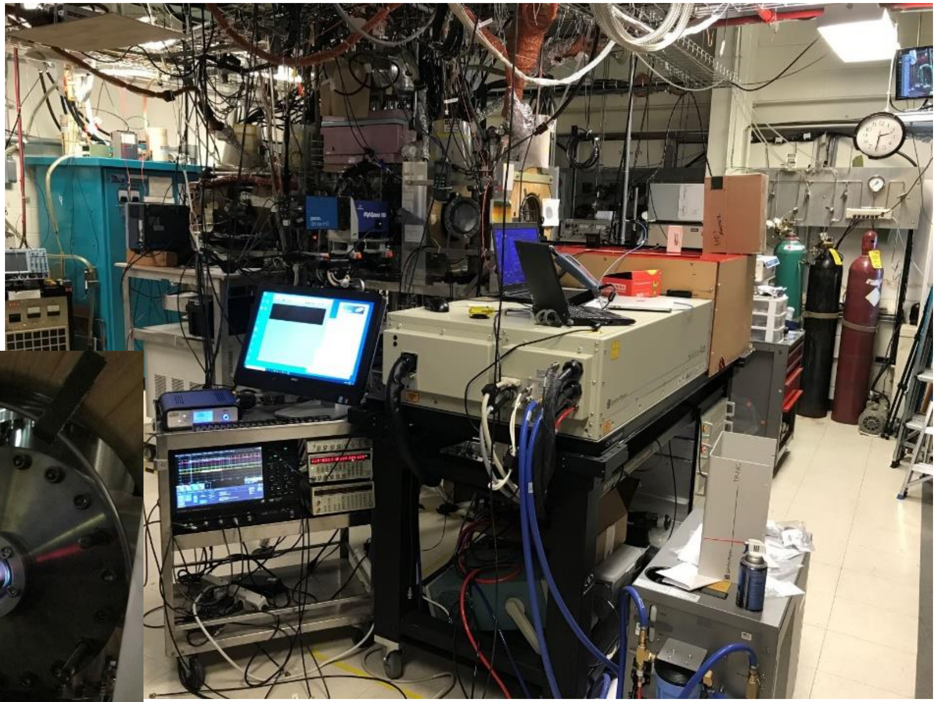
Atomic oxygen TALIF in a 2% O_2/He mixture APPJ

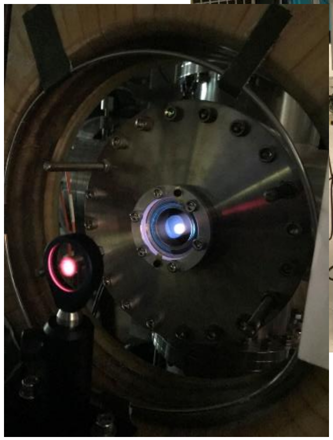
Schmidt *et al* 2017 *Plasma Sources Sci. Technol.* **26** 055004

Measurements of H density in RF helicon plasma

Goal: non-invasive measuring of neutral H concentration, dynamics of production and depletion under both steady state and pulsed RF plasma

- Quantify neutral density (H)
- Image the H density
- Time-resolve neutral concentration





Plasma mirror device for FRC (Field Reversal Configuration) – RF heating for quasi-steady state magnetized cylindrical plasmas *Sam Cohen group @PPPL*

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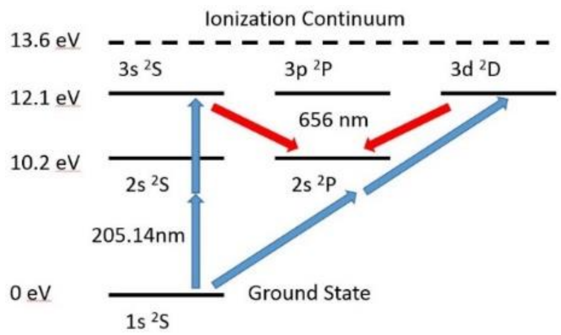
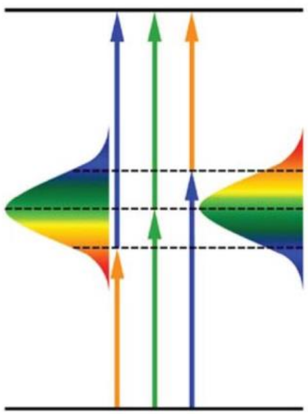
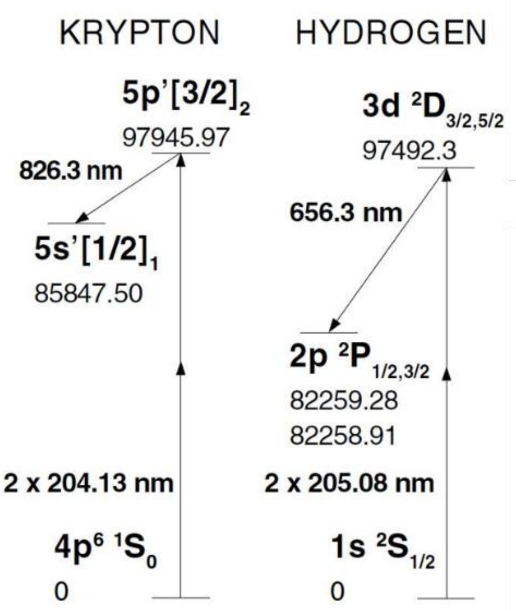
Femtosecond-TALIF in H

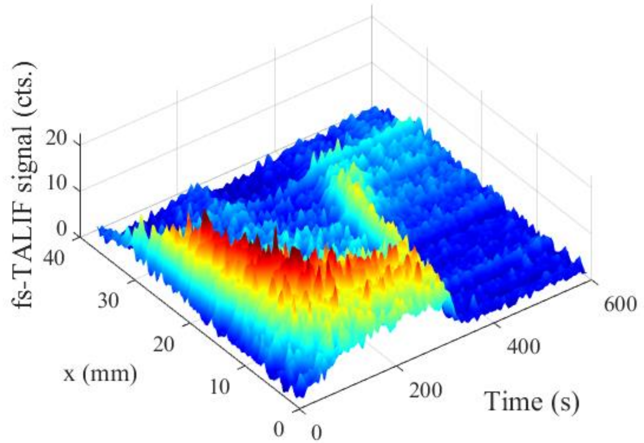


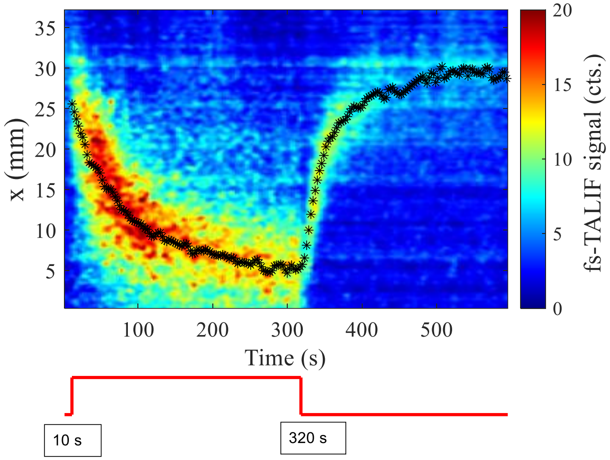


- Broadband two-photon excitation:
  - Very efficient (high intensity – fs)
  - Low energy per pulse
  - Fast excitation (no quenching)
  - kHz dynamics
- H pump at 205nm, record at 656nm
- Kr seeding for density calibration



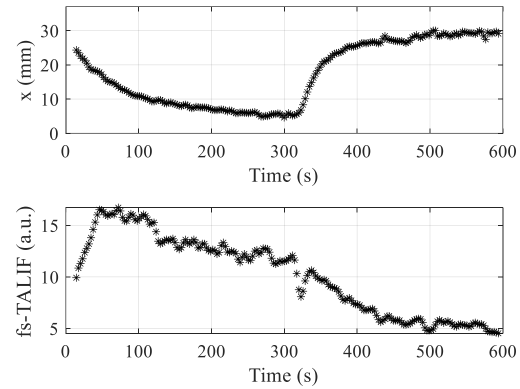
H-density dynamics – CW helicon plasma





Results

- Imaging H density as low as 10^{11} cm^{-3}
- Neutral density spatial distribution dynamics
- H lifetime in facility under CW plasma



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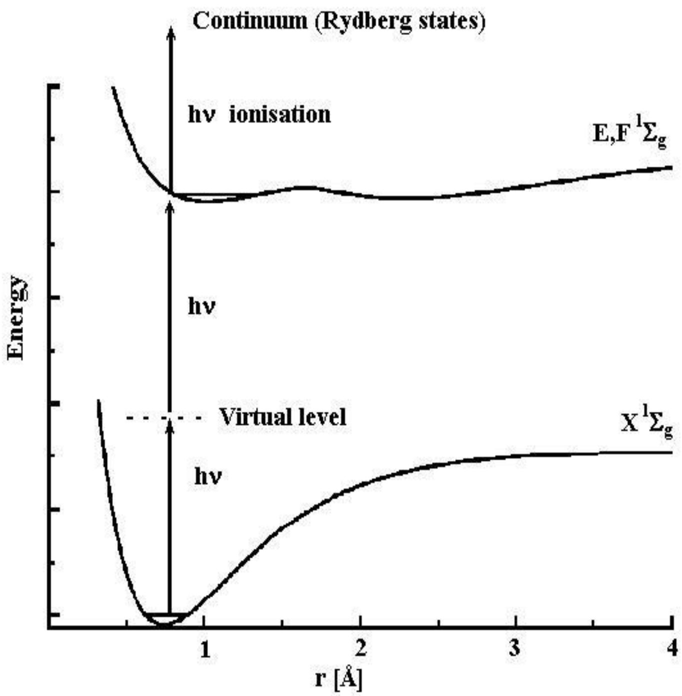
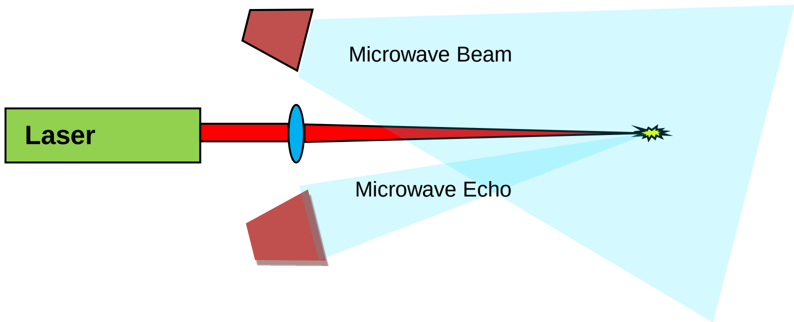
REMPI
Resonantly Enhanced Multi-Photon Ionization

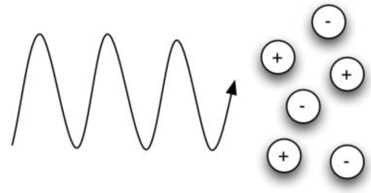
REMPI – highly selective spectroscopic technique

- An intense laser pulse ionizes the atom and creates charges/plasma.
- Detection requires electrodes or ion mass spectroscopy.



Radar REMPI – detection via microwave scattering

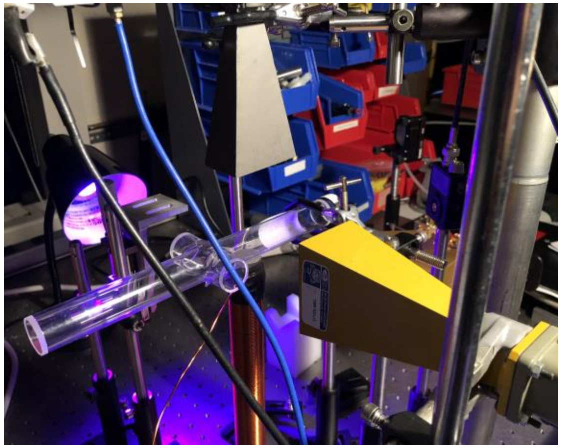




M. Shneider and R. Miles, "Microwave Diagnostics of Small Plasma Objects," J. Appl. Phys. ***98****, 0033301-1 – 033301-3 (2006).*

Radar REMPI -*The focused laser creates a small region of ionization which scatters the microwaves. Signal – proportional to plasma density.*

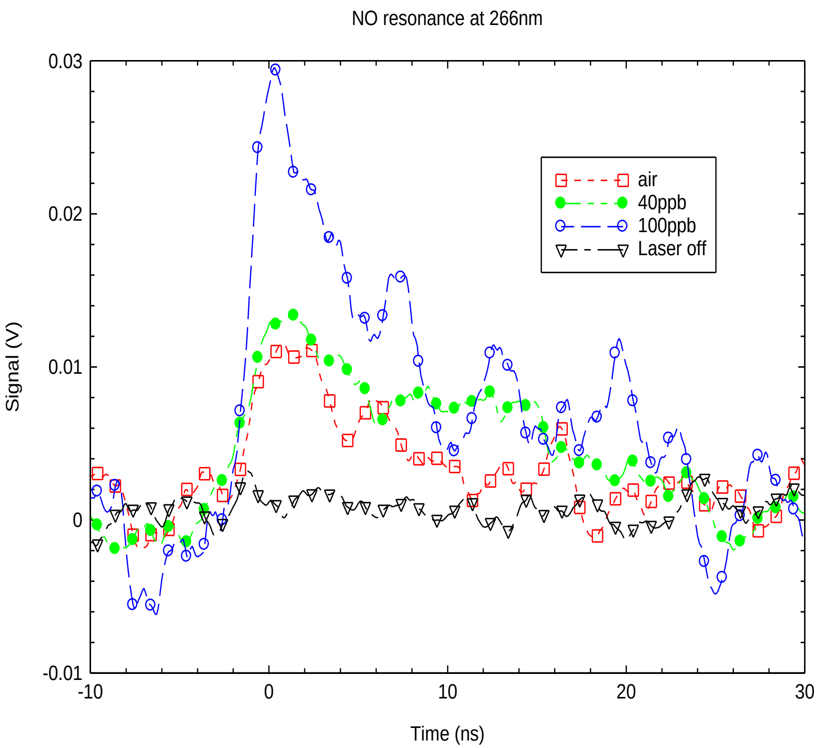
- Selectivity and sensitivity: independent!
  - Selectivity: laser wavelength ($\Delta\lambda \approx$ cm^{-1})
  - Sensitivity : microwave detection
- Truly standoff – backscattering detection
- Non-intrusive, localized (laser spot)
- No daylight optical interference
- Bonus: sub-nanosecond temporal resolution!

