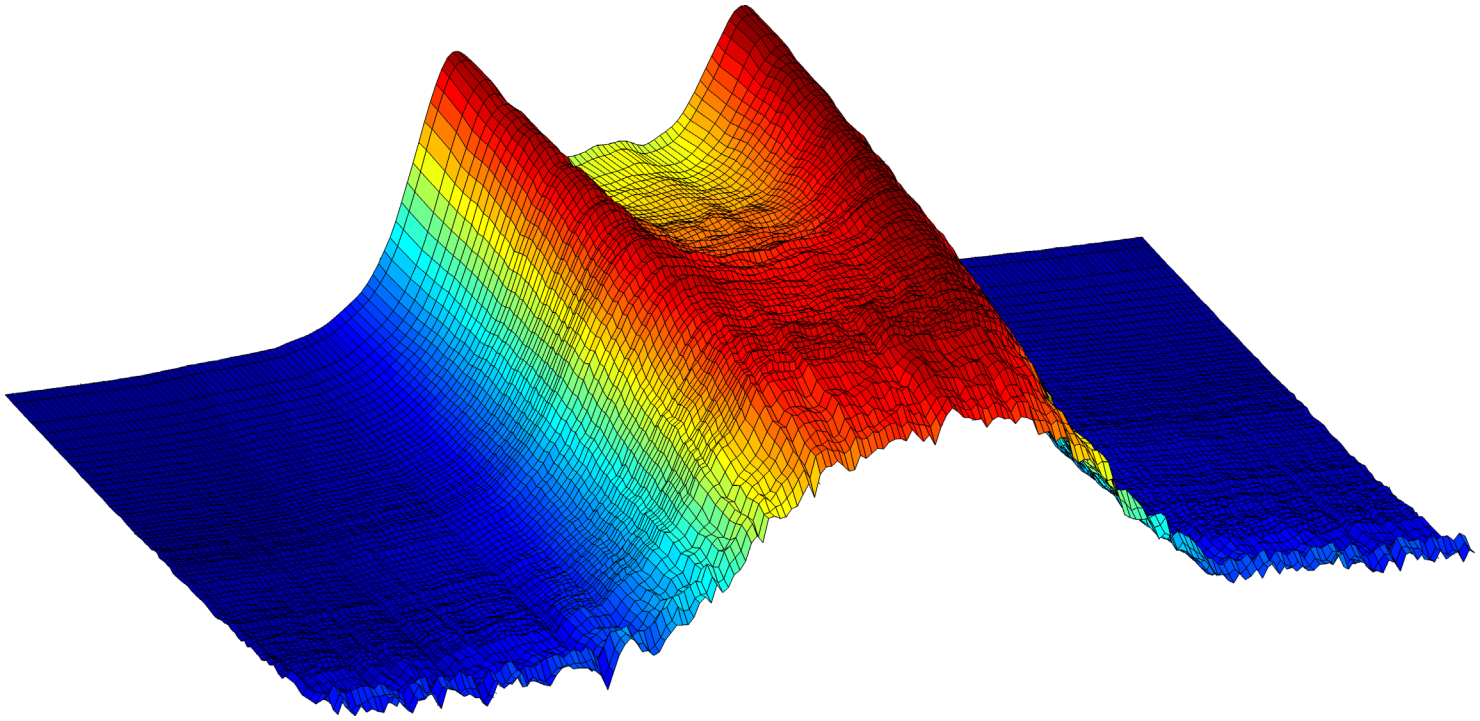

Coherent Rayleigh-Brillouin scattering for VDF, density and temperature measurement of neutral species in a discharge

Alexandros Gerakis

International Online Plasma Seminar
Michigan Institute for Plasma Science & Engineering
October 14th, 2021

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AEROSPACE ENGINEERING
TEXAS A&M UNIVERSITY

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ACKNOWLEDGEMENTS

Optical Probing
&
Manipulation Group

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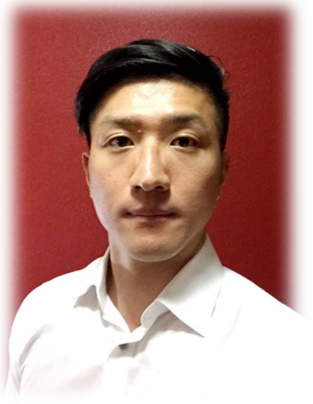

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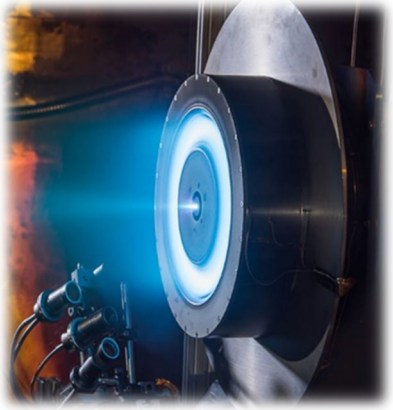
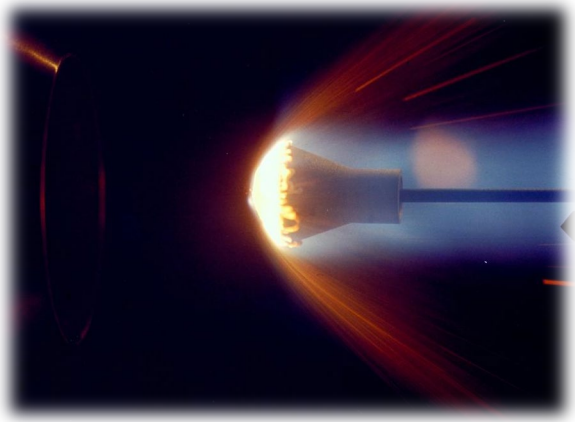
WHY CARE ABOUT FLOW METROLOGY?



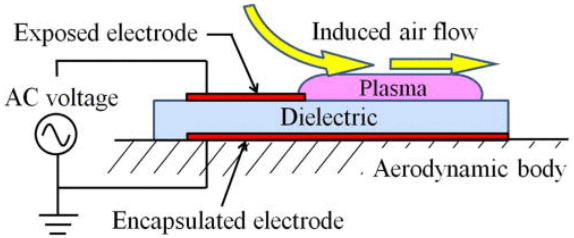
Hall Thruster

https://en.wikipedia.org/wiki/Hall-effect_thruster



Arc Jets

https://www.nasa.gov/centers/ames/multimedia/images/2008/A-28916-3.html

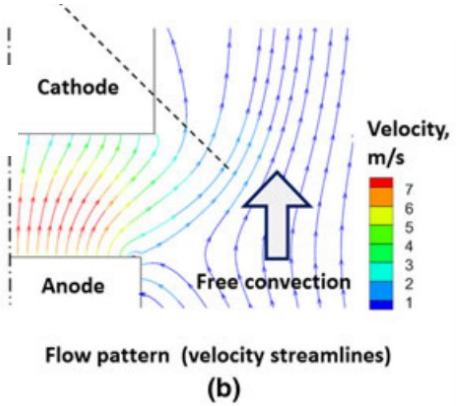


Dielectric Barrier Discharges

Nishida, Hiroyuki, Taku Nonomura, and Takashi Abe. "Three-dimensional simulations of discharge plasma evolution on a dielectric barrier discharge plasma actuator." *Journal of Applied Physics* 115, no. 13 (2014): 133301.

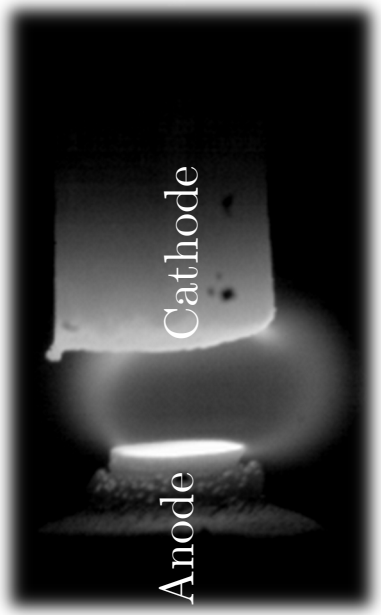
Magnetron sputtering

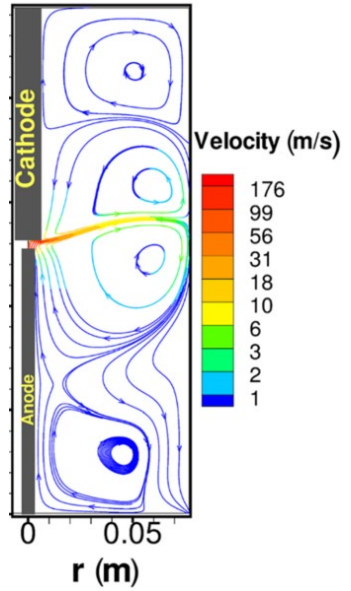
https://intlvac.com/News-Resources/ArticleID/5/What-is-Sputtering



Arc Discharges

S. Yatom, A. Khrabry, J. Mitrani, A. Khodak, I. Kaganovich, V. Vekselman, B. Stratton and Y. Raitses "Synthesis of nanoparticles in carbon arc: measurements and modeling", MRS. Comm. (2018)





M. Kundrapu, M. Keidar, Numerical simulation of carbon arc discharge for nanoparticle synthesis, Physics of Plasma, Vol. 19, No. 073510, 2012

Ideal characteristics for **every** diagnostic:

- Non-perturbative
- Fast
  - ➢ Probe dynamics
- Measure simultaneously as many (spatial) points of interest as possible.
- Work with as many species as possible without altering the setup

Important quantities for **every** flow:

- Temperature
- Density
- Flow velocity

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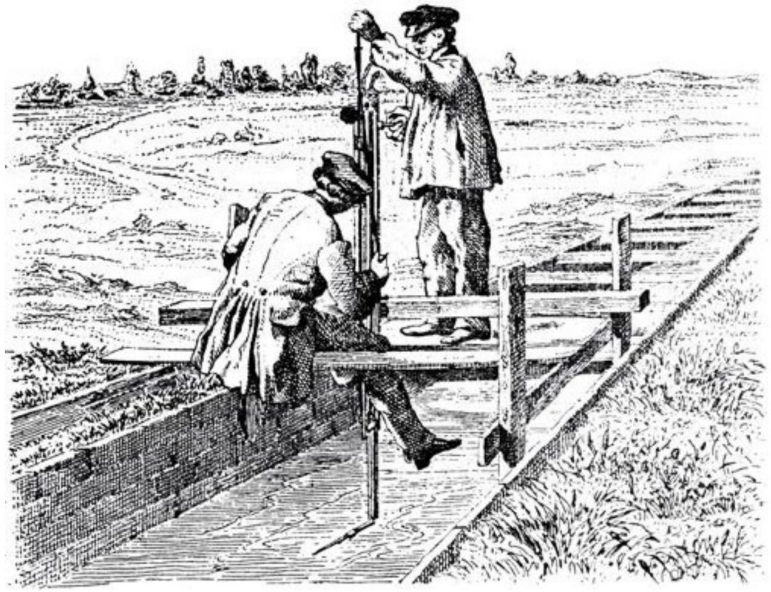
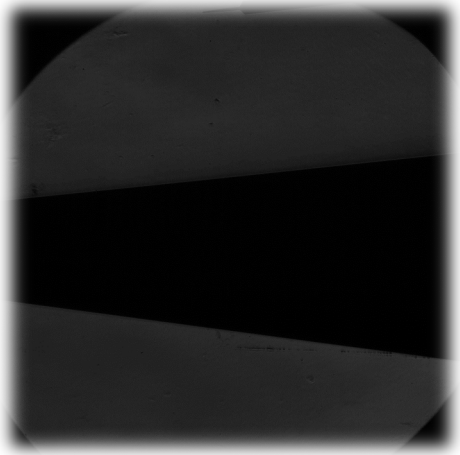
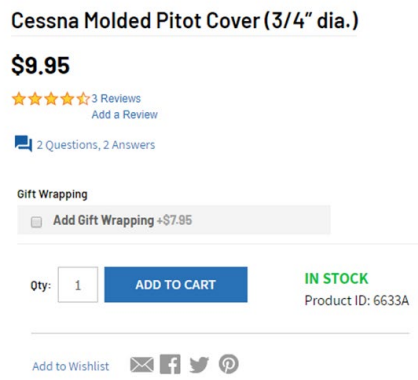
STATE-OF-THE-ART

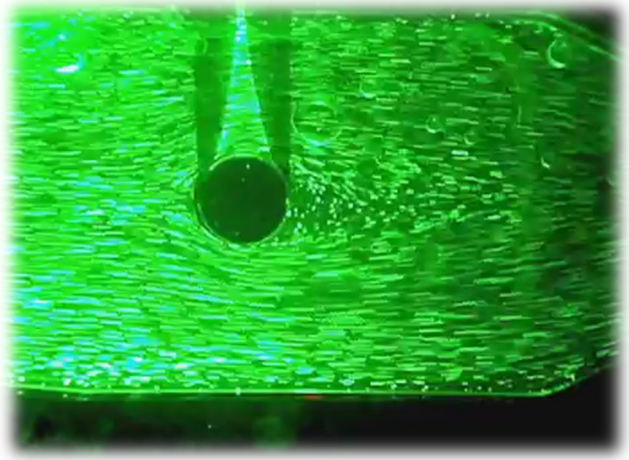
Pitot tube (invented in 1732!)



Measurement of flow velocity with the Pitot tube, improved by M. H. Darcy (Recherches hydrauliques, entreprises par M. H. Darcy, continuées par M. H. Bazin. Extract from volume XIX of Mémoires présentés par divers savants à L'institut Impérial de France, 1st part (501 p., 28 pl.): Recherches expérimentales sur l'écoulement de l'eau dans les canaux découverts. Imprimerie impériale, Paris 1865, planche IV).







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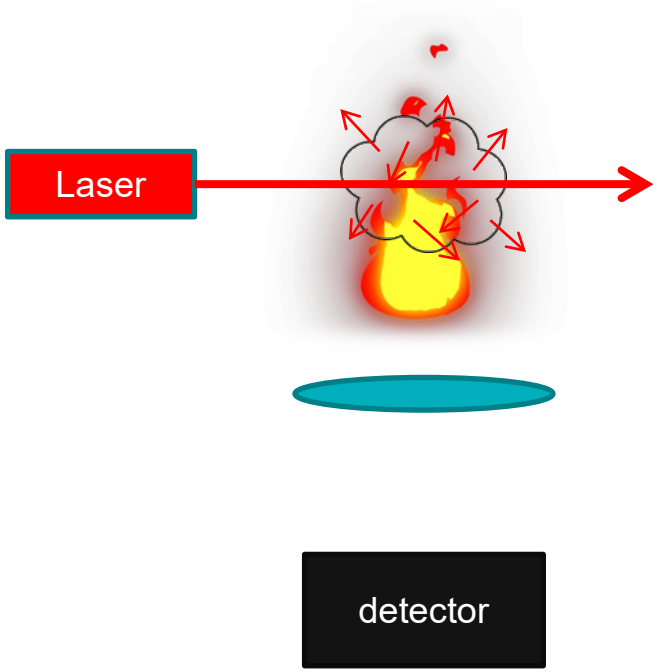
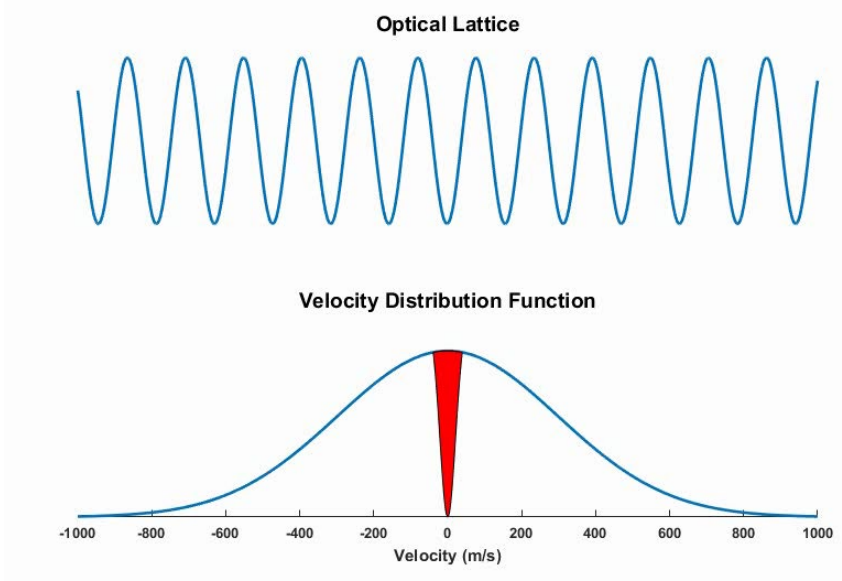
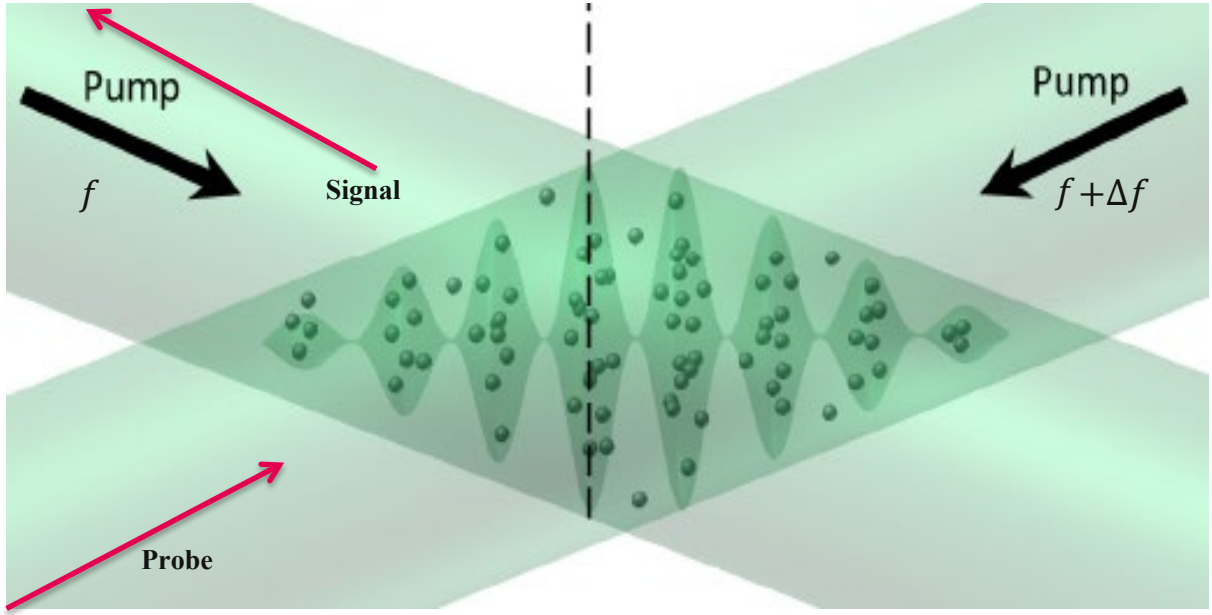
RAYLEIGH-BRILLOUIN SCATTERING

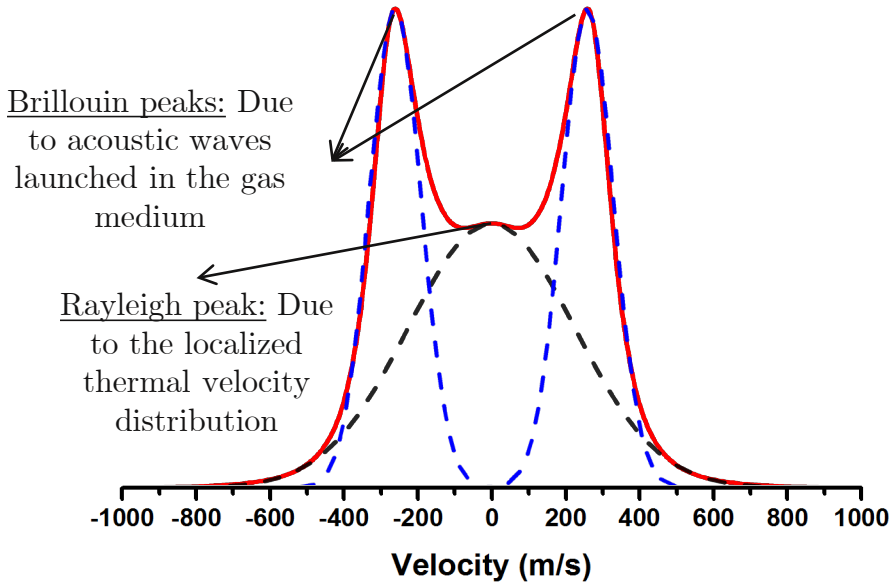


Other neutral and plasma flow laser diagnostics, resonant and non-resonant, e.g. vibrationally excited nitric oxide monitoring (VENOM), femtosecond laser electronic excitation tagging (FLEET) laser induced fluorescence (LIF), Coherent Anti-Stokes Raman Scattering (CARS) and others have also been demonstrated to measure flow velocity and/or temperature.