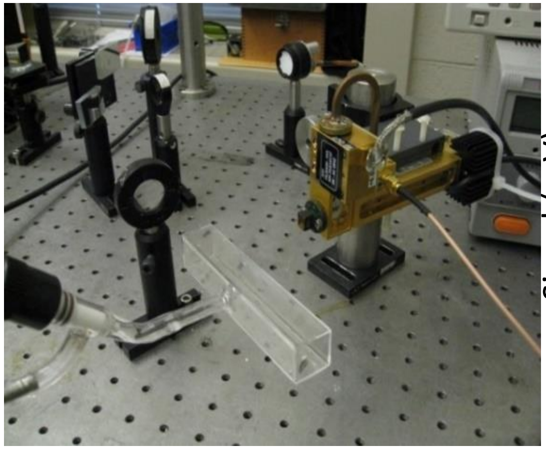


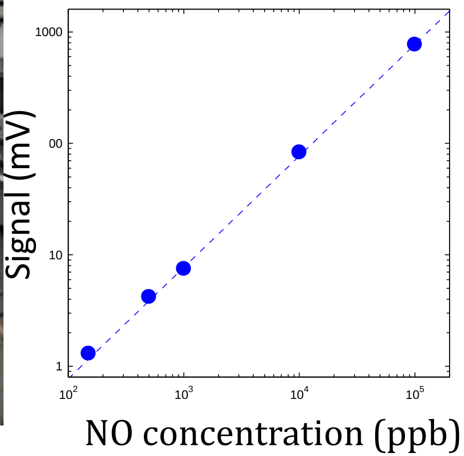
Enables - Direct measurement of plasma density and of electron dynamics in air
- Gas species, density and temperature, nanoparticle charge, negative ions

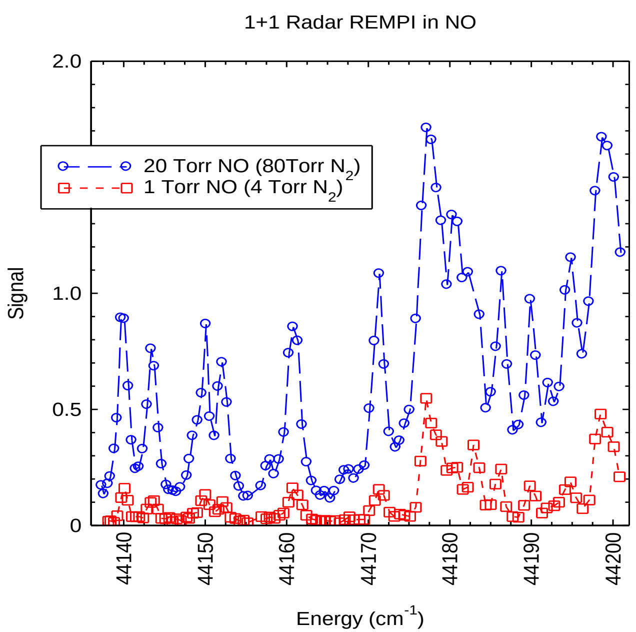
Radar REMPI for Trace Species Detection

- Linearity from ppm to ppb
- High temporal resolution
- NO detection sensitivity: ~ ppb









A. Dogariu and R. B. Miles, "Detecting localized trace species using Radar REMPI," Appl. Opt. ***50****, A68 (2011)*

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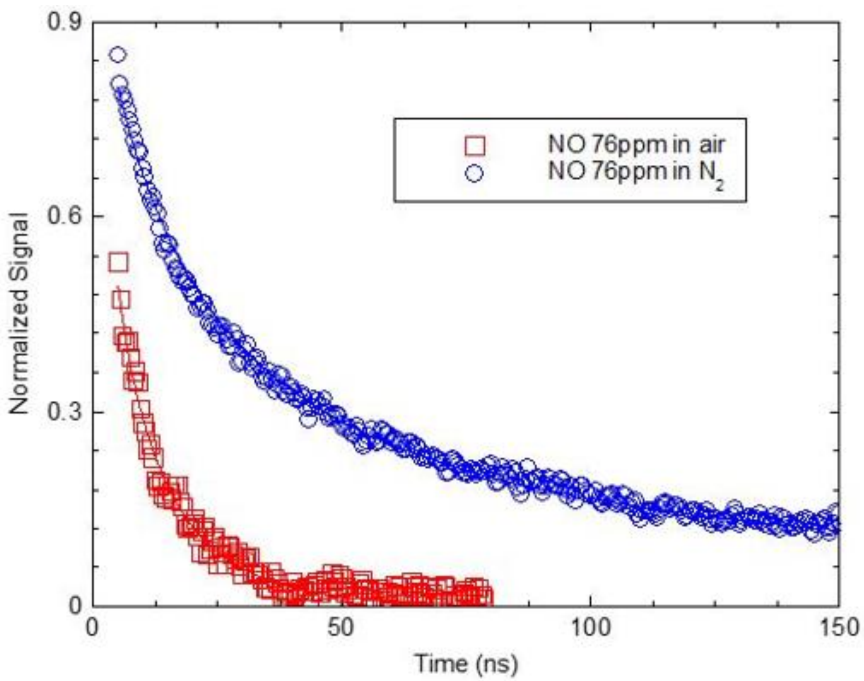
Direct measurement of electron dynamics in air

recombination

attachment

$$\frac{\partial N}{\partial t} = -\nu_a N - \beta N^2$$



1. NO in N_2 - recombination only

$$N(t) = \frac{N_0}{1+\beta N_0 t}$$ $N_0 = 2.5x10^{14}\ cm^{-3}$

Electron density measurement!

2. NO in air - recombination and attachment

$$N(t) = \frac{N_0 e^{-\nu_a t}}{1 + \frac{\beta N_0}{\nu_a}\left(1 - e^{-\nu_a t}\right)}$$ $\upsilon_a = 0.76x10^8\ s^{-1}$

Electron attachment rate measurement!

Theoretical prediction $\nu_a \cong 0.8 \cdot 10^8 s^{-1}$

Dogariu et. al, Appl. Phys. Lett. 103, 224102 (2013)

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Electron density and its dynamics in atmospheric pressure plasma jet (APPJ)

APPLIED PHYSICS LETTERS **96**, 171502 (2010)

Temporary-resolved measurement of electron density in small atmospheric plasmas

A. Shashurin,[1,a)] M. N. Shneider,[2] A. Dogariu,[2] R. B. Miles,[2] and M. Keidar[1,a)]
[1]*Department of Mechanical and Aerospace Engineering, School of Engineering and Applied Science, The George Washington University, Washington DC 20052, USA*
[2]*Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey 08544, USA*

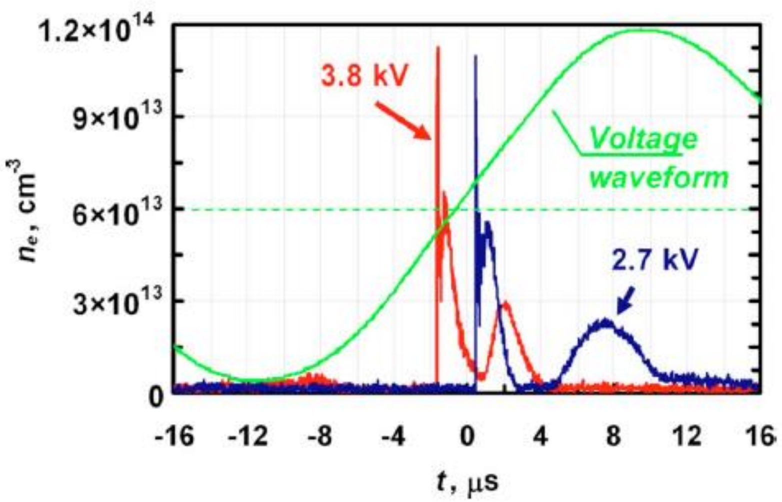

FIG. 4. (Color online) Temporal evolution of average plasma density in atmospheric plasma jet for U_{HV}=2.7 and 3.8 kV.

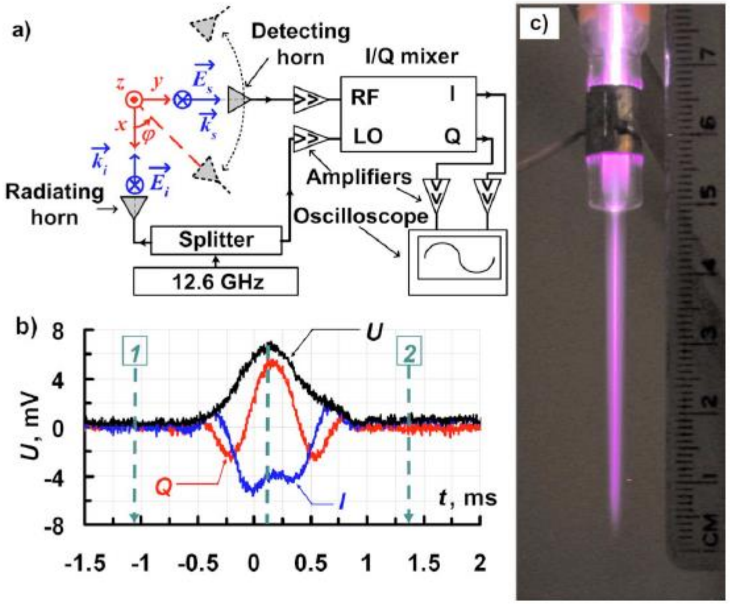

FIG. 1. (Color online) (a) The schematics of RMS experimental setup. (b) Typical scattering signals measured by RMS setup induced by calibrator bullet flying over the microwave horns along *z*-axis [in-phase (*I*) and quadrature (*Q*) components, and total amplitude of output signal *U*]. Teflon bullet of 8.5 mm length and 3.2 mm diameter was used. (c) Typical image of plasma jet for U_{HV}=3.8 kV, He flow of 15 1/min.

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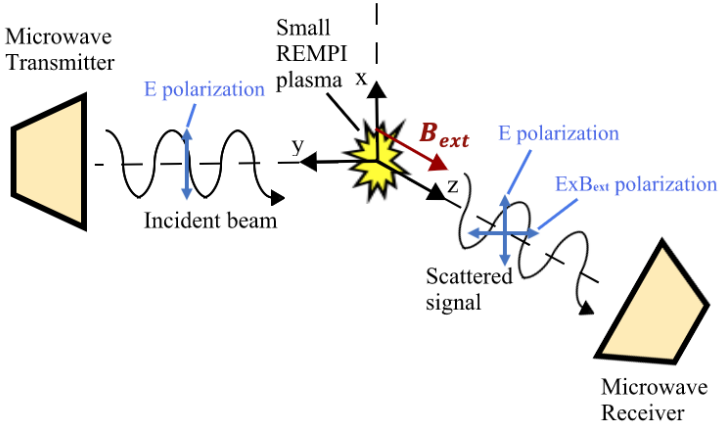
Radar REMPI for Hall Thrusters

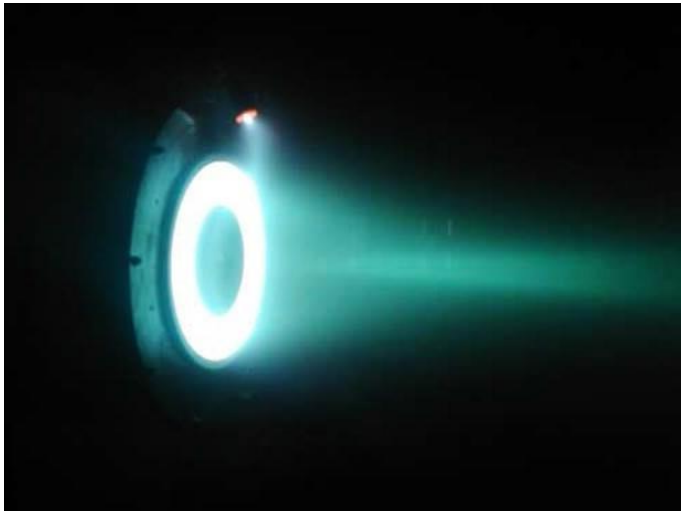
- Neutral xenon density and temporal dynamics measurements in Hall thrusters (sub-ns resolution)
- Use 2+1 REMPI in Xe:He mixtures at <1 Torr

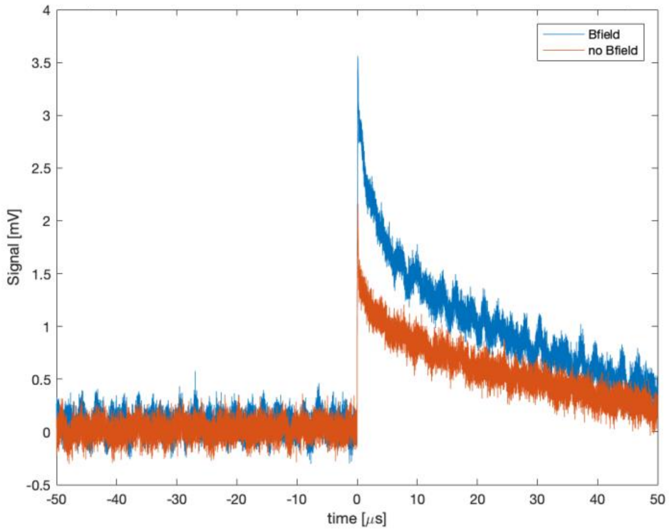
New effect: Radar REMI allows magnetic field measurements via depolarization of microwave scattering!



C.A. Galea, M.N. Shneider, A. Dogariu, and R.B. Miles, "Magnetically induced depolarization of microwave scattering from a laser-generated plasma," Phys. Rev Appl. ***12****, 034055 (2019).*

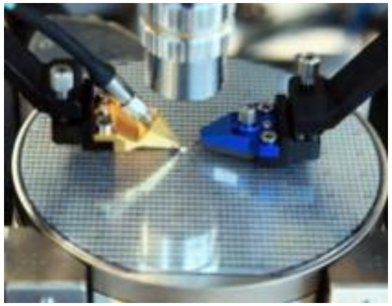
2 kW Hall thruster at PPPL

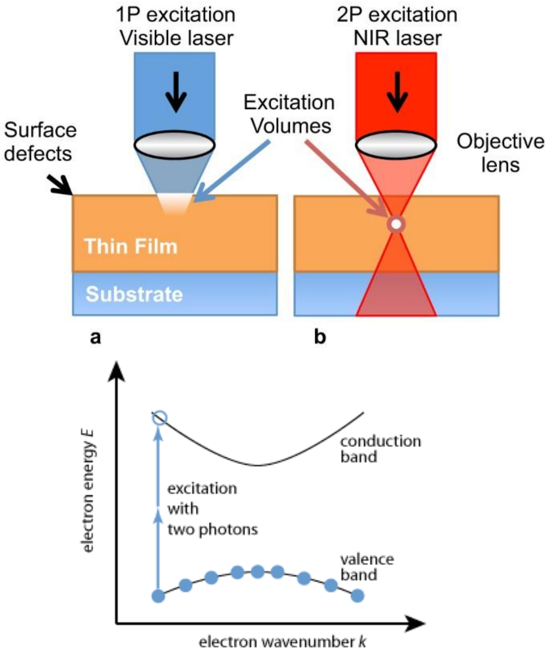


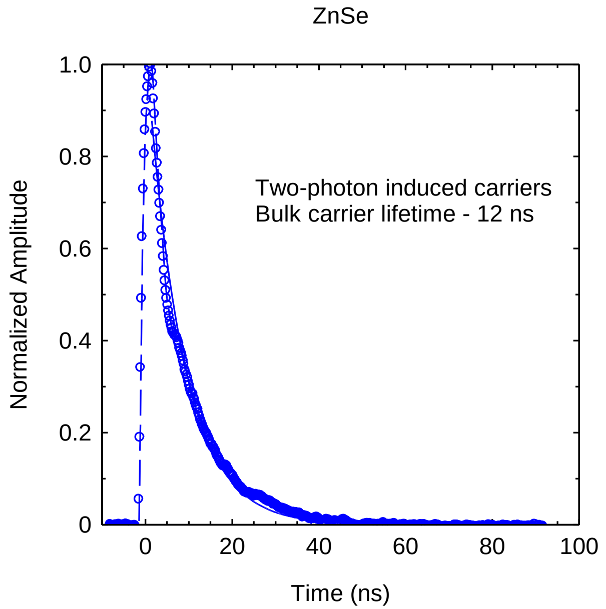


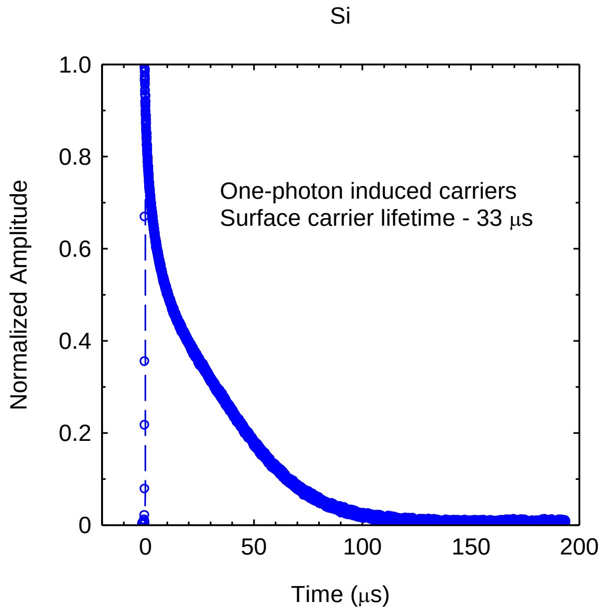
Radar REMPI for semiconductors

- Capability to monitor the doping profile in semiconductors as an *in-situ* alternative to SIMS (Secondary Ion Mass Spectroscopy, *ex-situ*)
- Real-time localized measurements of carrier density, lifetime, bandgap
- Single photon (above bandgap) – surface
- Two photon (below bandgap) – bulk