COHERENT RAYLEIGH-BRILLOUIN SCATTERING







Measurable quantities

Temperature
Density
Speed of sound
Shear & Bulk viscosity
Polarizability

CRBS:

- ✓ Highly localized
- ✓ Laser beam signal output
- ✓ Much lower resolvable densities
- ✓ Single Shot

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COHERENT RAYLEIGH-BRILLOUIN SCATTERING

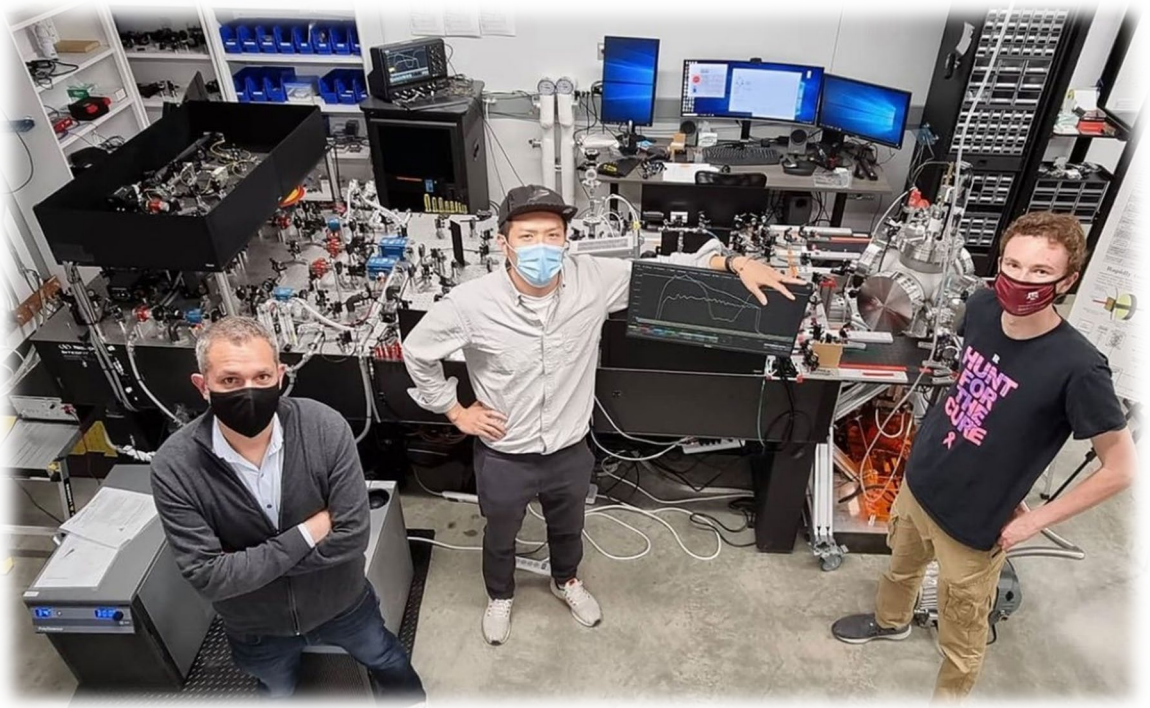
Single shot

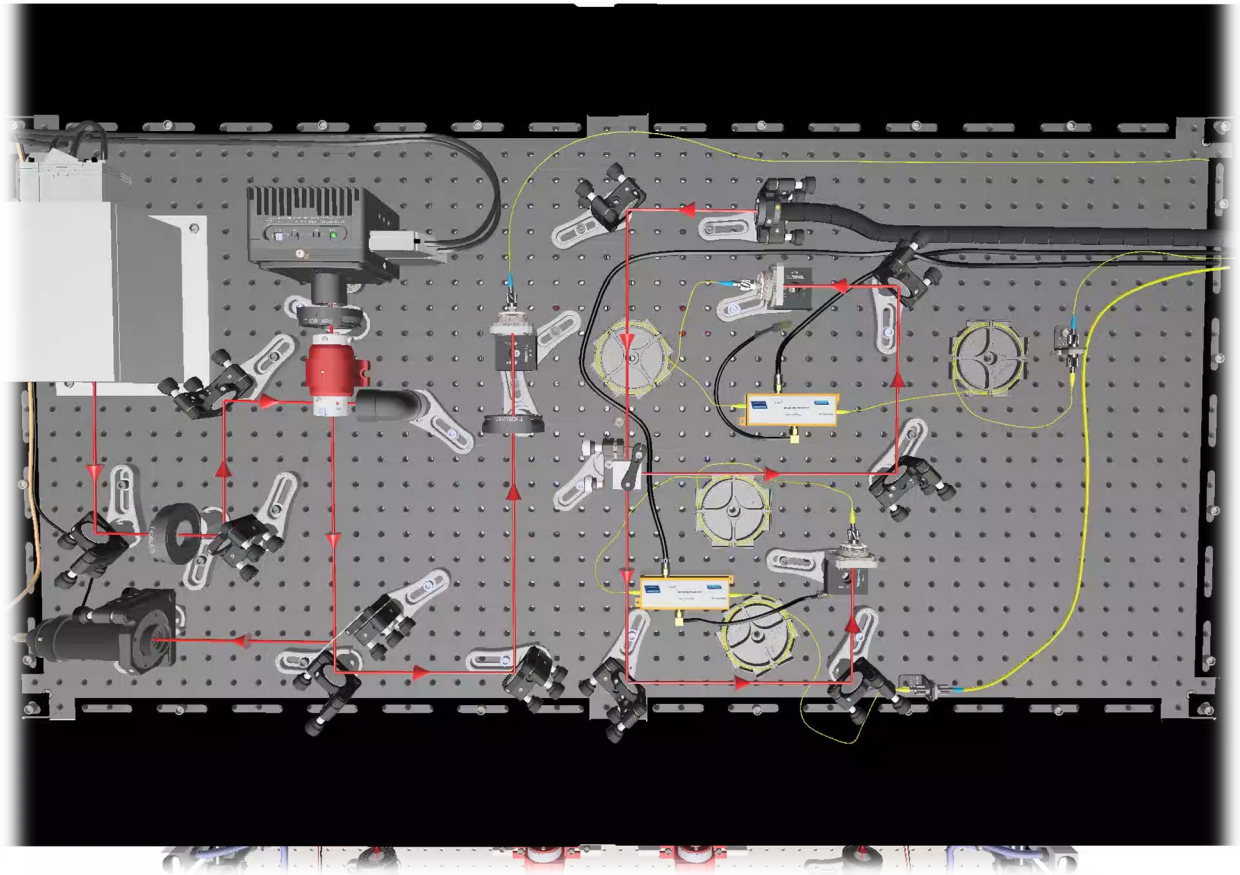
Gerakis, A., Shneider, M.N. and Barker, P.F., 2013. Single-shot coherent Rayleigh–Brillouin scattering using a chirped optical lattice. Optics letters, 38(21), pp.4449-4452.

COHERENT RAYLEIGH-BRILLOUIN SCATTERING
Experimental Setup

Experimental parameters

- >450 mJ/pulse/arm
- Up to ~10 GHz chirp rate
- Variable pulse durations: 10-1000ns
- Rep. Rate: 10-30 Hz





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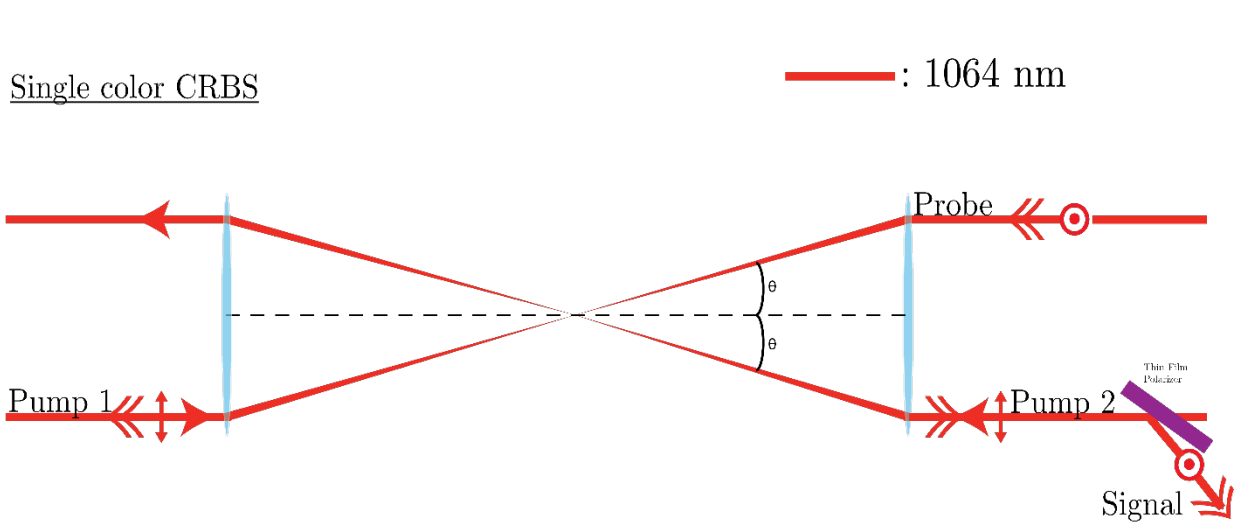
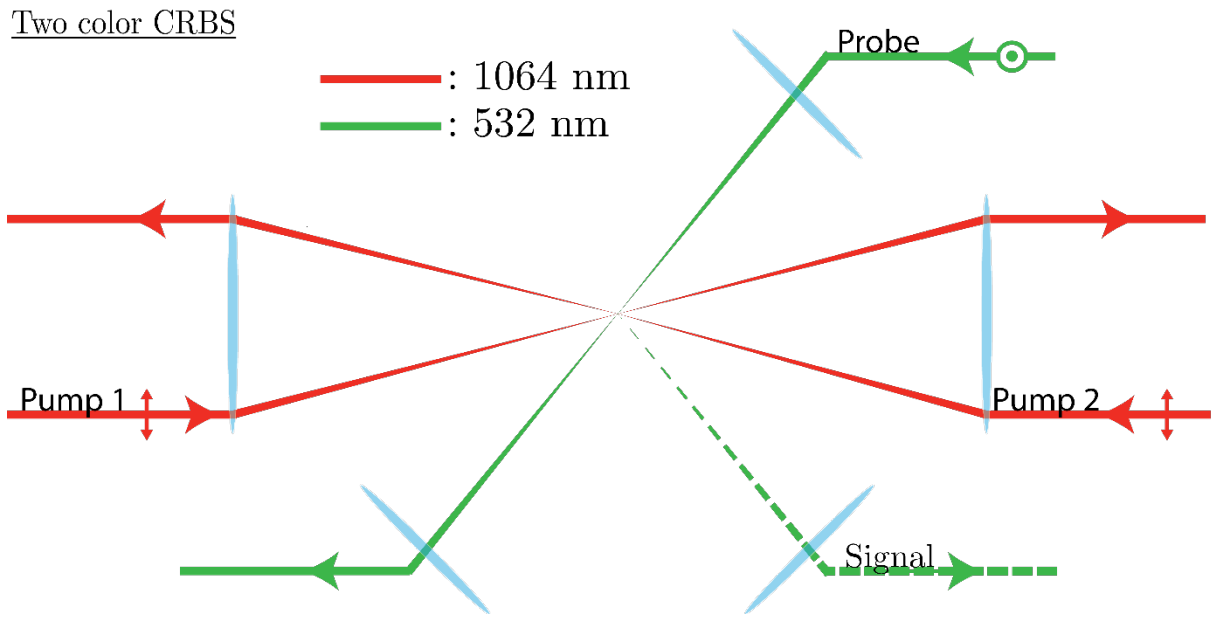
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Two color CRBS scheme