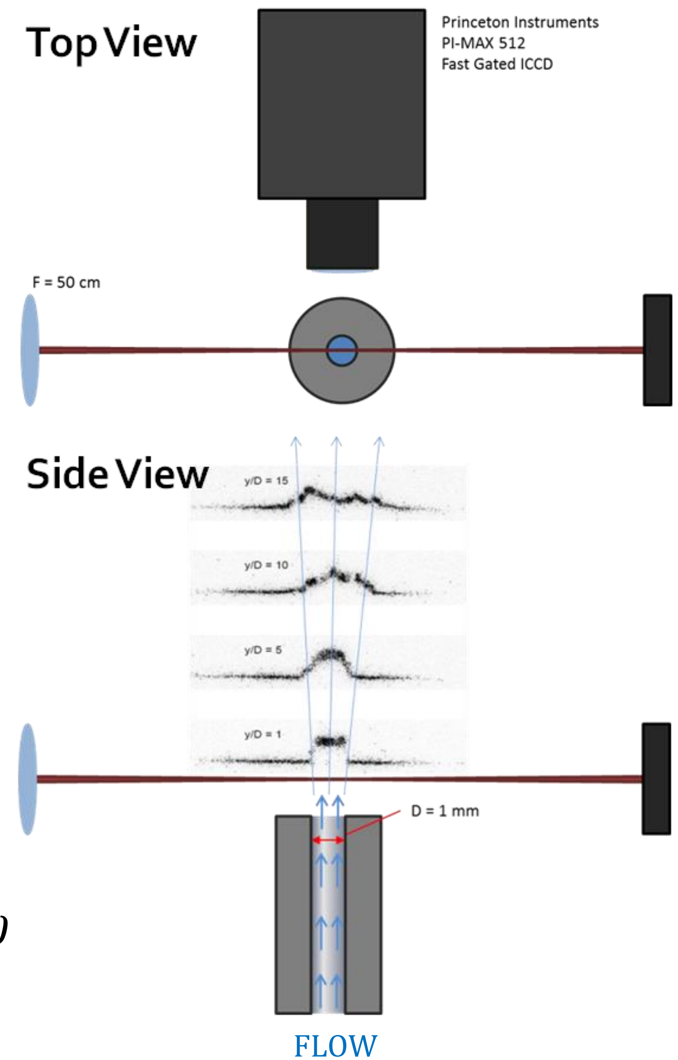


Patent US7728295 - Method and apparatus for detecting surface and subsurface properties of materials (2010)

FLEET: A new molecular tagging diagnostic

Femtosecond **L**aser **E**lectronic **E**xcitation **T**agging

- Based on tagging nitrogen for unseeded flow velocimetry in gases and plasma
- Time of flight measurement based on delayed imaging

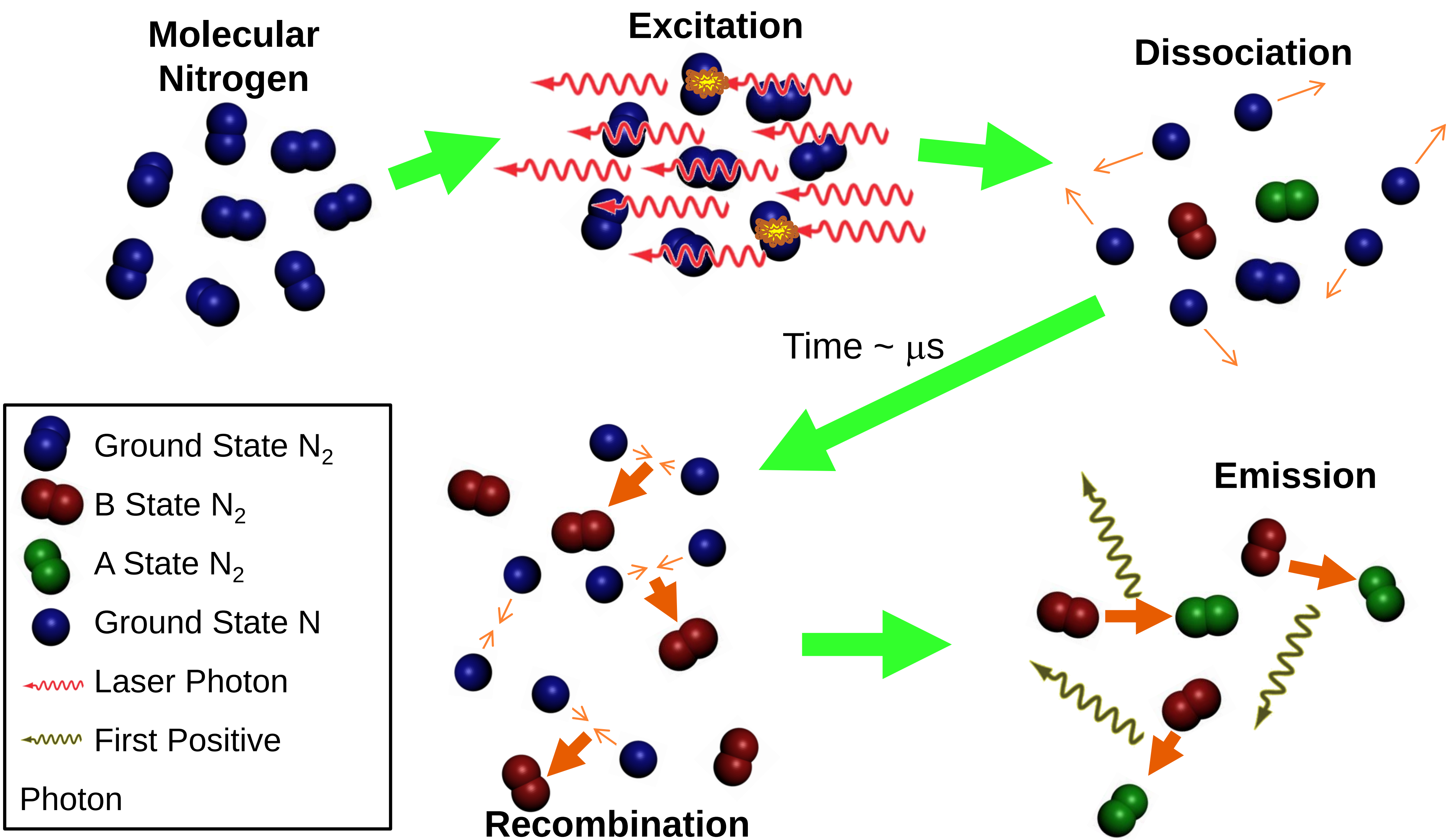


Femtosecond laser electronic excitation tagging for quantitative velocity imaging in air, Appl. Opt. 50, 5158-5162 (2011)

Patent US9863975 - Femtosecond laser excitation tagging anemometry (2018)

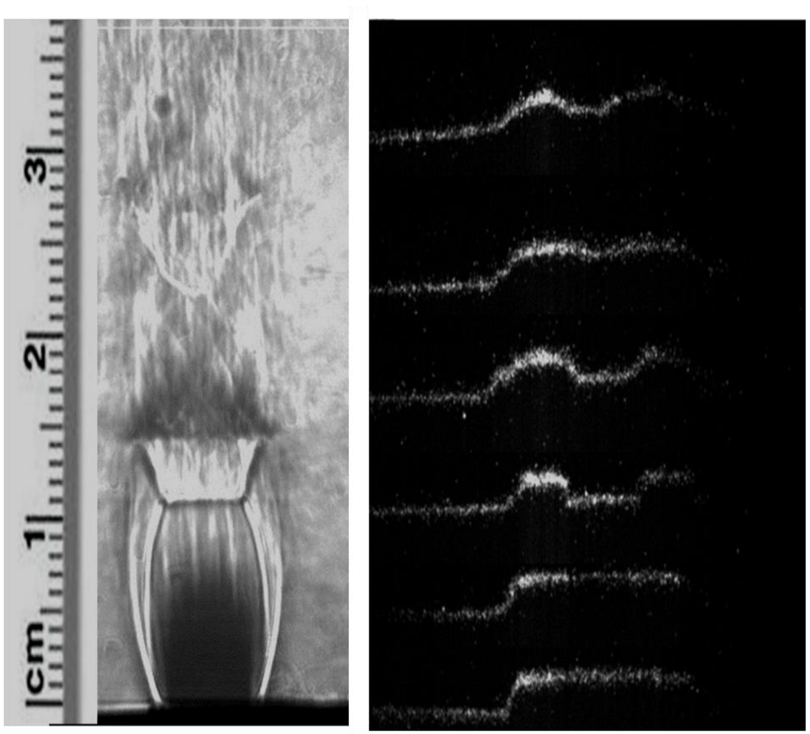
Princeton University

Mechanism for FLEET



FLEET Velocimetry - Capabilities

Schlieren FLEET



Underexpanded sonic jet

- Unseeded air or nitrogen flows (gases and plasmas)
- Single shot measurements (kHz)
- High spatial resolution (tens of microns)
- High dynamic range (m/s to km/s)
- Pressure range: from <1 Torr to >> 1 atm
- Any gas temperature

FLEET applications to hypersonic flows

Hypersonic vehicles (Mach >5)

SCRAMJET engines (supersonic RAM)

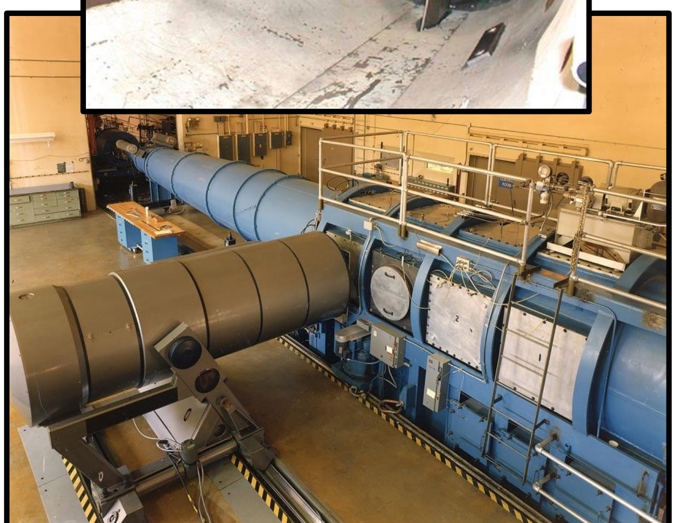
- NASA X43 (Mach 9, 2004)
- AFRL X51 (Mach 7, 2013)
- Lockheed SR-72 (Mach 6, 2018)

SR-72

Lockheed Martin SR-72 rendering

Princeton University

Hypersonic Wind Tunnel 9, AEDC White Oak, MD



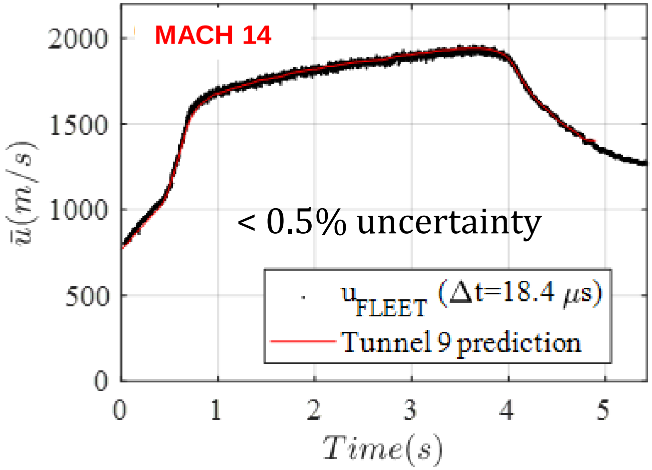
Optical diagnostics for hypervelocity flows

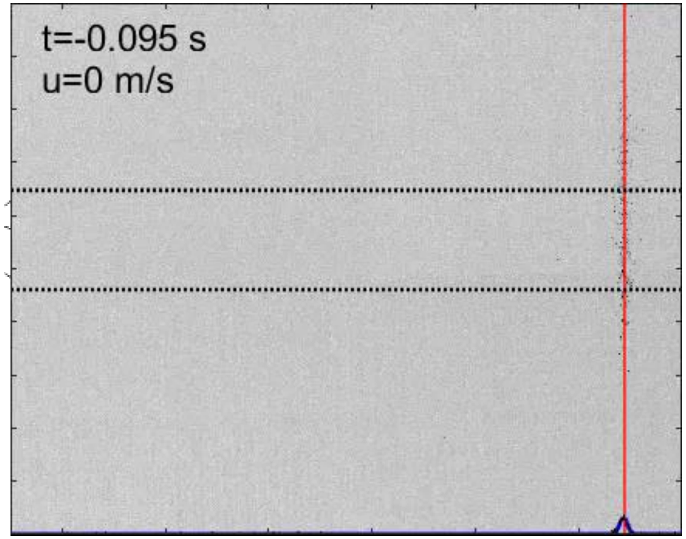
- Hypersonic wind tunnel: Nitrogen flow
- Run time: ~1-3 seconds!
- Simultaneous measurements:
  - FLEET (flow velocity mapping)
  - CARS (vibrational temperature)
- 2016-2018 MACH 10 – 14
- 2019-2020 MACH 18

Photos courtesy of AEDC

FLEET for Hypersonic Flow Velocimetry

FLEET measurements vs Tunnel 9 prediction





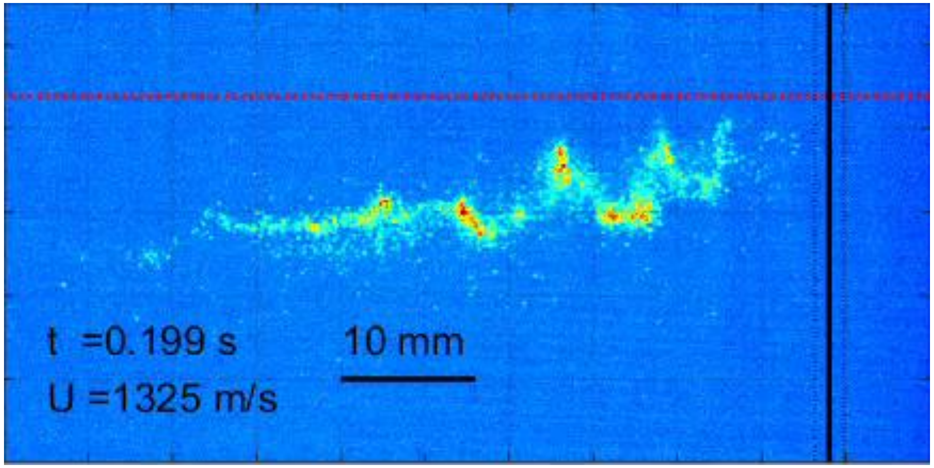
First direct flow measurements in Tunnel 9!