Two-color CRBS scheme

- Better Signal/Noise Ratio
- Lower gas densities accessible
  - Better detector technology @ 532 nm
  - Spectral filtering of pumps @ 1064 nm
  - More efficient Rayleigh scattering ($\propto \lambda^{-4}$)

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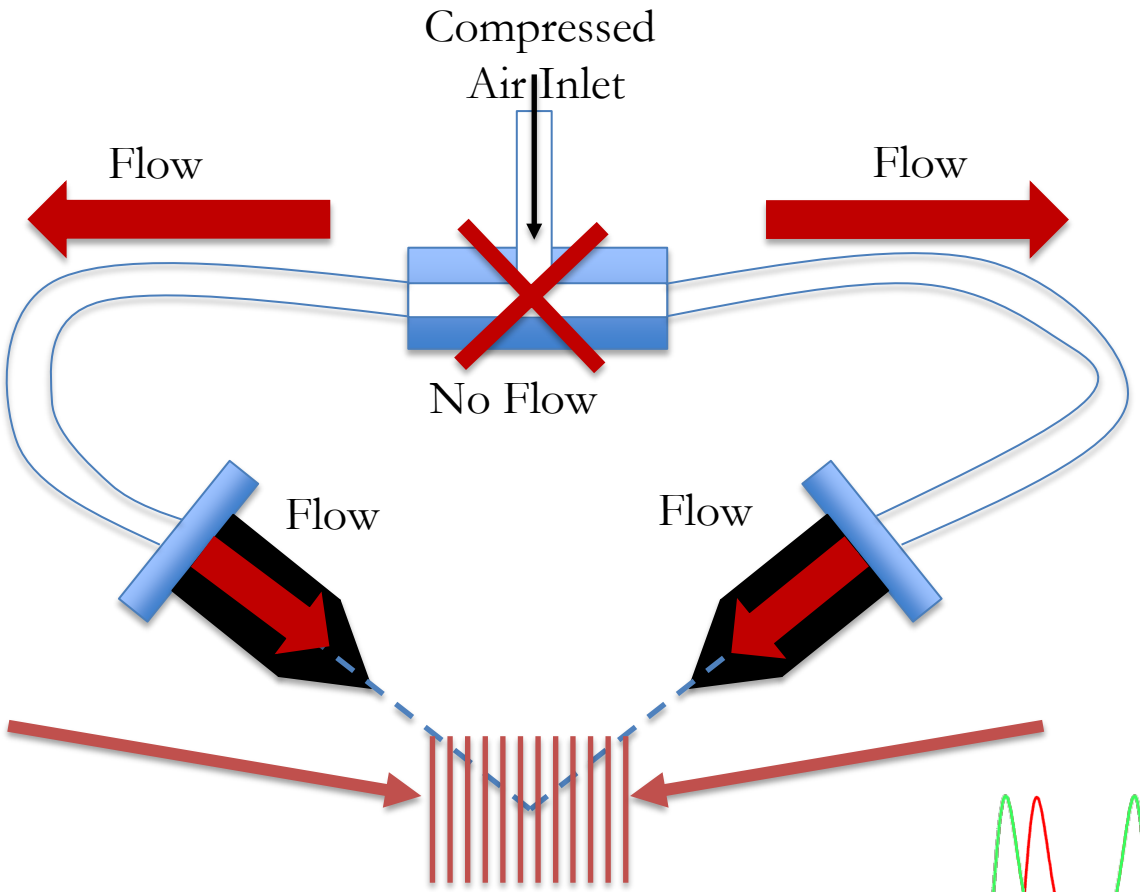
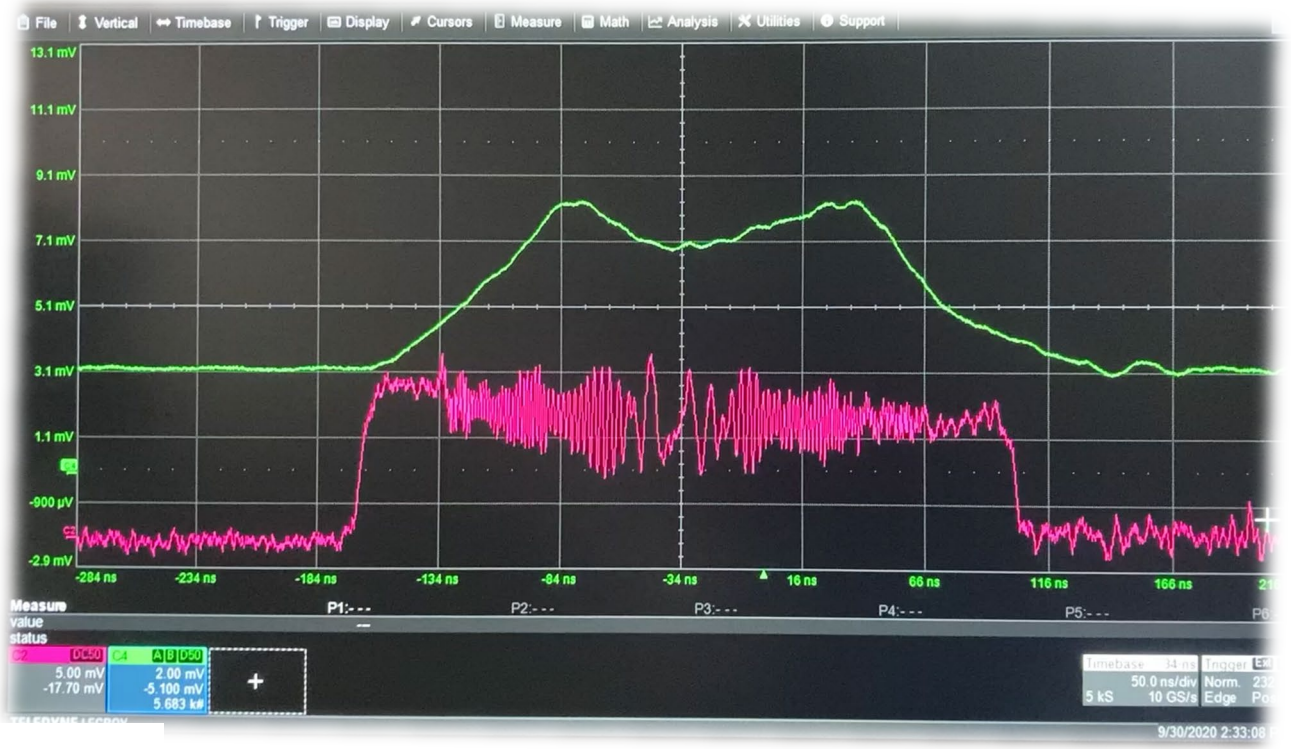
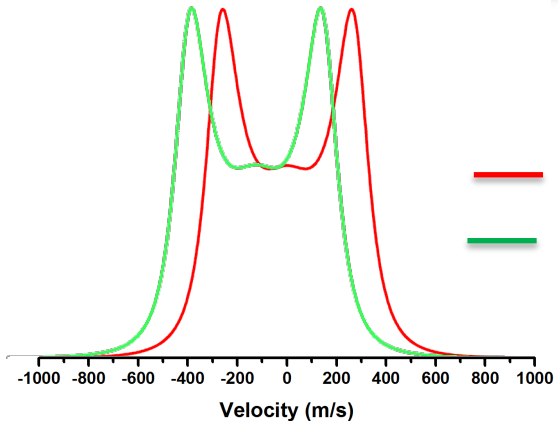
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutral gas flow measurement