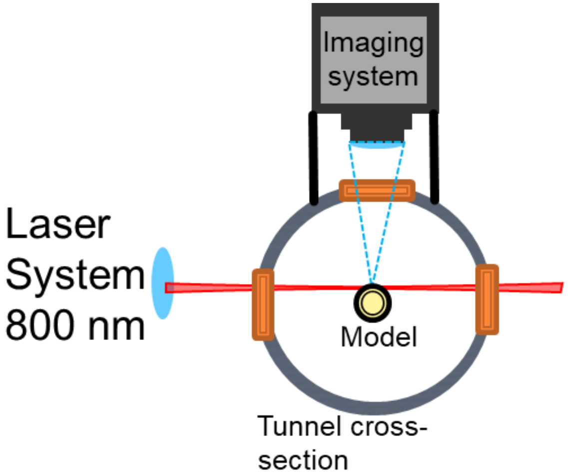
AEDC Air Force Hypersonic Facility

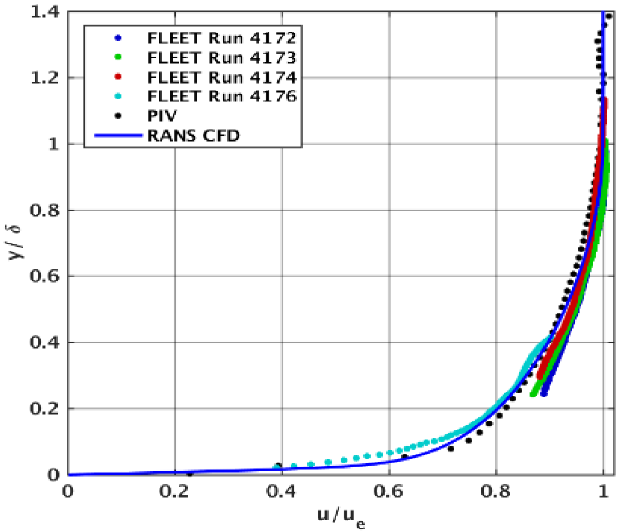
2017-2018 – Mach 10 and Mach 14
2019-2020 – Mach 18

Princeton University

FLEET in Boundary-Layer Flow



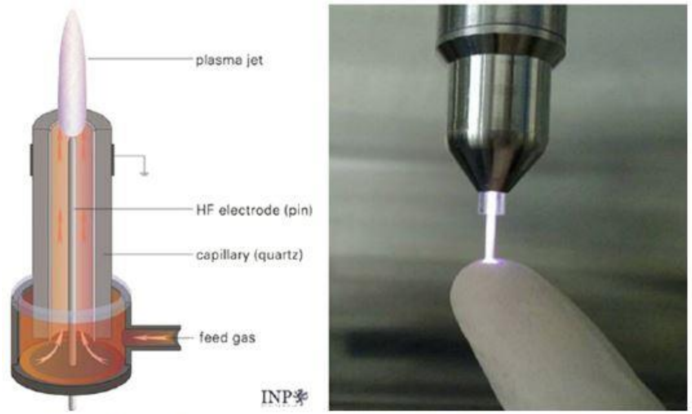




Dogariu et al., "Hypersonic Velocity Measurements in Large Scale Wind Tunnel Using FLEET", AIAA Journal 57, 4725 (2019)

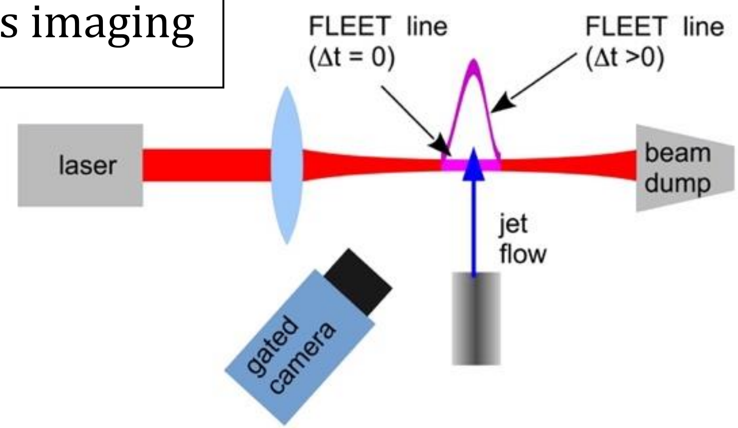
Princeton University

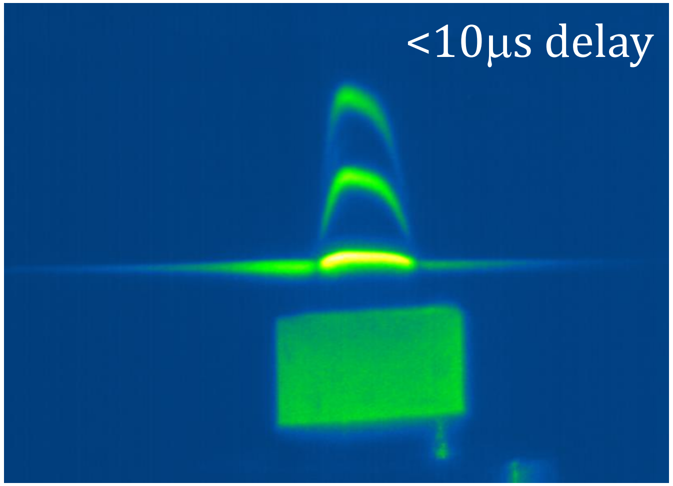
FLEET in Atmospheric Pressure Plasma Jet (APPJ)



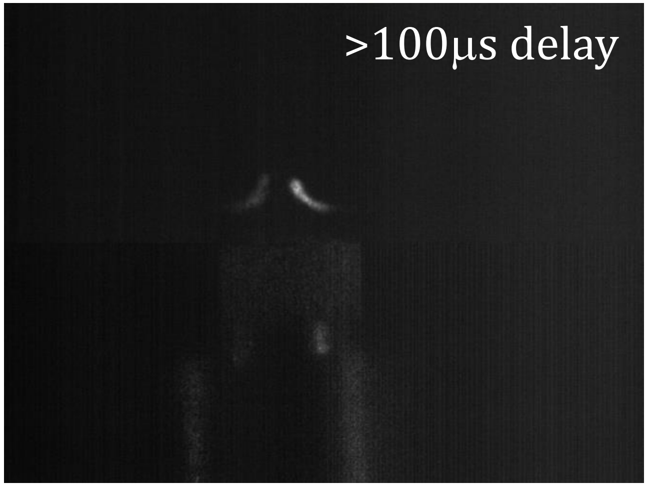
Schematic setup of the APPJ plasma source (left); original plasma jet (right) of the kINPen ® 09.

- Flow velocimetry
- 2D species imaging





Argon flow velocity mapping

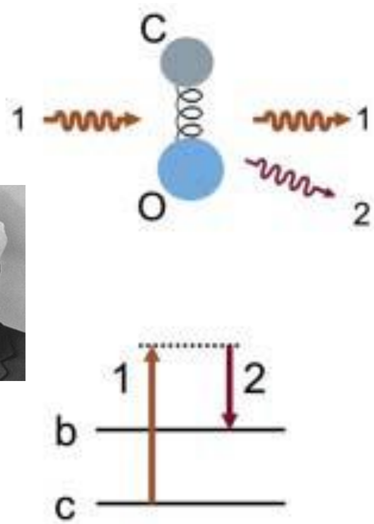


Nitrogen (entailed air) flow velocity mapping

Princeton University

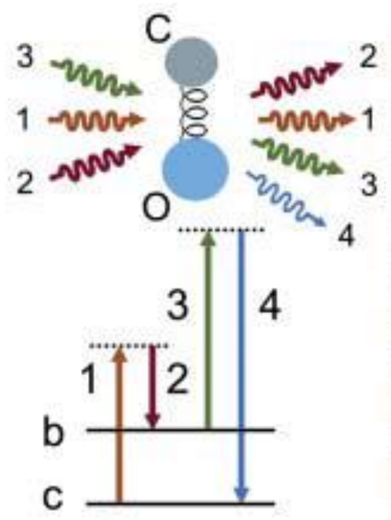
Coherent Anti-Stokes Raman Scattering (CARS)

Spontaneous Raman



- High specificity identifying nuclear vibrations
- High spectral resolution

- Low conversion efficiency
- Non-directional
- Background - fluorescence



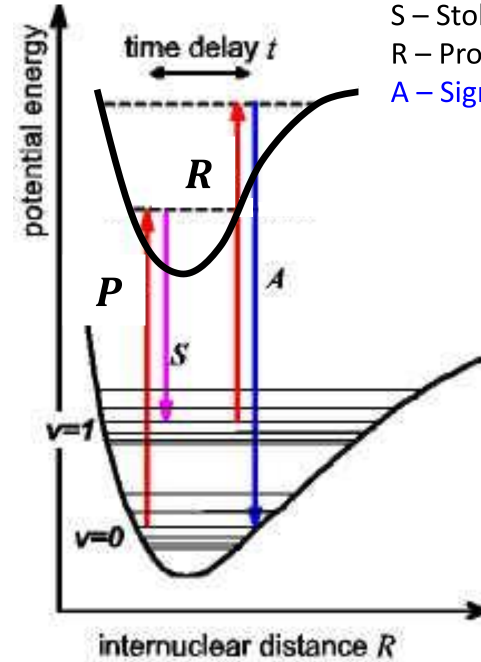
Maker and Terhune, Ford Motor Company, 1965

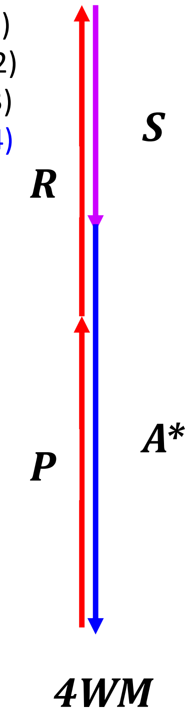
- Can achieve Raman spectral resolution
- High efficiency (10^9 higher)
- Directionality (phase-matching)

- Background – nonresonant contributions

CARS

P – Pump (1)
S – Stokes (2)
R – Probe (3)
A – Signal (4)





Problem: The CARS signal (A) is hindered by the background four-wave mixing (4WM) signal (A*).

Solution: Minimize non-resonant contribution using polarization, heterodyne, interferometric, **time-delayed techniques**.

Hybrid CARS - background free

Optimizing the Laser-Pulse Configuration for Coherent Raman Spectroscopy
Dmitry Pestov, *et al.*
Science **316**, 265 (2007);
DOI: 10.1126/science.1139055

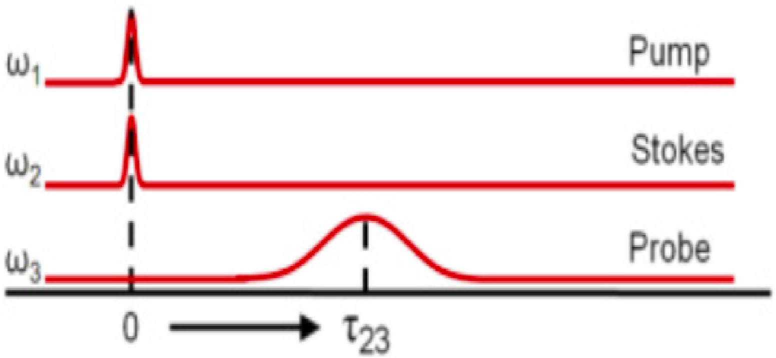
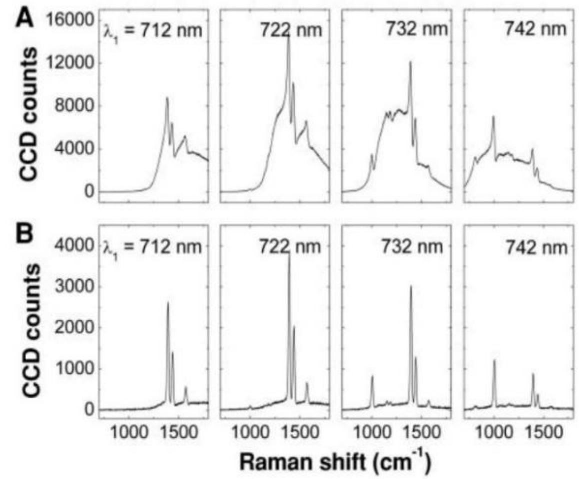


Fig. 3. Cross sections of the CARS spectrograms from Fig. 2 for two probe delays, (**A**) 0 ps and (**B**) 1.5 ps. The wavelengths within the observed range were transferred into the Raman shift, relative to the probe central frequency. The integration time was 1 s: 0.5 s for the signal and 0.5 s for the background acquired for the delayed Stokes pulse. The absolute frequencies of the Raman transitions in NaDPA, observed in the CARS experiment and spontaneous Raman measurements, are summarized in Table 1. CCD, charge-coupled device.