Stationary gas

Gas flow

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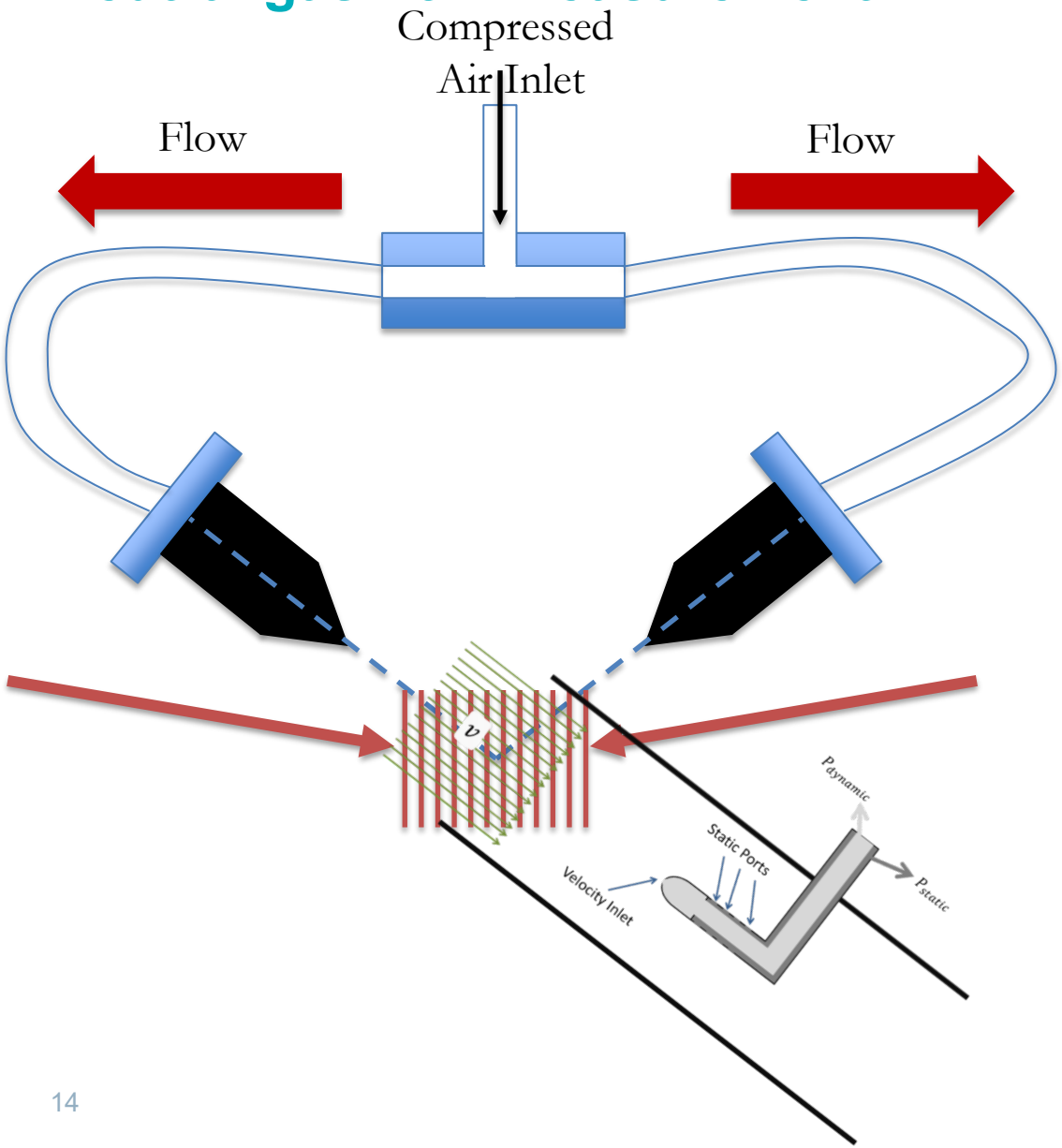
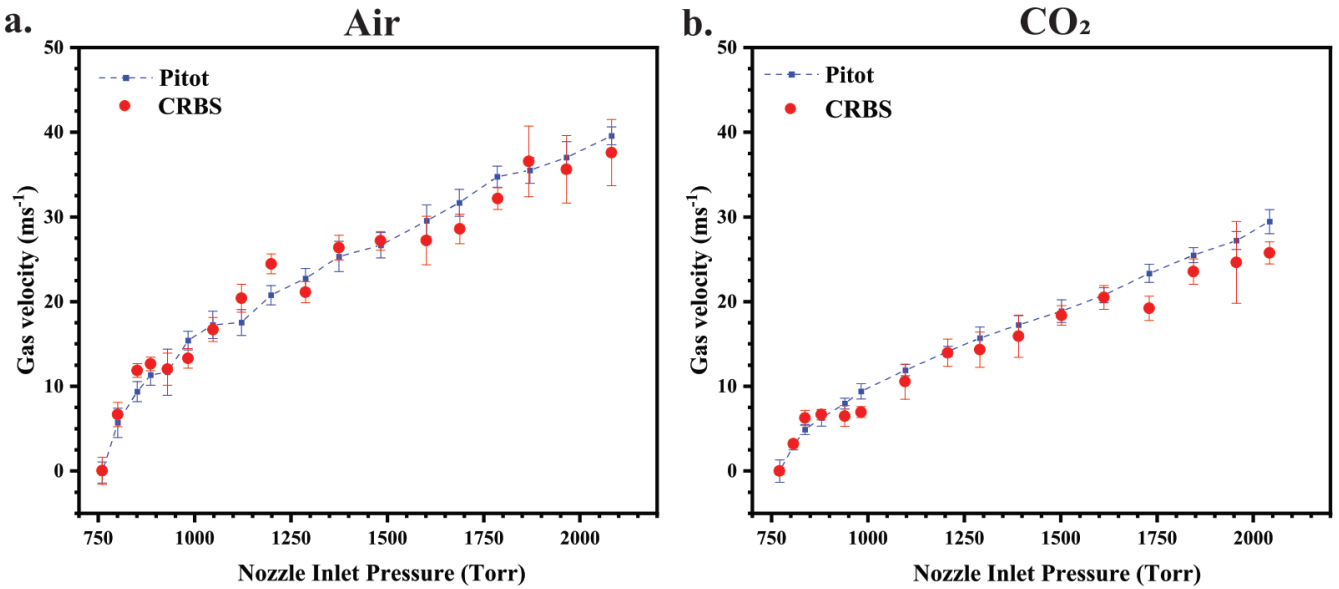
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutral gas flow measurement





Alexandros Gerakis, Junhwi Bak, Robert Randolph and Mikhail N. Shneider. "Demonstration of single shot laser velocimetry with coherent Rayleigh-Brillouin scattering," AIAA 2021-0224. *AIAA Scitech 2021 Forum*. January 2021.

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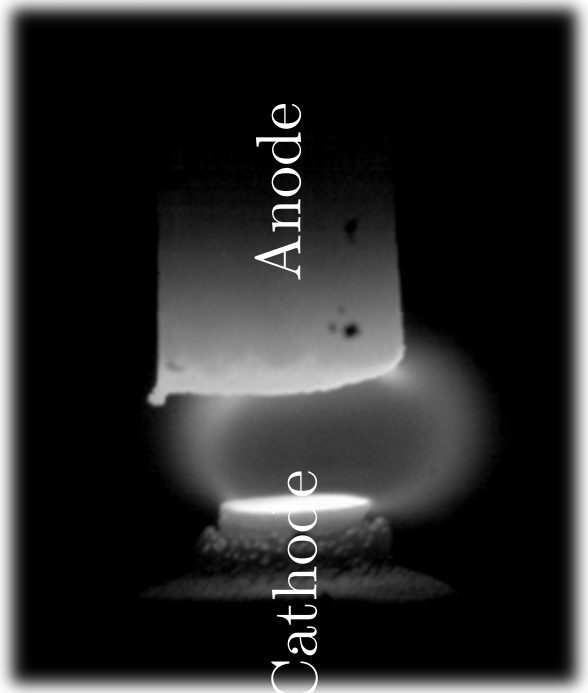
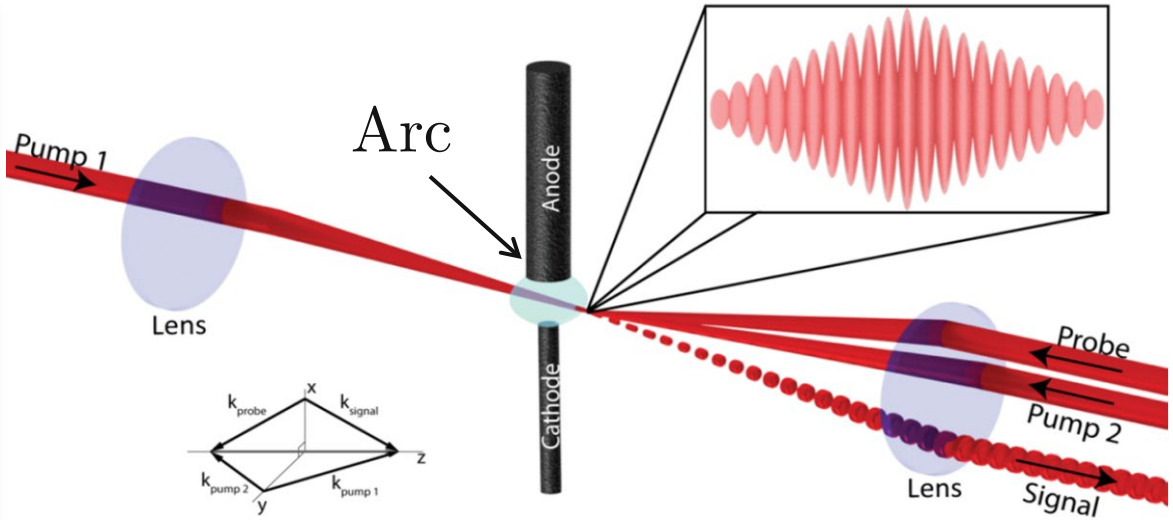
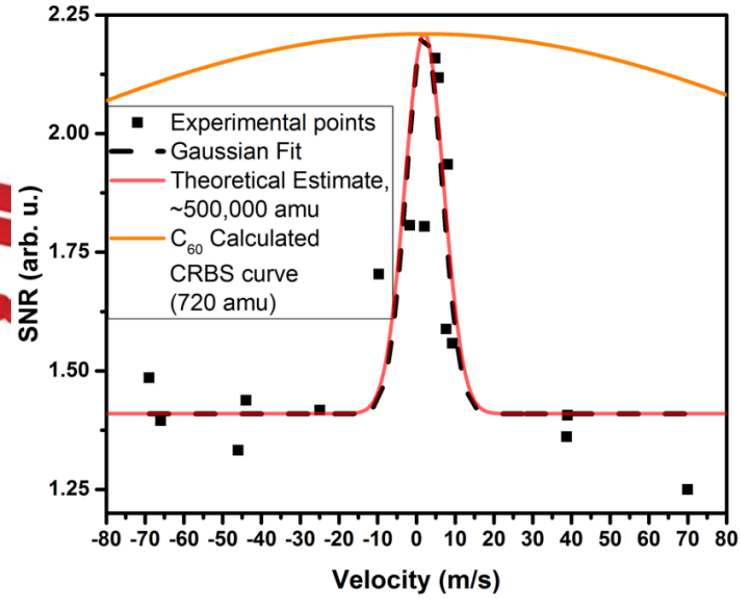
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Nanoparticles in arc discharge measurement



Imaging through C2 filter





For the first time detection of nanoparticles of dimensions of <10 nm, *in situ* in plasma.

- Dimensions: ~6nm
- Density: 10^{12} cm^{-3}

A. Gerakis, Y-W. Yeh, M. N. Shneider, J. M. Mitrani, B. C. Stratton, and Y. Raitses, "Four-Wave-Mixing Approach to *In Situ* Detection of Nanoparticles", Phys. Rev. Applied 9, 014031 (2018)

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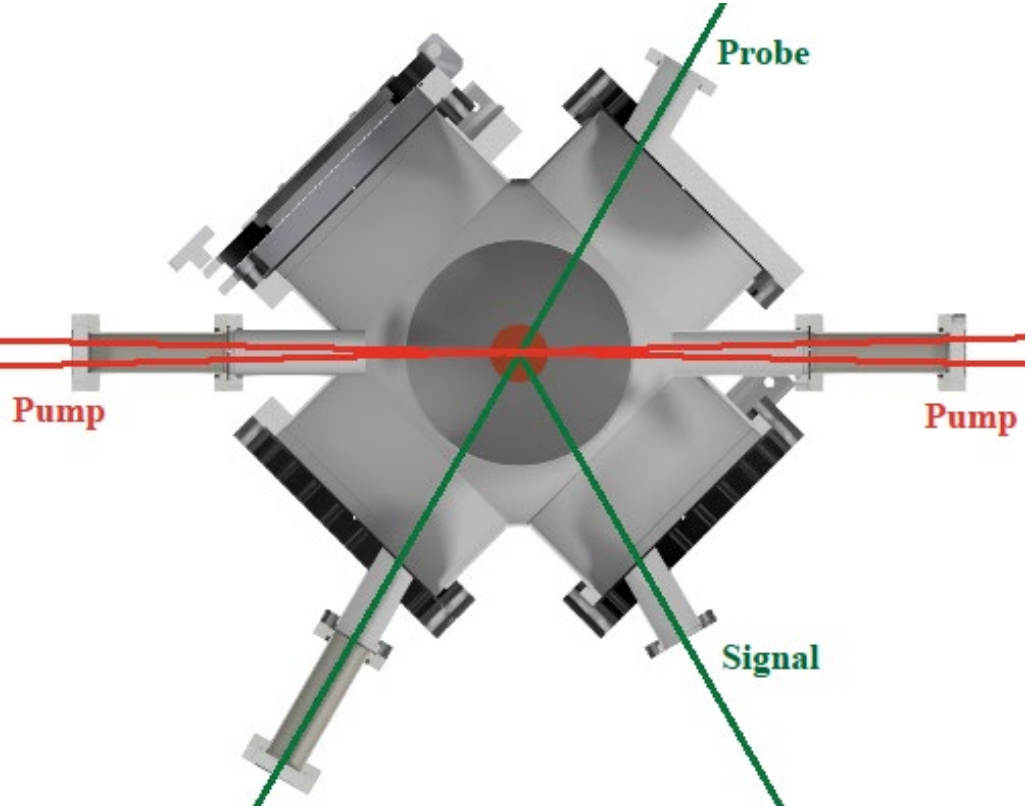
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