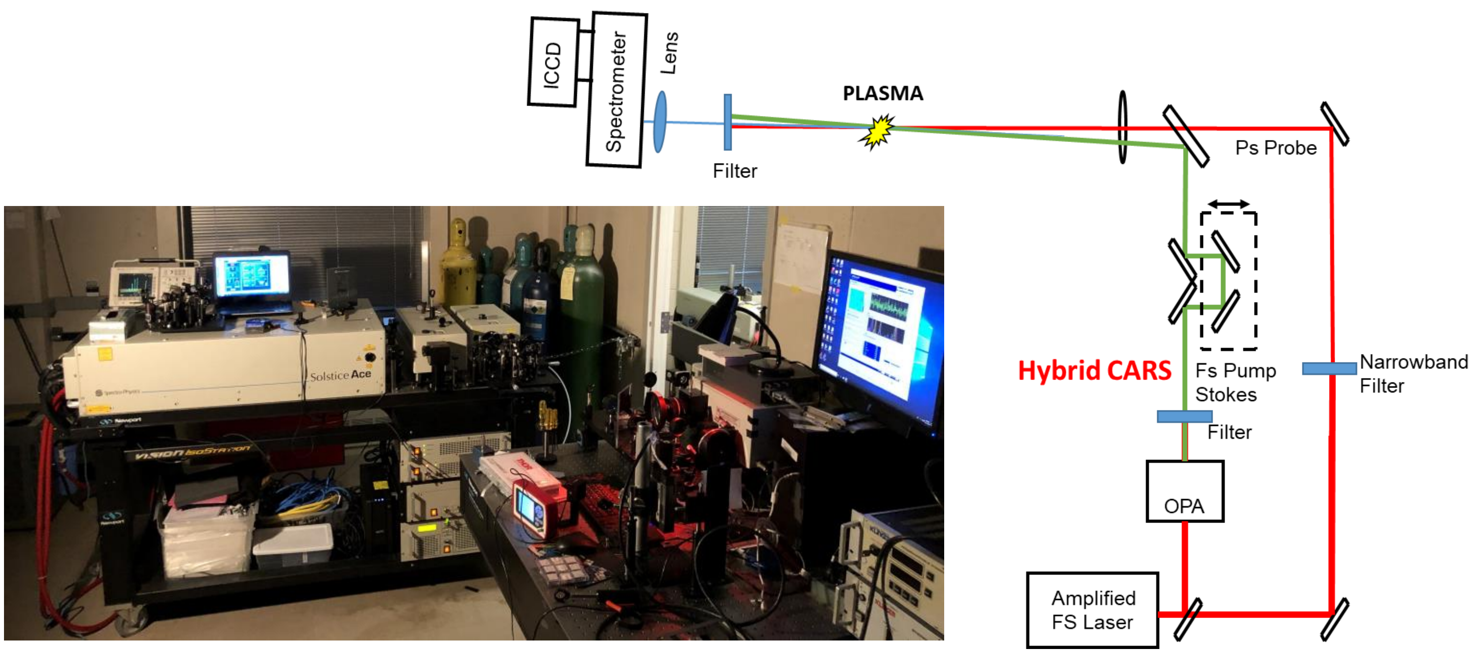
13 APRIL 2007 VOL 316 SCIENCE www.sciencemag.org

- Femtosecond pumping – allows broadband excitation, single shot spectroscopy
- Picosecond probing – narrowband probe provides spectral resolution
- Delay eliminates background
- kHz repetition rate

- *“Optimizing the Laser-Pulse Configuration for Coherent Raman Spectroscopy,” Science 316, 256 (2007).*
- *“Real-time detection of bacterial spores using Coherent anti-Stokes Raman Spectroscopy,” J. Appl. Phys. **103**, 036103 (2008).*
- *“Real-time monitoring of blood using coherent anti-Stokes Raman spectroscopy,” J. Biomed. Opt. **13**, 54004 (2008).*
- *“Coherent Anti-Stokes Raman Spectroscopy for detecting explosives in real-time,” Proc. SPIE, 8358-27 (2012).*

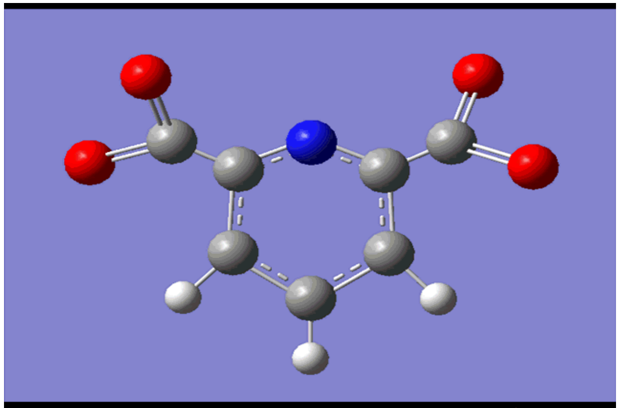
Hybrid CARS applications

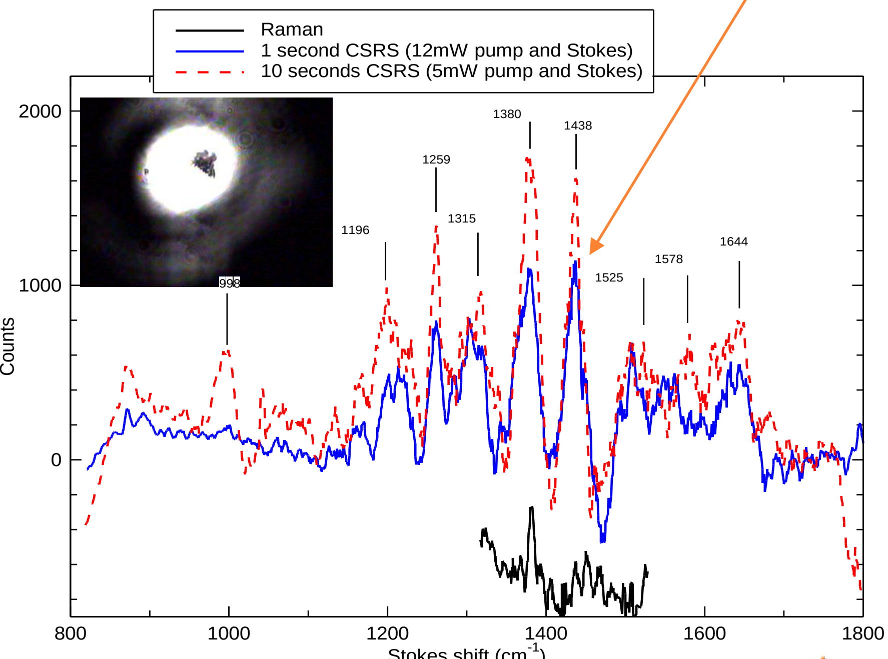
- Gas density and temperature measurement
- Solid/liquid molecular composition
- Surface changes under plasma interaction

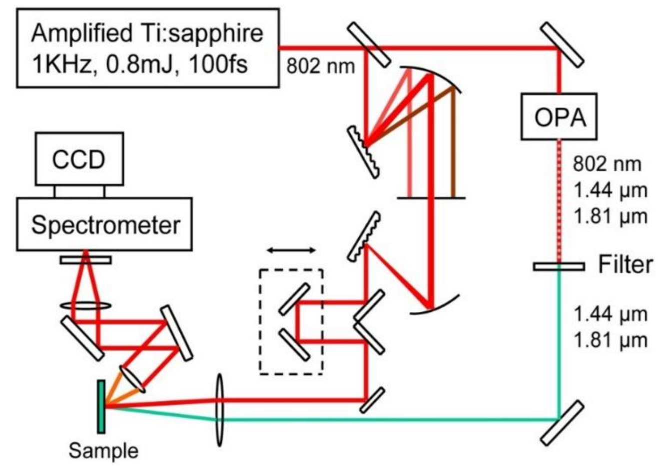


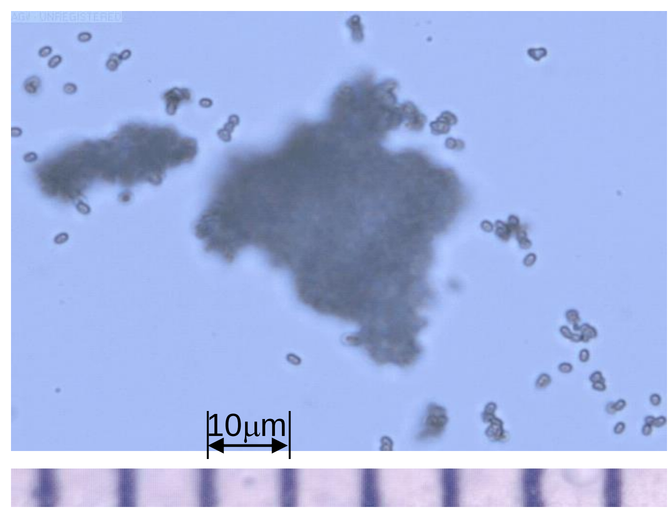
Femtosecond hybrid CARS setup for measurements in solid/liquid/gas

Hybrid CARS for real-time bacterial spore detection





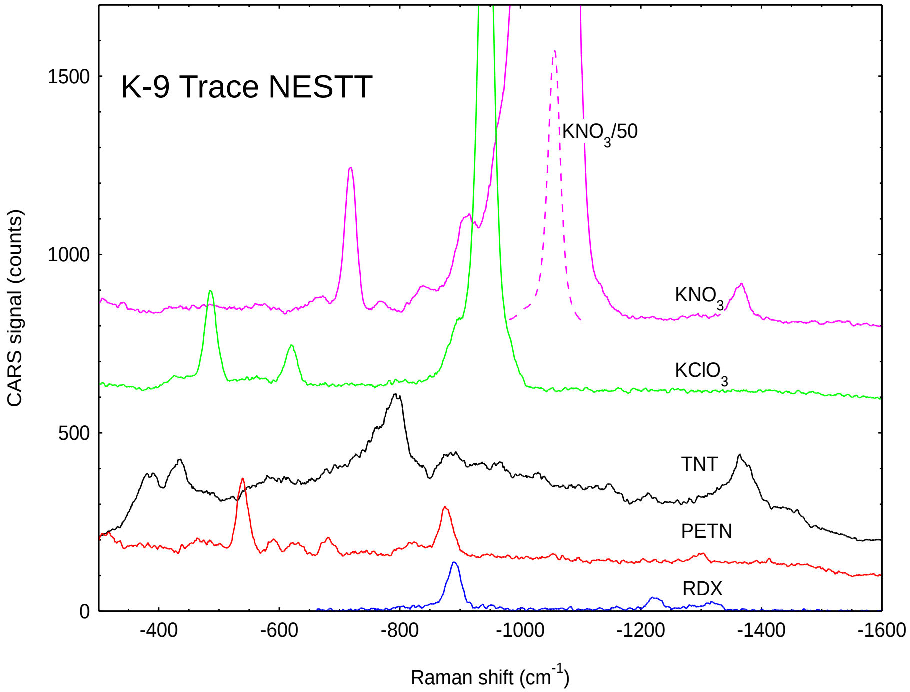


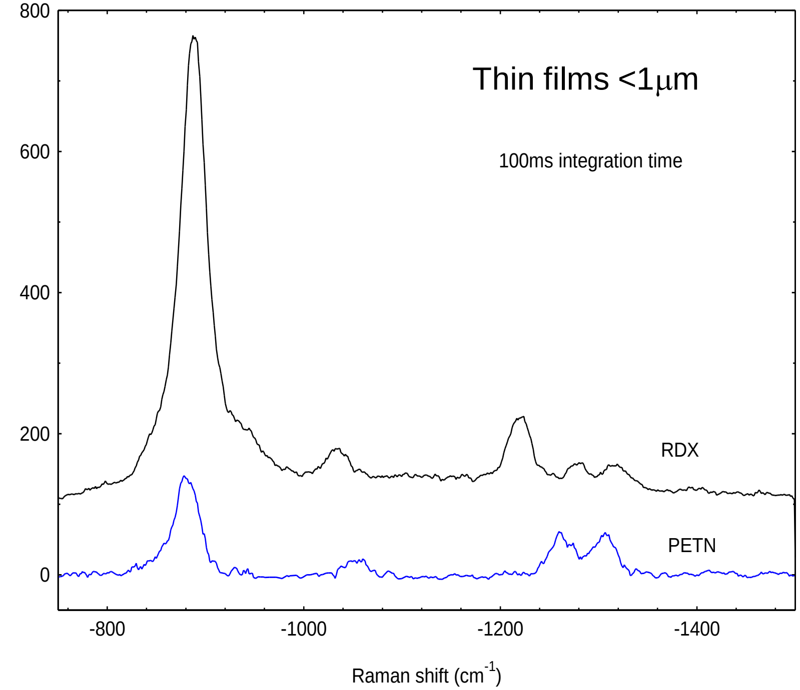


Spore clump
< 200 spores

Dogariu et al., J. Appl. Phys. 103, 036103 (2008)

Hybrid CARS for real-time, standoff trace explosives detection





- Backscattered CARS spectra are obtained in 100ms.
- Spectra can be analyzed at video rates.

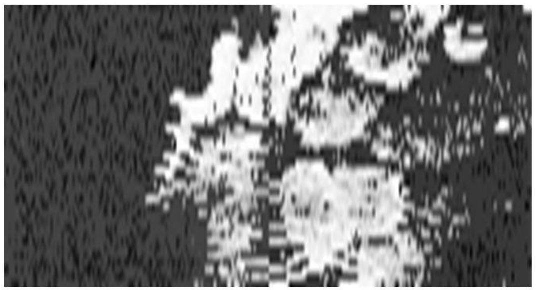
Detection limit: ~ 20ng @ 1m (<1ng @30cm)

A. Dogariu and A. Pidwerbetsky, "Coherent Anti-Stokes Raman Spectroscopy for detecting explosives in real-time," Proc. SPIE, 8358-27 (2012).
K. P. Pfeuffer, T. Le, L. E. Dogariu, D. Zipse, and A. Dogariu, "Characterization and applications of a fieldable single-laser standoff CARS detection system," Opt. Eng. ***59****, 092007 (2020).*

Hyper-Spectral Imaging

Ammonium Nitrate (AN) on vinyl

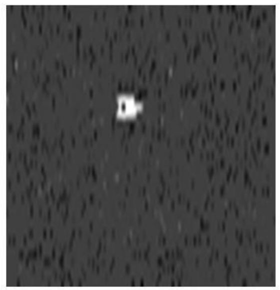
PA2



8x4mm

Spray deposit

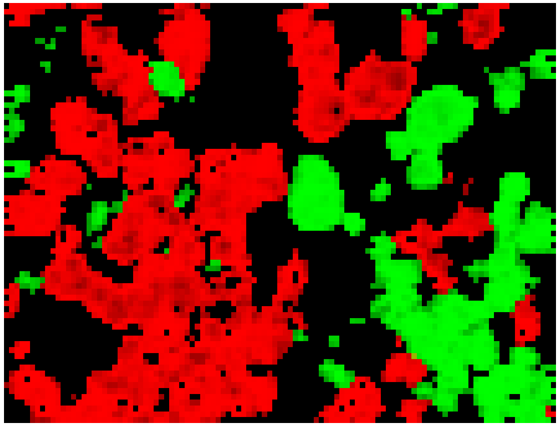
PB2



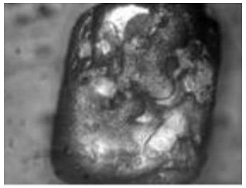
4x4mm

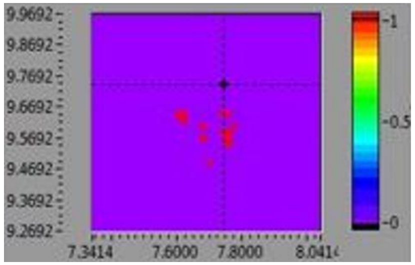
Dry transfer

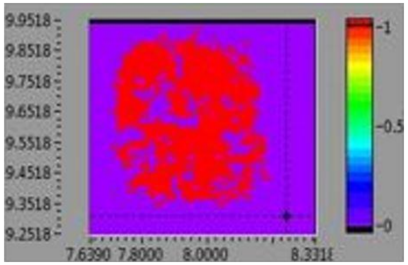
AN + $KClO_3$



10 x 7mm







500 x 500µm

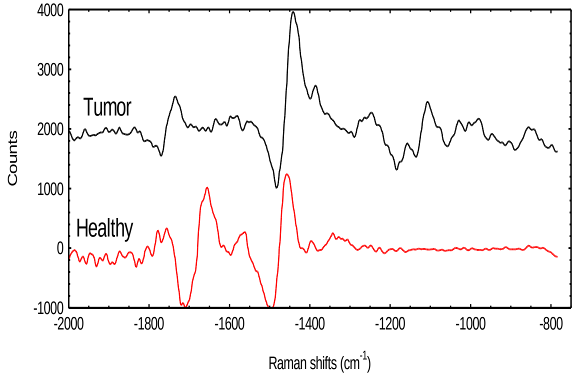
- Raster scanning at 1m standoff
- Total energy at the sample: 10µJ
- Sample density 100µg/cm^2

Samples provided by DHS

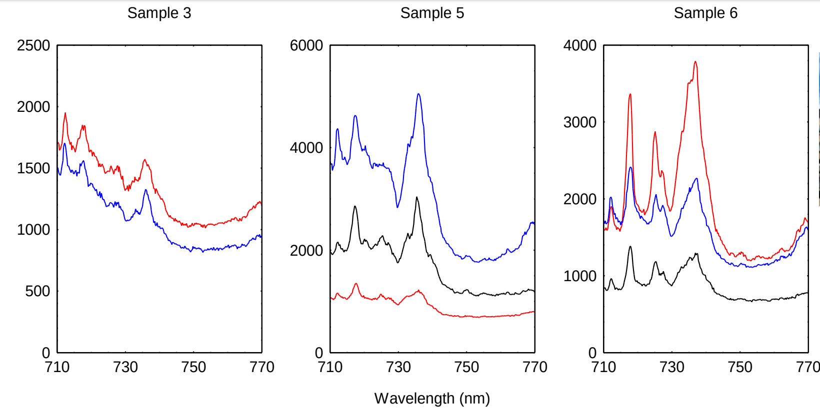
Homeland Security
Science and Technology

Princeton University

Biomedical Applications

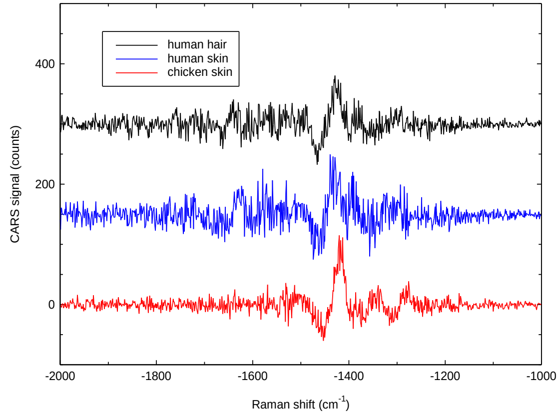


Mammalian Cancer: real-time non-invasive spectroscopy of tumors

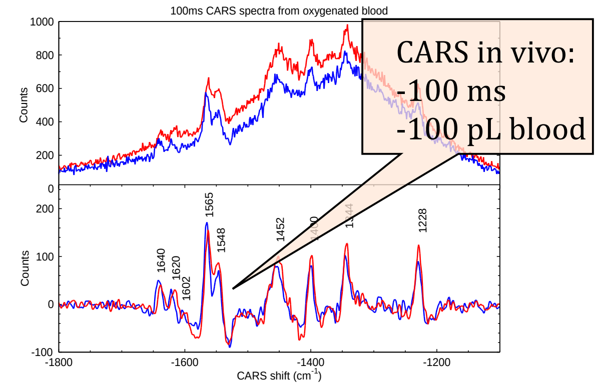


UPenn

Skin Cancer: real-time non-invasive carcinoma detection



Remote skin evaluation: Hair and skin spectroscopy in real-time



Blood monitoring: 20,000x faster, real-time, non-invasive, no sample preparation

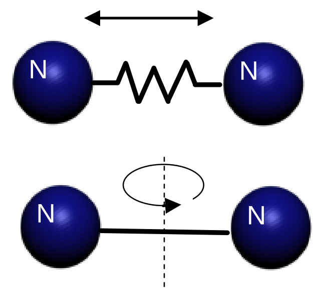
Princeton University

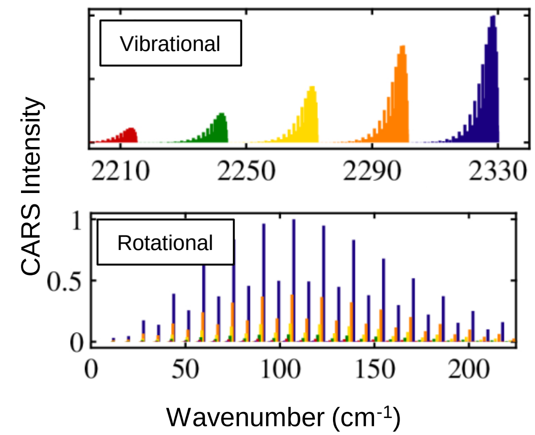
Dogariu et al., J. of Biomed. Opt. 13(5), 054005 (2008)

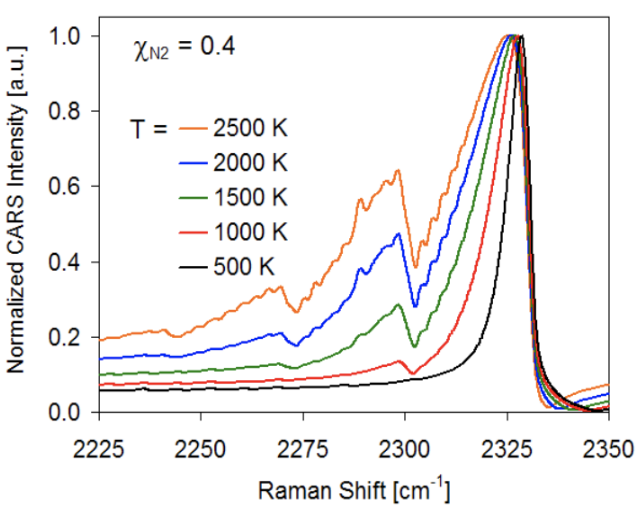
Gas and Plasma Applications: Remote CARS Thermometry

Equilibrium vibrational and rotational Raman spectra at equilibrium - Boltzmann distribution

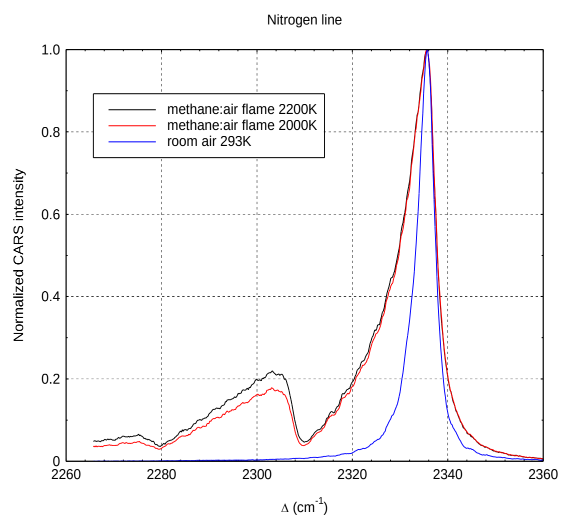
$$N(v,J) \propto exp\left(-\frac{E_{vib(v)}}{kT_{vib}}\right) exp\left(-\frac{E_{rot(J)}}{kT_{rot}}\right)$$







Theoretical spectra (Sandia CARSFIT code)

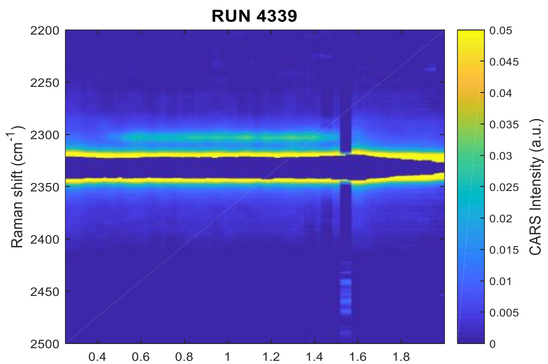


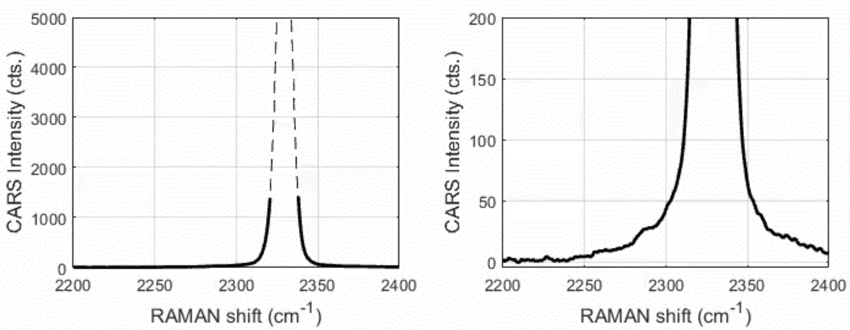
Measurements *in real time using collinear hybrid CARS*

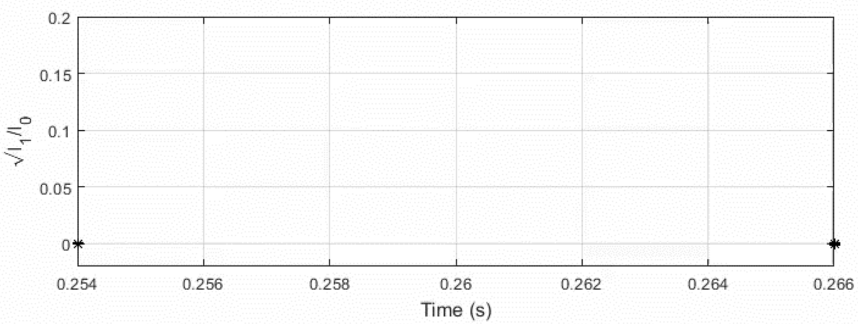
Non-equilibrium temperature

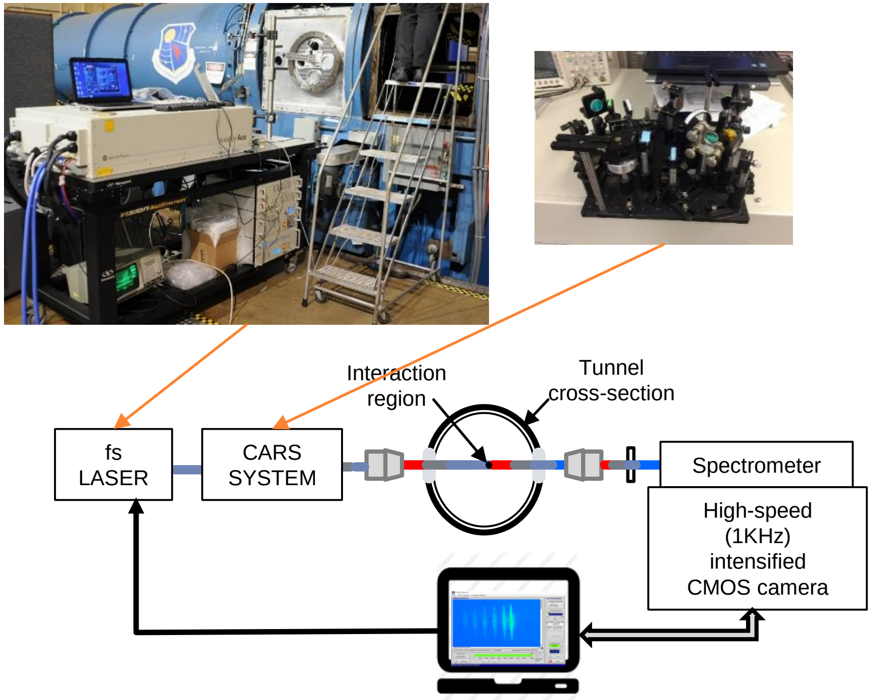
- Combustion
- Air vehicle propulsion systems
- Gas dynamics
- Plasma

Vibrational Temperature in Hypersonic Flow





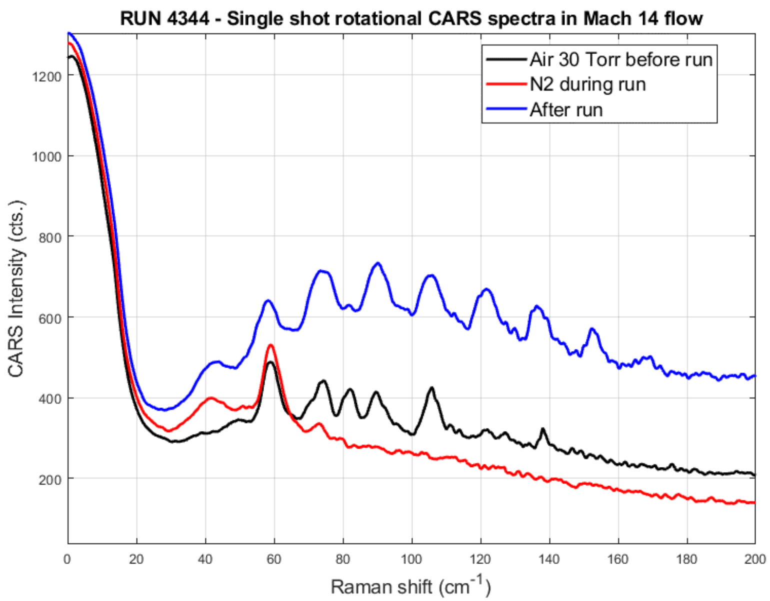


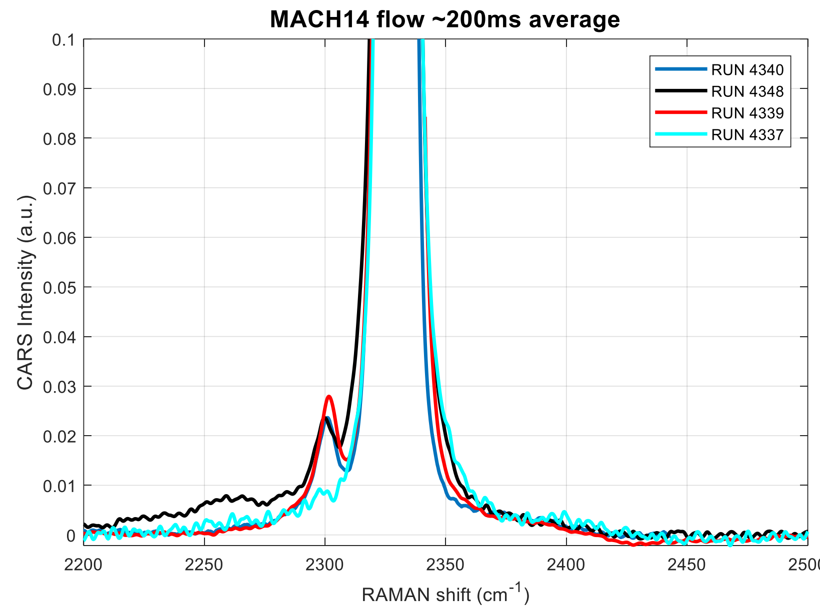


- First ever real-time temperature measurements in Tunnel 9 (March 2018)
- Single shot, 1kHz (<1s run time)
- Mach 14, 1,500m/s, 1 Torr Nitrogen
- Validate presumption of non-equilibrium temperature

Princeton University

Validation of Non-Equilibrium Temperature





Rotational temperature ~55K

Vibrational temperature ~1300K

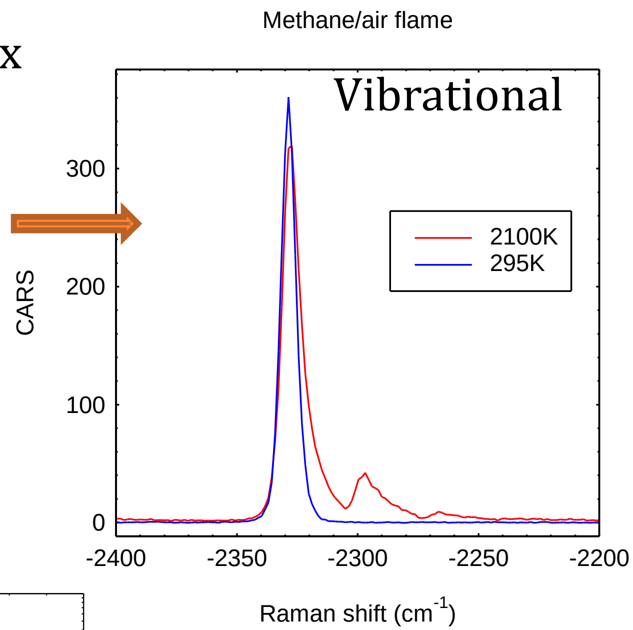
- Rotational temperature as expected – in equilibrium with translational T
- Vibrational energy frozen, high non-equilibrium predicted by Computational Fluid Dynamics (CFD) and measured by CARS in real time (@1kHz)

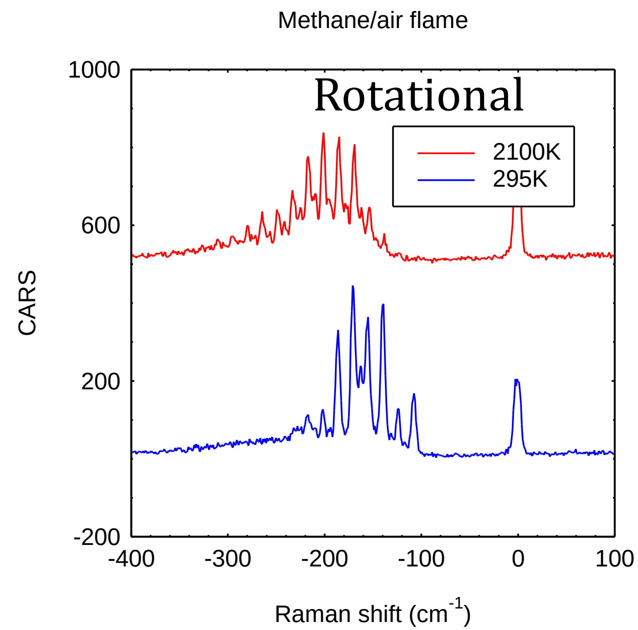
A. Dogariu, L. E. Dogariu, M. S. Smith, J. Lafferty, and R. B. Miles, "Single Shot Temperature Measurements using Coherent Anti-Stokes Raman Scattering in Mach 14 Flow at the Hypervelocity AEDC Tunnel 9," AIAA SciTech 2019 Forum, 1089 (2019).