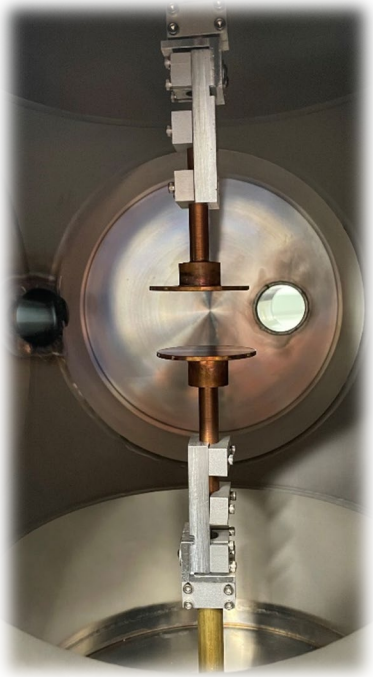
Neutrals in glow discharge measurement

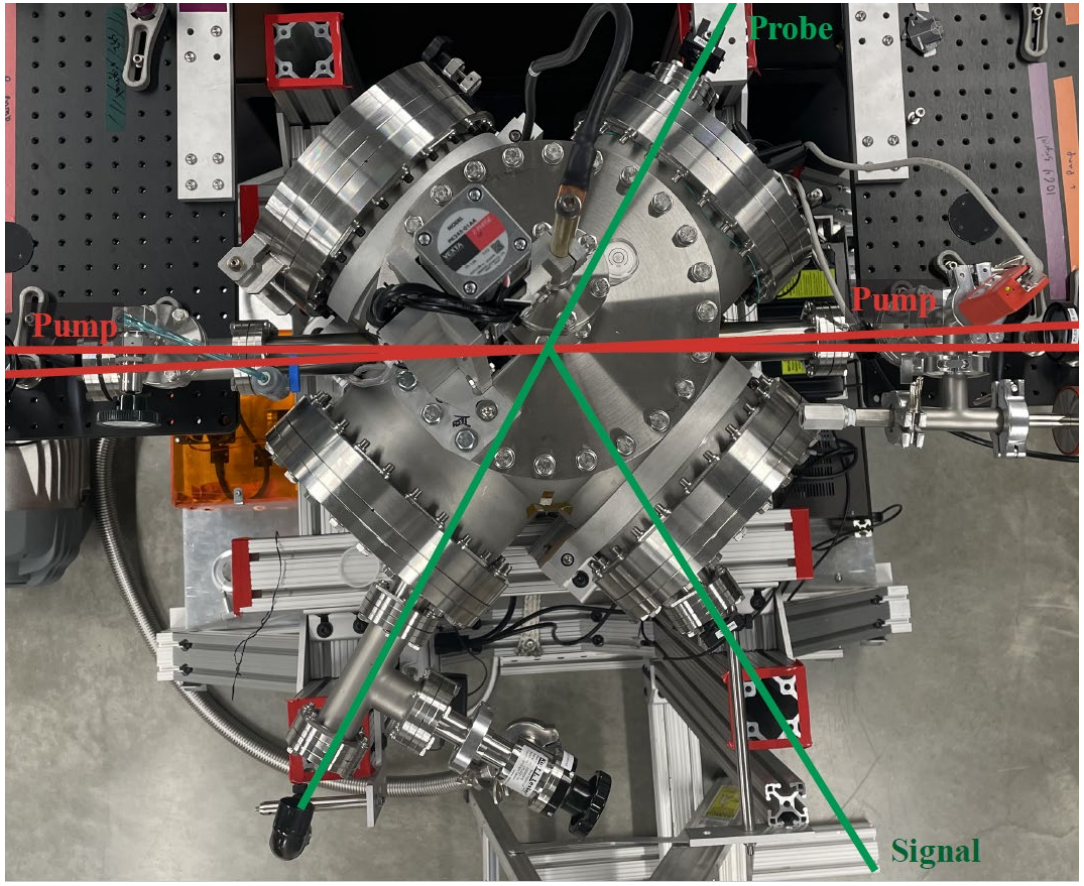
- Measure simultaneously neutral density and translational temperature in glow discharge
  - ➢ Two color, single shot CRBS as means of measurement
  - ➢ Assume ionization ratio small (10^{-6} – 10^{-4}) -> neutrals dominant
  - ➢ Scan radially across the discharge.

COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutrals in glow discharge measurement







Dual color CRBS chamber setup

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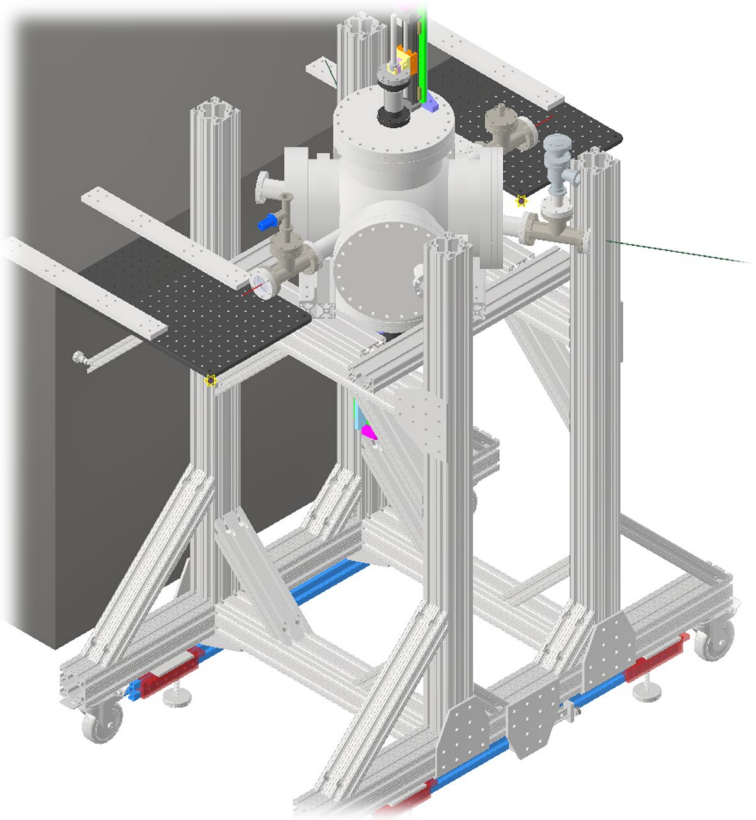
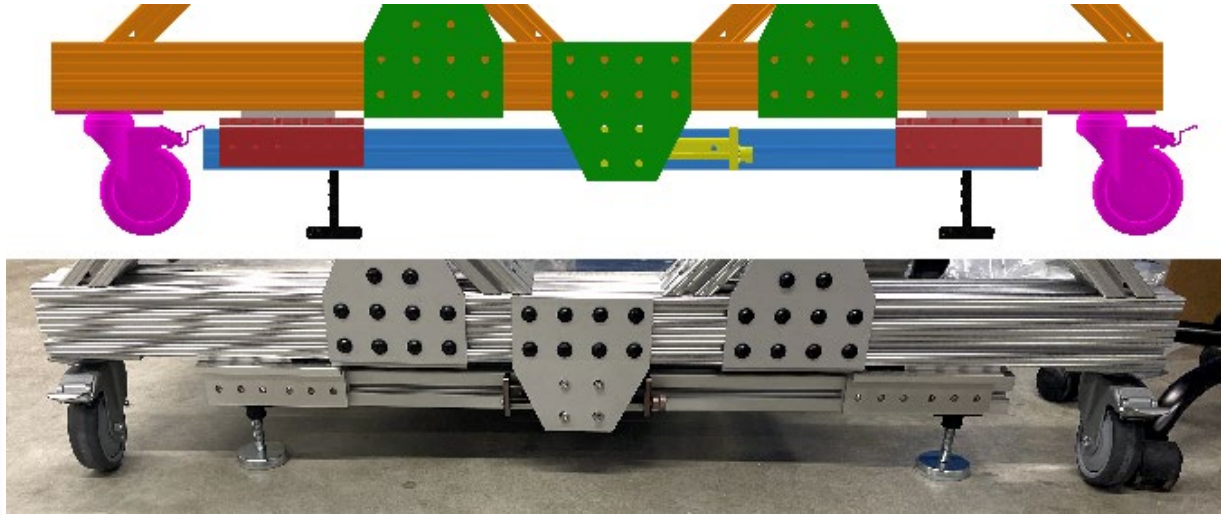
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutrals in glow discharge measurement





- Measurements radially across the positive column of glow discharge, from center to periphery.
  - Assumption: Positive column is radially symmetric
  - Assumption: Operating conditions are the same from point to point and run to run.

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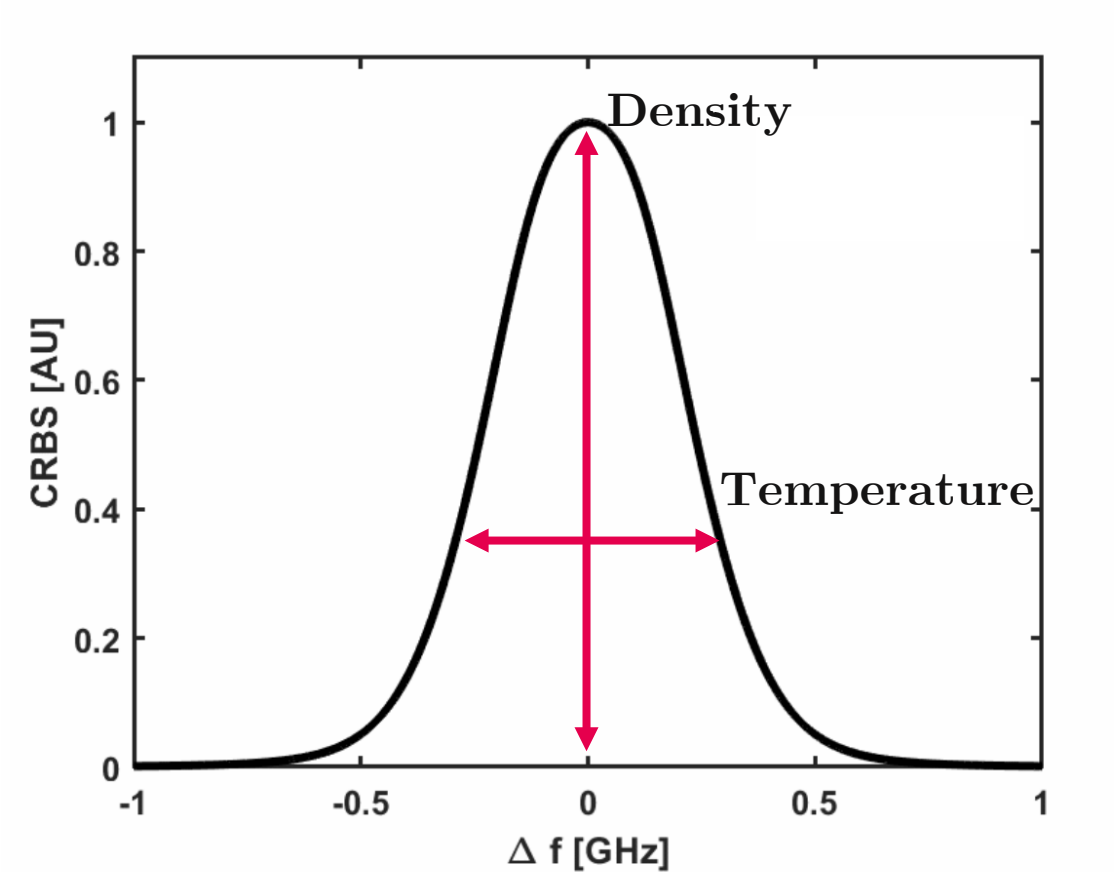
COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutrals in glow discharge measurement



Xenon 15 Torr @300K

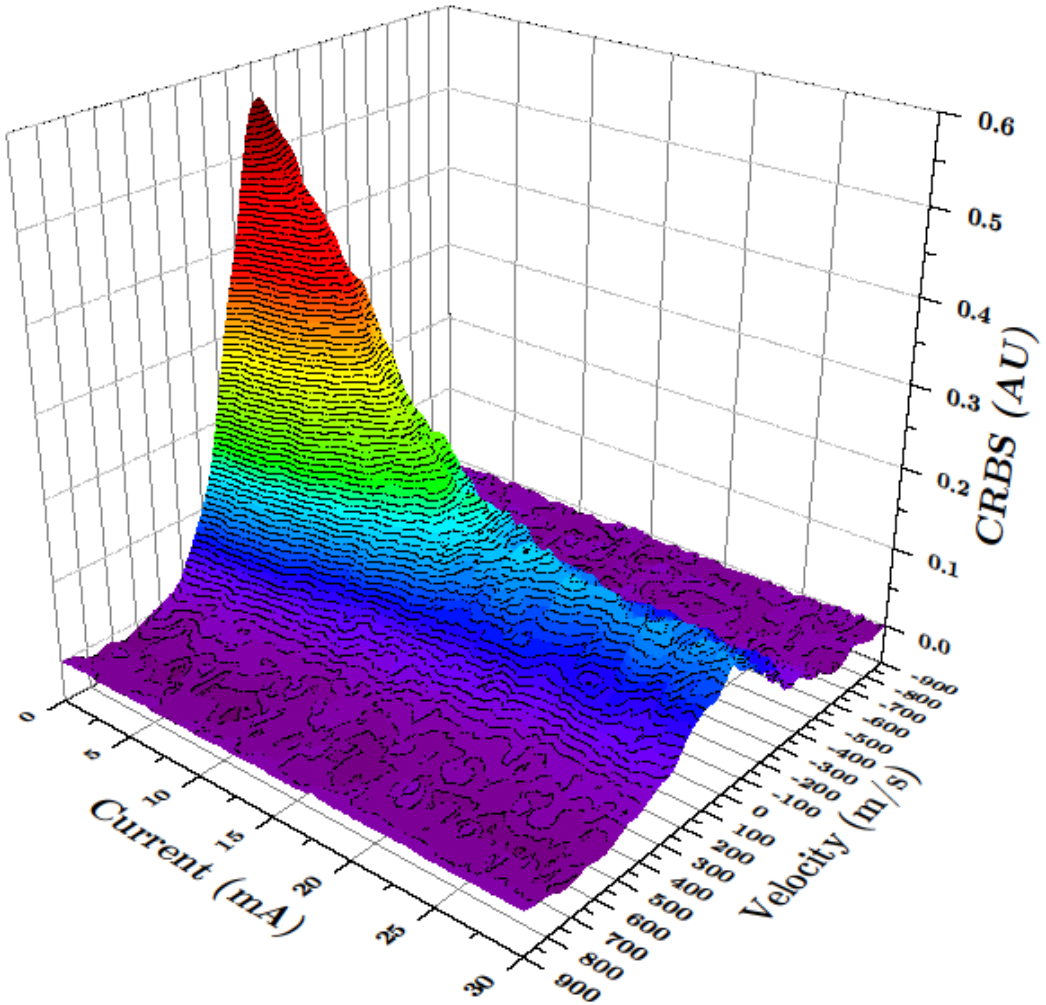
- **Temperature:**

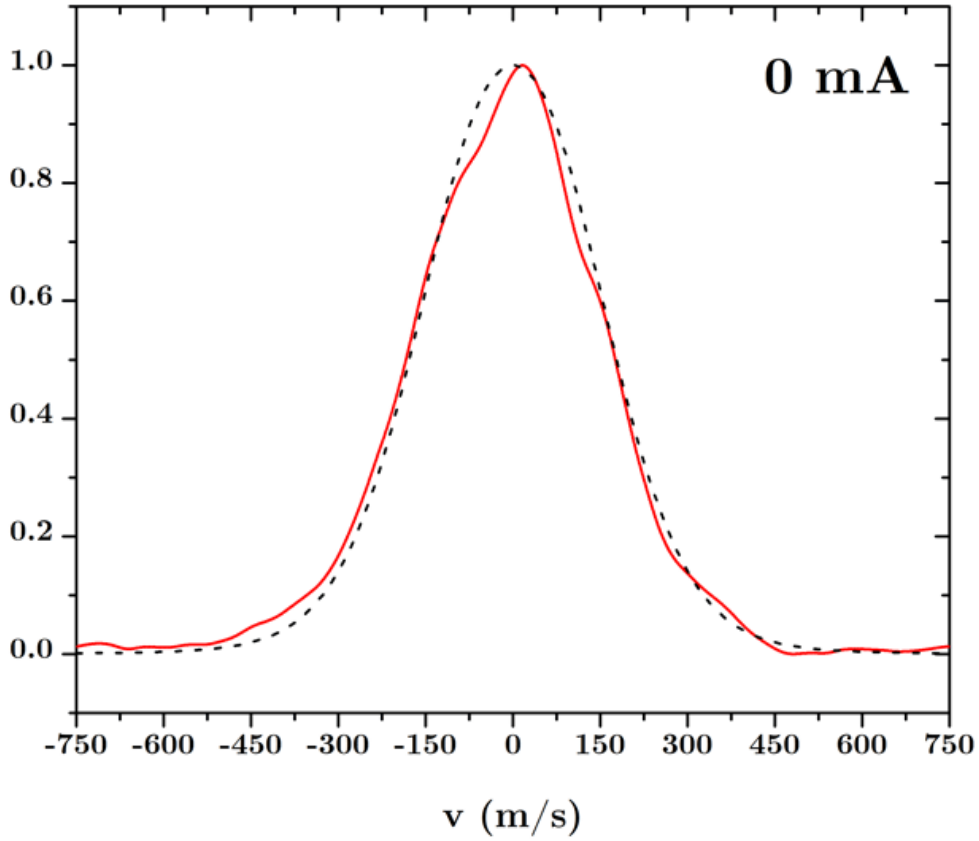
$$f(v_z) \propto e^{\frac{-mv_z^2}{2kT}}$$

- **Density:** $I_S \propto \Delta n^2$

COHERENT RAYLEIGH-BRILLOUIN SCATTERING

Neutrals in glow discharge measurement





Pan, Xingguo & Shneider, M.N. & Miles, R.B.. (2004). Coherent Rayleigh-Brillouin scattering in molecular gases. Physical Review A. 69. 33814-. 10.1103/PhysRevA.69.033814.