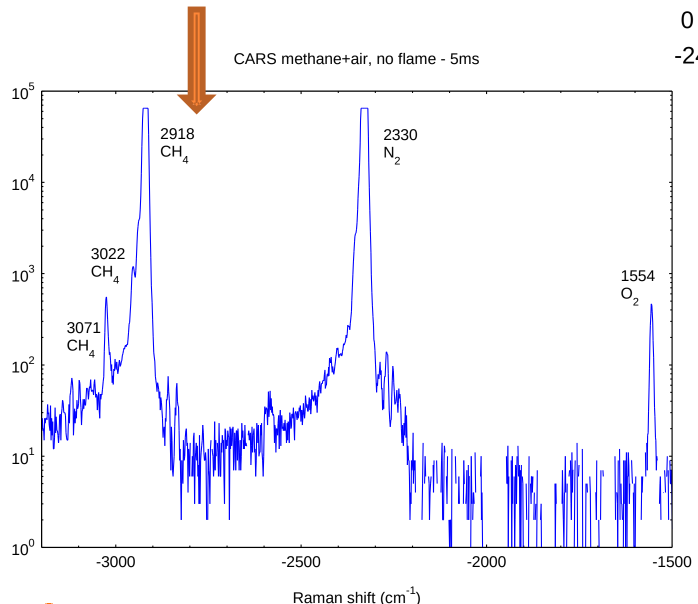
Hybrid CARS thermometry in combustion

Hencken burner: CH4/air mix

- Equivalence ratio ~1 vibr. and rot.
- Room temperature vibrational CARS



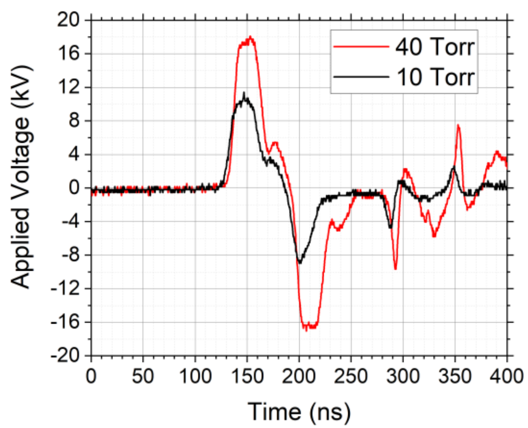


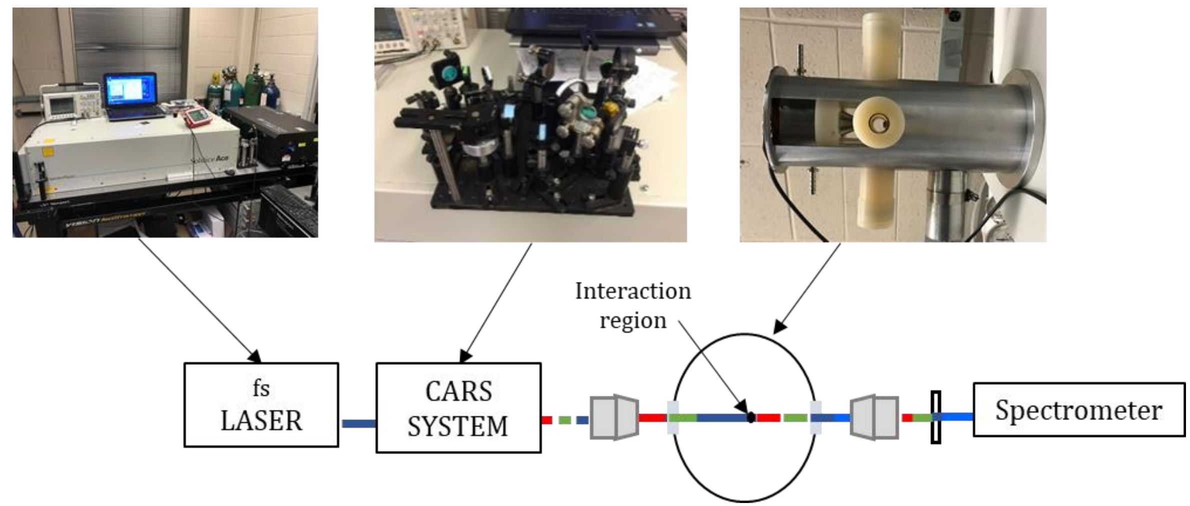


Single shot, simultaneous vibrational and rotational spectra (@1kHz)

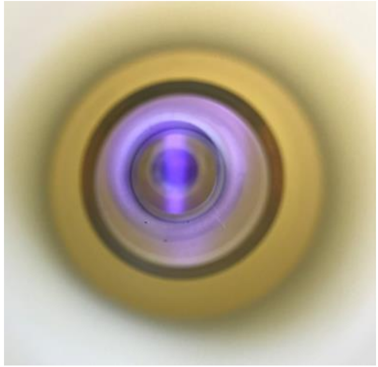
Princeton University

Hybrid CARS thermometry in ns plasma discharge

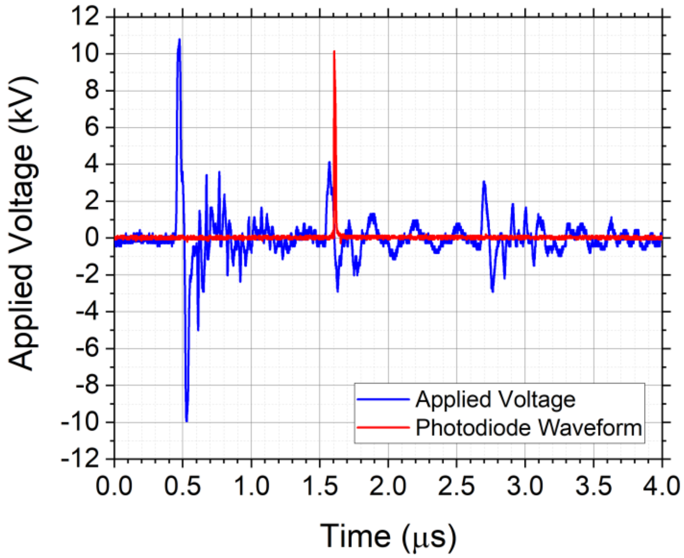


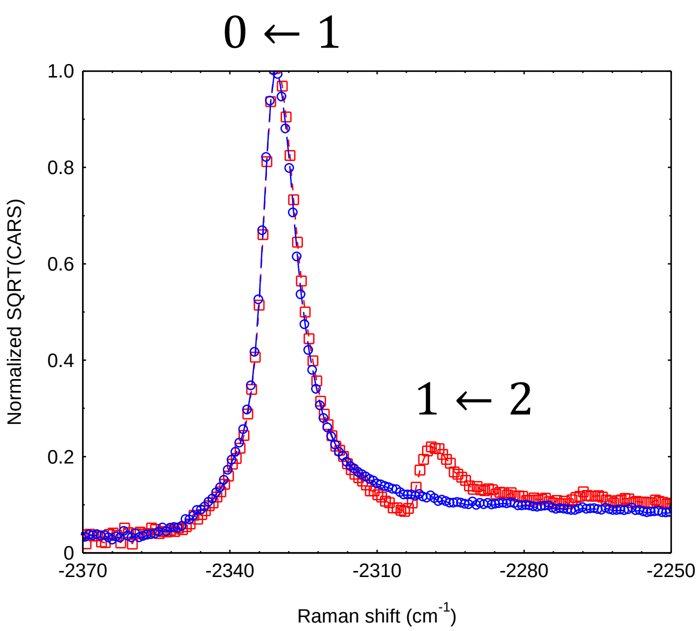


- Non-equilibrium temperature and dynamics from vibrational spectrum of nitrogen in a nanosecond plasma discharge.
- ns discharge – 18ns, 10-20kV
- Plasma glow discharge - 10-40 Torr air

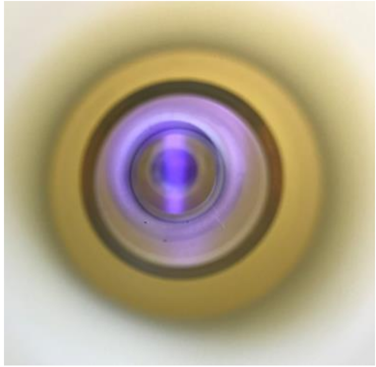


Rotational and Vibrational Temperature in Plasma Discharge





- Non-equilibrium temperature and dynamics at 10 Torr
- High vibrational temperature (~1400K)
- Low rotational temperature low (~400K)
- Non-equilibrium dynamics - ms time scale



Second Harmonic Generation (SHG)

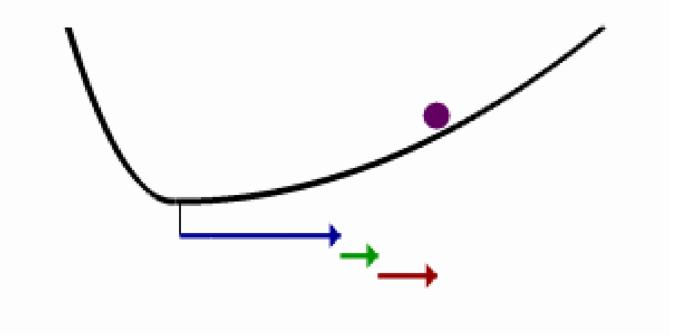
$$\boldsymbol{P} = \chi\varepsilon_0\boldsymbol{E} \qquad P = \varepsilon_0\left(\chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \cdots\right)$$

- $\boldsymbol{P}$: Induced polarization
- χ: Electric Susceptibility
- ε_0: Permittivity of vacuum
- $\boldsymbol{E}$: Electric Field

- For SHG, second order polarizability:

$$P^{(2)} = \varepsilon_0\chi^{(2)}E^2$$

- Second order nonlinear interactions can only occur in non-centrosymmetric media



- **Harmonic generation in gases?**
  - "Second harmonic generation is not possible using gases as the nonlinear medium, since they are isotropic materials"

Laser Fundamentals 2nd Edition by William T. Silfvast

  - While in a centrosymmetric medium second harmonic generation is impossible**, applying an electric field** destroys the symmetry and **allows SHG**

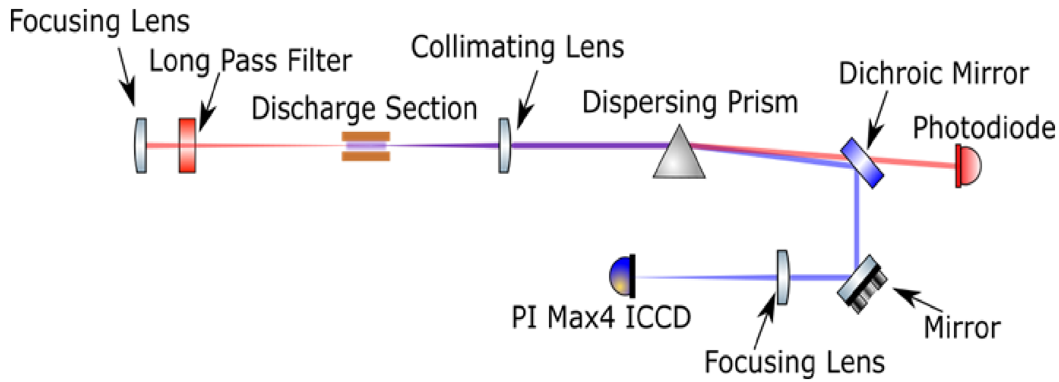
fs E-FISH – use ultrafast lasers to measure electric field in gases and plasmas

Electric Field Induced Second Harmonic Generation (E-FISH)

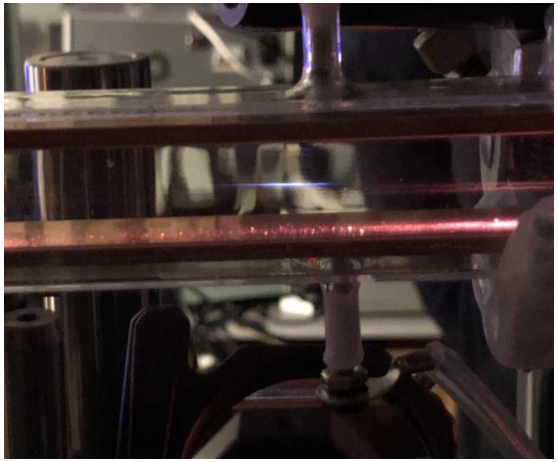
$$P^{(2\omega)} = \frac{3}{2} N \chi^{(3)}(-2\omega, 0, \omega, \omega) E_{Ext} E_{Pump} E_{Pump}$$

- $P^{(2\omega)}$: Induced Polarization at Second Harmonic Frequency
- N: Number Density
- $\chi^{(3)}(-2\omega, 0, \omega, \omega)$: Nonlinear Susceptibility
- E_{Ext}: Applied Field to be Measured
- E_{Pump}: Electric field of Incident Lasr

$$\Rightarrow I^{(2\omega)} \propto A \cdot N^2 (E_{Ext})^2 \left(I_{Pump}\right)^2$$



- Ns pulser (~kV)
- 100fs, 1kHz laser source
- Fs temporal resolution
- Sub-mm spatial resolution