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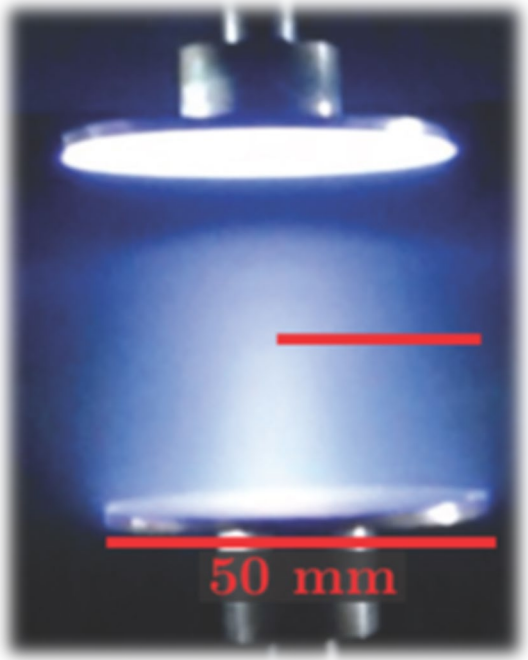
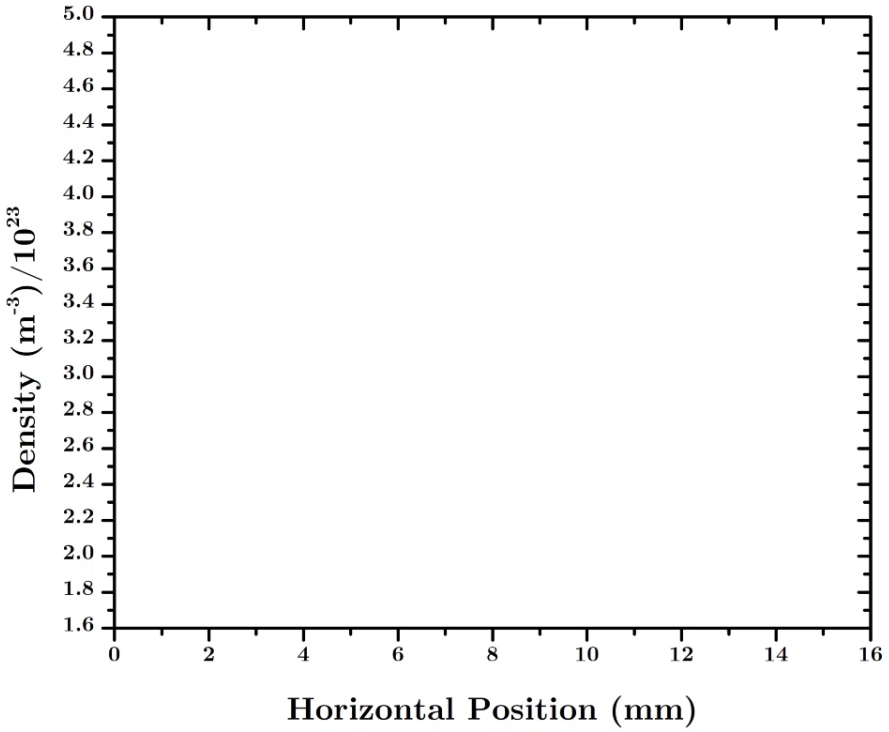
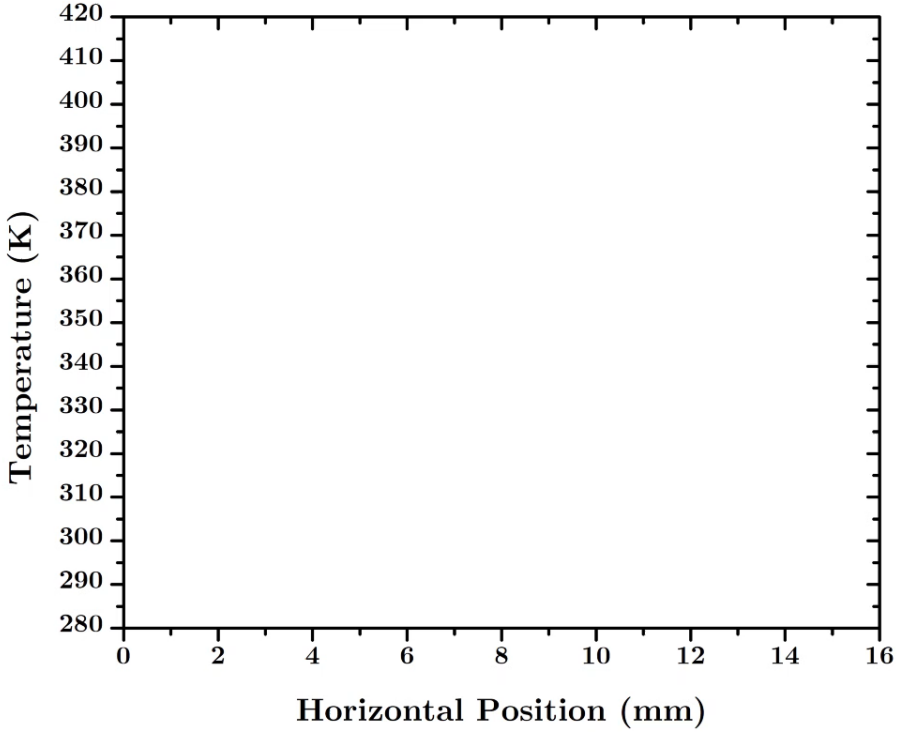
Neutrals in glow discharge measurement



Glow in 15 Torr Xe





- Average of 100 samples taken at each point, samples collected at 10 Hz rate

(single spectrum acquisition time ~150 ns)

	Density (10^{-23} m^{-3})	Temperature (K)
Edge	4.8± 0.4	295± 15
Center	1.9± 0.4	370± 15

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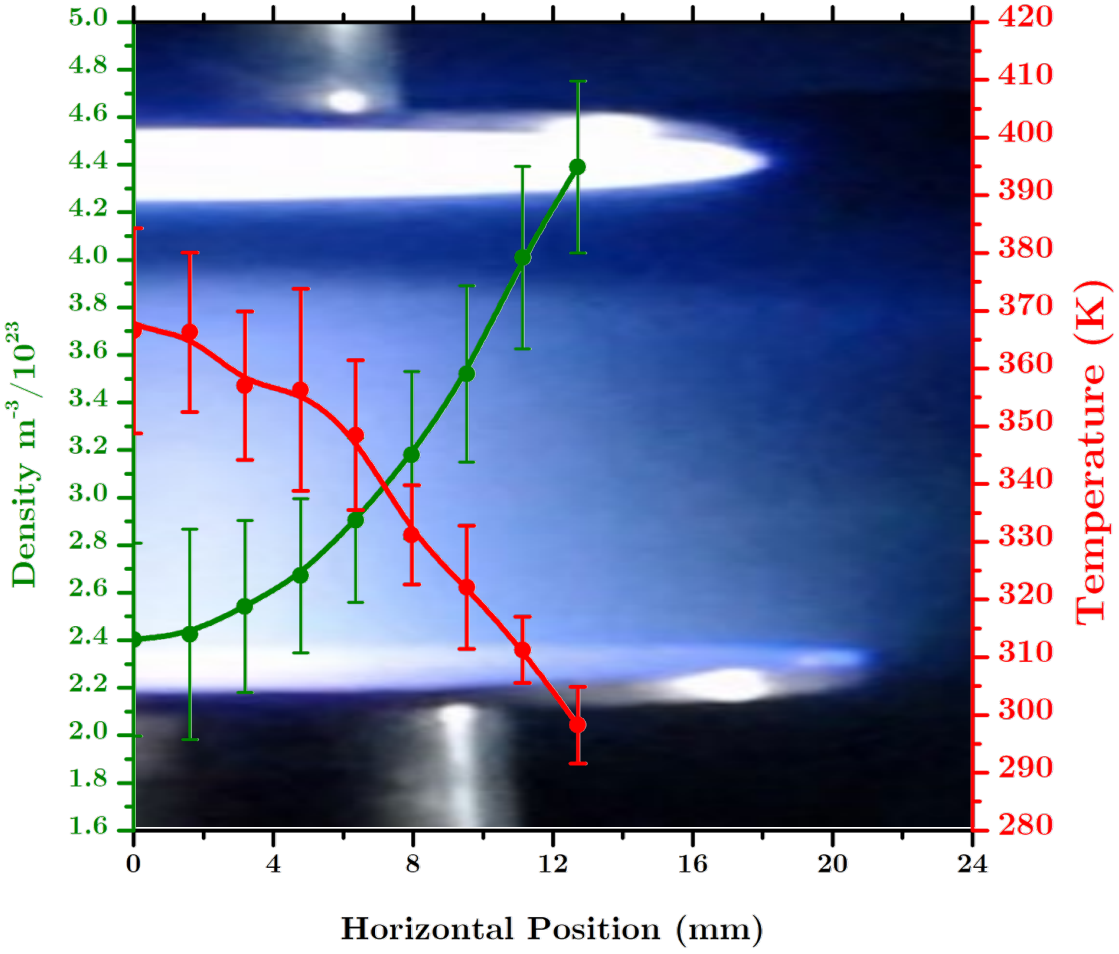
SUMMARY & FUTURE WORK

Simultaneous density and temperature measurements in glow discharge with single shot CRBS

- Spectra in agreement with s7 model

Future Work

- Dimensional extension of CRBS to simultaneous 1D line profile measurements
- Measurement in different types of discharges



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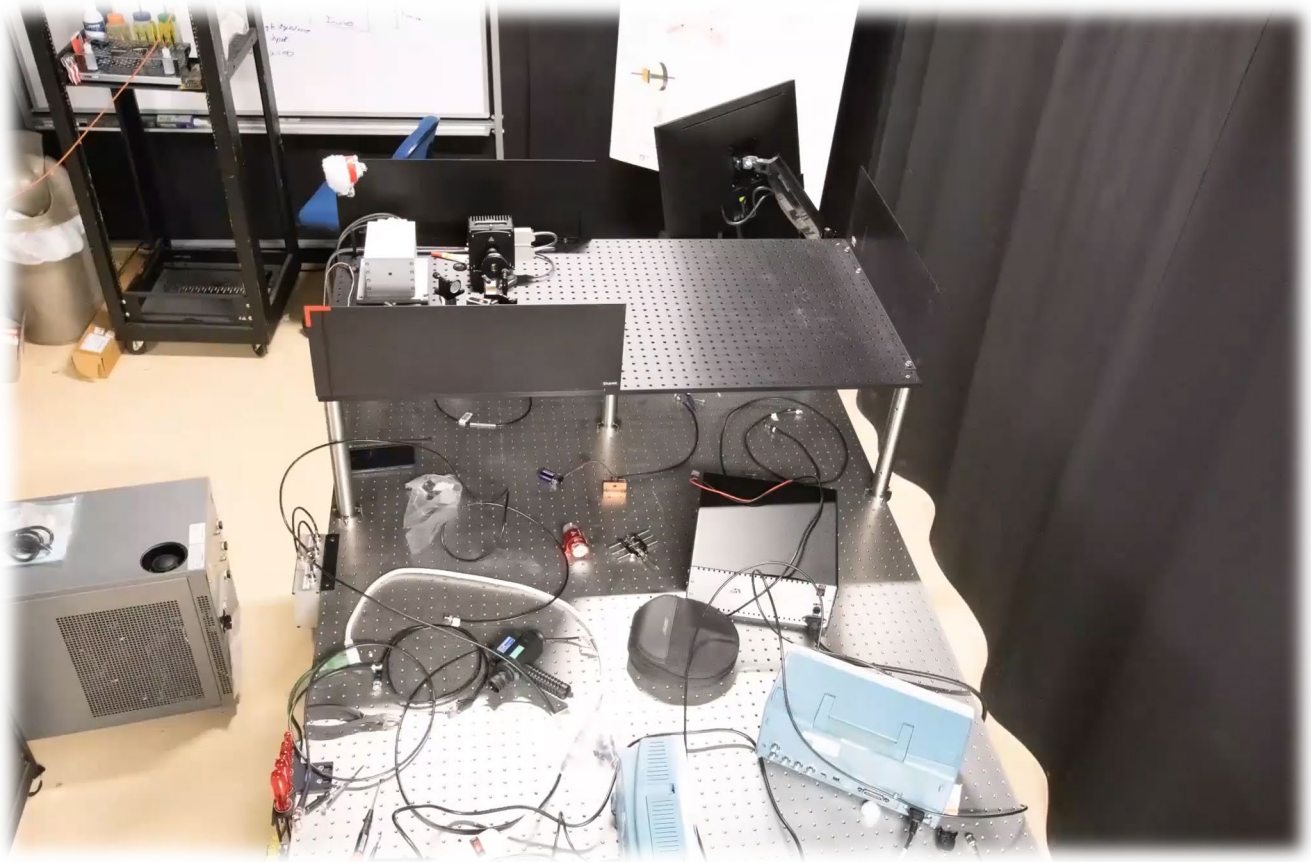

Thank you!
Questions?

www.gerakis-lab.com
alexandros.gerakis@list.lu

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