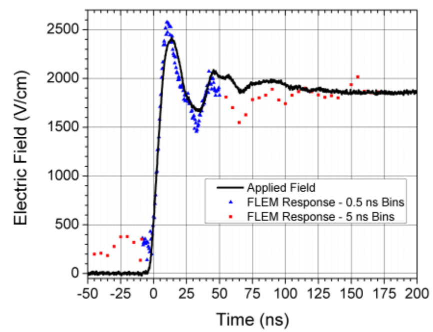


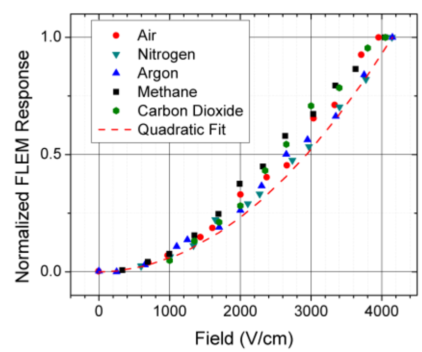
Dogariu et al., Phys. Rev. Applied ***7****, 024024 (2017)*

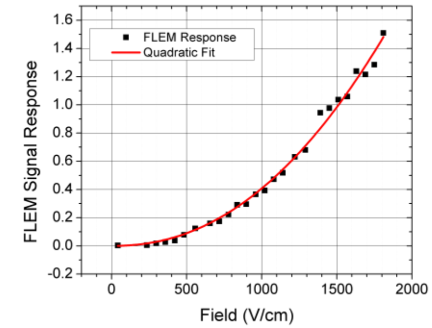
Princeton University

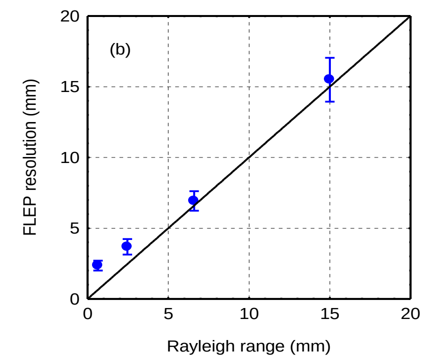
Properties of E-FISH for E-field measurements in gases and plasmas

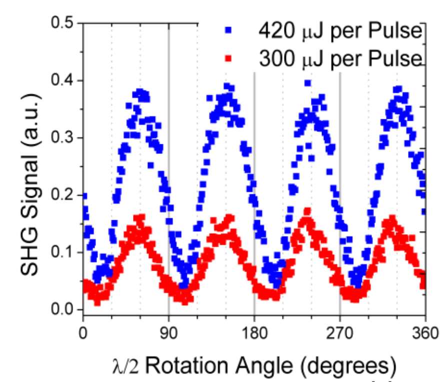
- **Quadratic Dependence on E-Field**
  - Sensitive down to 100’s of V/cm
- **Temporal Resolution**
  - Femtosecond laser pulsewidth
- **Spatial Resolution**
  - Sub-mm, determined by the focal volume
- **Species Independence**
  - Non-Resonant technique that can be used in any gaseous mixture
- **Field Vector Sensitivity**
  - Nonlinear susceptibility polarization allows for measuring the field vector components





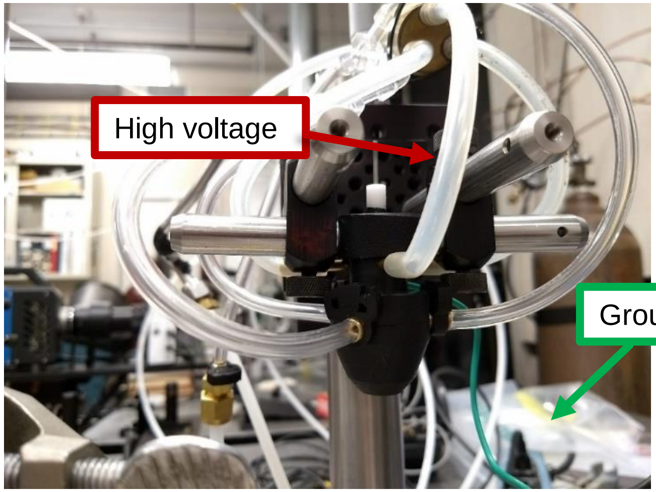


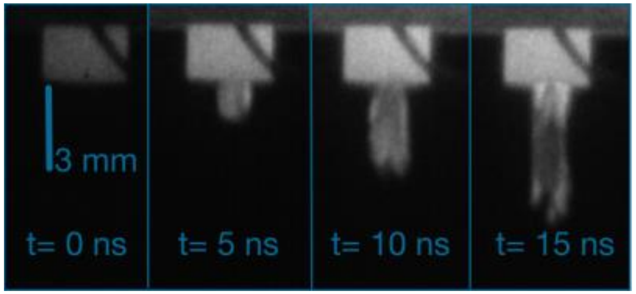


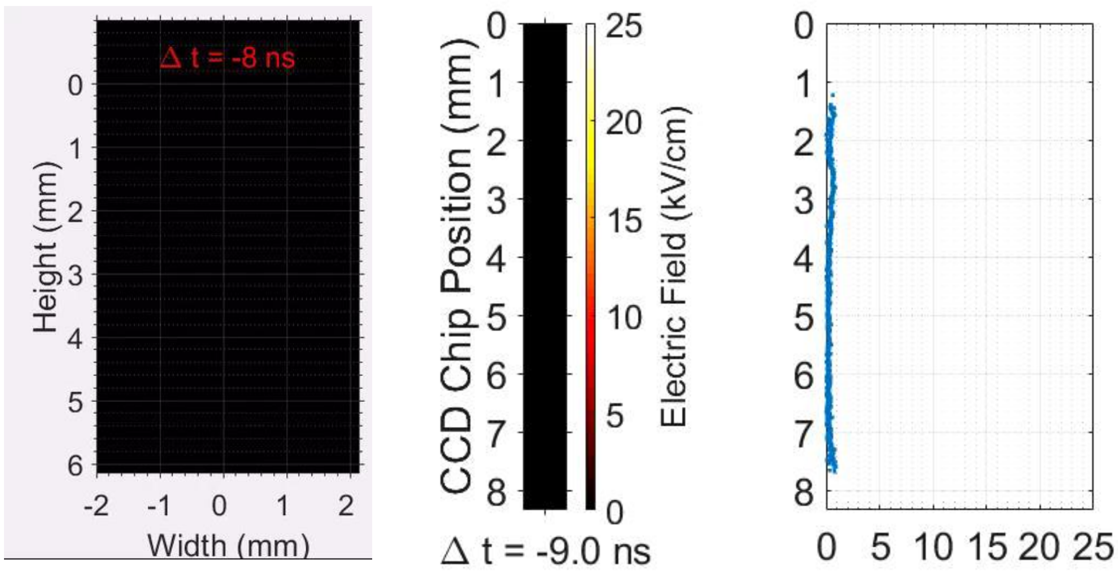


E-FISH in Atmospheric Pressure Plasma Jet (APPJ)

- Streamer front propagation in filamentary plasma jets
- 2D E-FISH – mapping electric field with sub-ns temporal resolution

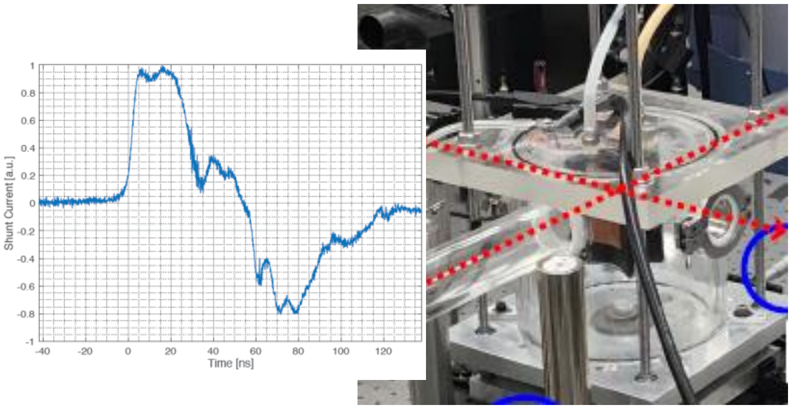


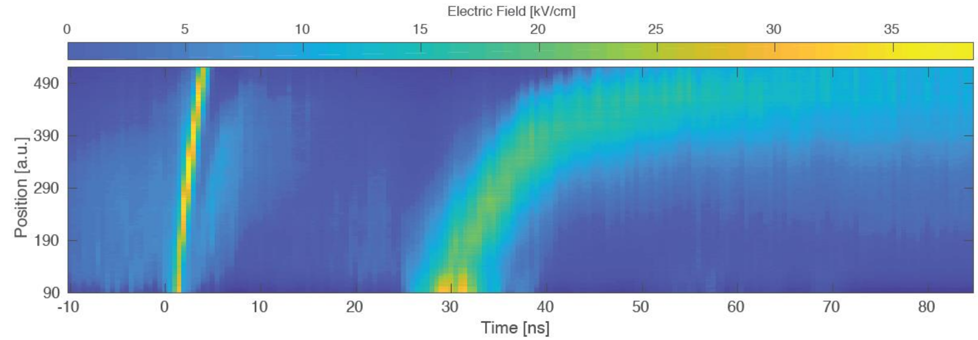




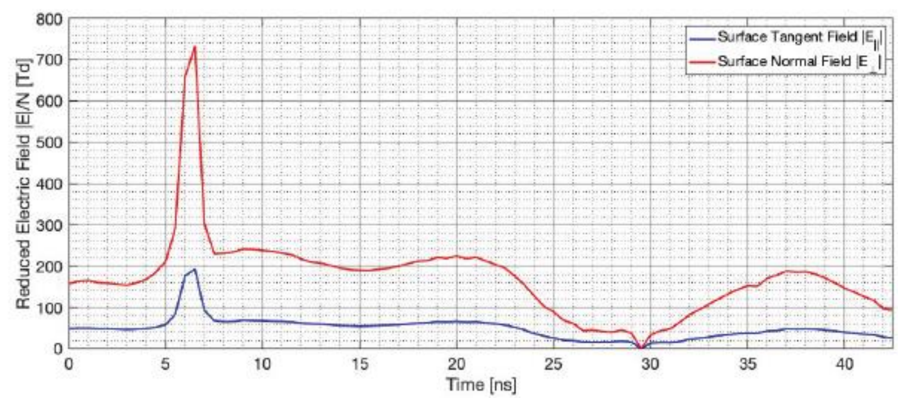
Space-Time resolved E-Field in cold Plasma Jet

2D E-Field dynamics in ns Surface Dielectric Barrier Discharge (SDBD) using E-FISH





- Ns pulses applied to DBD – measure/image E-field in atmospheric discharge
- Cylindrically focused beam allows for imaging of E-Field
- Fast gating allows sub-ns temporal resolution

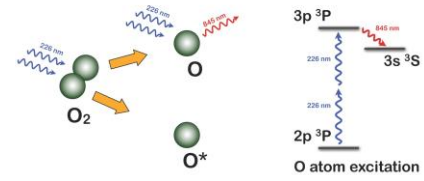


Meehan et al, "Two Component Electric Field Dynamics of a ns-SDBD Plasma with Sub-Nanosecond Resolution by Femtosecond EFISH," AIAA Scitech 1747 (2020)

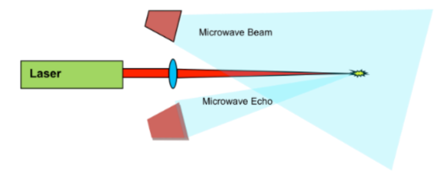
Princeton University

Optical Diagnostics for Gases and Plasma

- Remote backwards air lasing

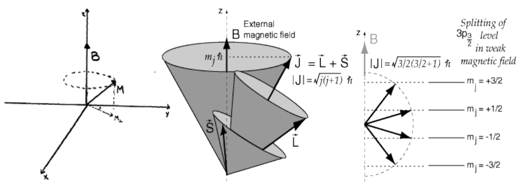


- Remote trace gas detection using Radar REMPI

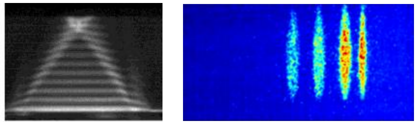


- Remote magnetometry with atomic Xe

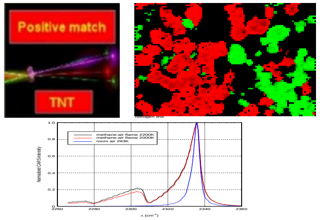
- Two-photon absorption laser induced fluorescence (TALIF)



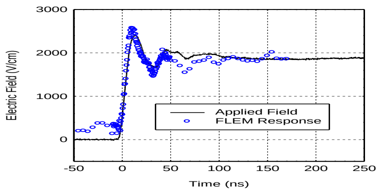
- Flow velocimetry -Fs Laser Electronic Excitation Tagging (FLEET)



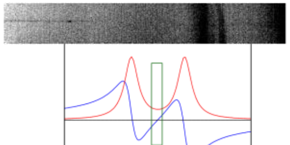
- Standoff real-time molecular detection and imaging using coherent Raman (*CARS*)
- Remote gas thermometry (*CARS*)



- Femtosecond Localized Electric Field Measurement (EFISH)



- Slow Light Imaging Spectroscopy (SLIS) – Spectroscopy without spectrometer



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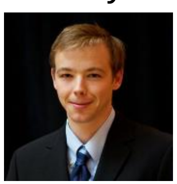

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Homeland Security Science and Technology
NIITEK Before the first step
Chemring Sensors & Electronic Systems
APL Johns Hopkins Applied Physics Laboratory
LGS Bell Labs Innovations

Collaborations:

Arnold Engineering Development Center
Plasma TEC
Penn Medicine University of Pennsylvania School of Medicine University of Pennsylvania Health System
SpeckoDyne Harnessing the power of small fluctuations

Princeton University

PCRF Princeton Collaborative Low Temperature Plasma Research Facility

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About

The Princeton Collaborative Low Temperature Plasma Research Facility (PCRF) is focused on low temperature plasma physics and is open to all users.

The PCRF provides state-of-the-art research capabilities and expertise for comprehensive characterization of low temperature plasma (LTP) properties with the goal to advance methods of predictive control of LTP with a focus on plasma-liquid and plasma-solid interactions, collective phenomena in LTP, and use of LTP in modern applications (e.g. material synthesis and processing).

The facility is formed from the existing low temperature plasma laboratories at PPPL and the Mechanical and Aerospace Engineering (MAE) Department of Princeton University (PU), with a total collective lab space greater than 7000 sq. ft., each located within 3 miles from each other.

The PCRF research and facility program are built on the existing and fruitful collaboration between PPPL and PU MAE researchers, and demonstrated excellent track record of successful integration of experimental and modeling research in their collaborative efforts. PCRF users will be able to access PPPL/PU computer network and helpdesk services, and use PPPL engineering, facilities, and administrative services. Staff of PCRF and PCRF users have direct access to specialized laboratories and institutes at the Princeton University such as the Princeton Institute for the Science and Technology of Materials (PRISM) with state-of-the-art materials evaluation diagnostics.

PCRF Princeton Collaborative Low Temperature Plasma Research Facility

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Information for Users

Proposal Information

A copy of the joint call and submission process instructions can be downloaded here.

A copy of the user proposal template can be downloaded here.

A copy of the available equipment at PCRF can be downloaded here.

Currently users can submit applications to Yevgeny Raitses via email (yraitses@pppl.gov). In your email, please include:

- your name
- affiliation
- title of proposal
- attached completed proposal document

Current Call for Proposals

Opening call for proposals: November 4, 2019

Closing call for proposals: December 20, 2020

Review of proposals: December 21, 2019 to January 20, 2020

Deadline for decisions: by February 3, 2020

The facilities will consider out-of-cycle proposals throughout the year depending on facility utilization. Interested applicants should contact the respective facilities.

- https://pcrf.pppl.gov/
- https://pcrf.pppl.gov/user%20info/index.html

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