Microsecond Lifetime Nitric Oxide MTV with 1+1 REMPI

Spectral Energies

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Hypersonic Measurements

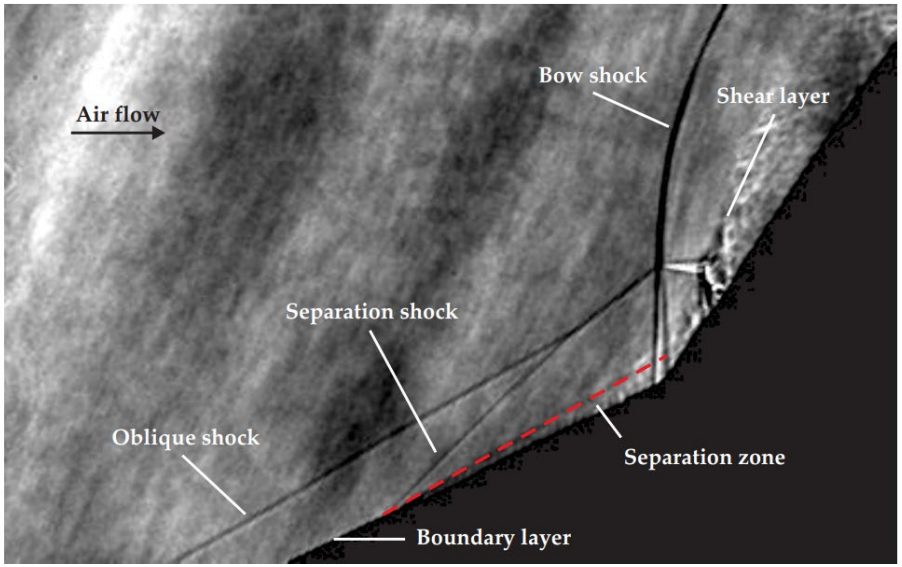
Hypersonic measurements are crucial to understand underlying physics

Boundary layer transition

- Understand where/why/when boundary layer (BL) transitions

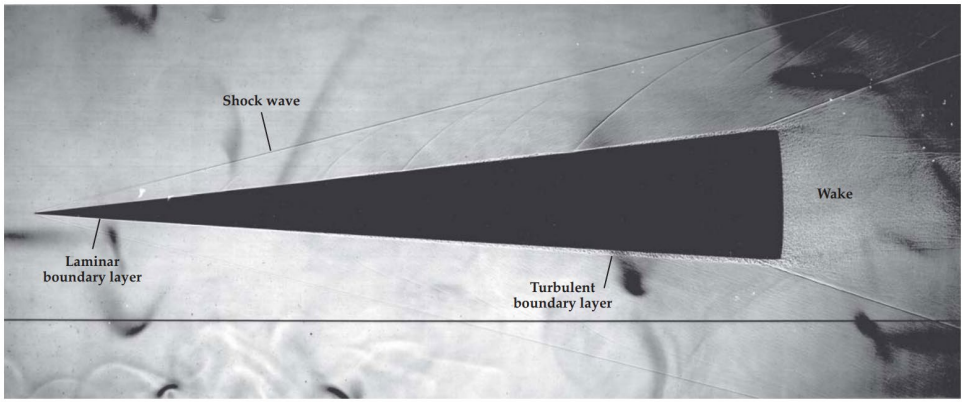
Shock-boundary layer interaction

- Resolution of shock wave and BL crucial to determine impact on BL



Our Goals:

- Develop/implement high-rep-rate (1 – 100 kHz), noninvasive diagnostics to characterize *V*, ρ, *T*, … in hypersonic environments

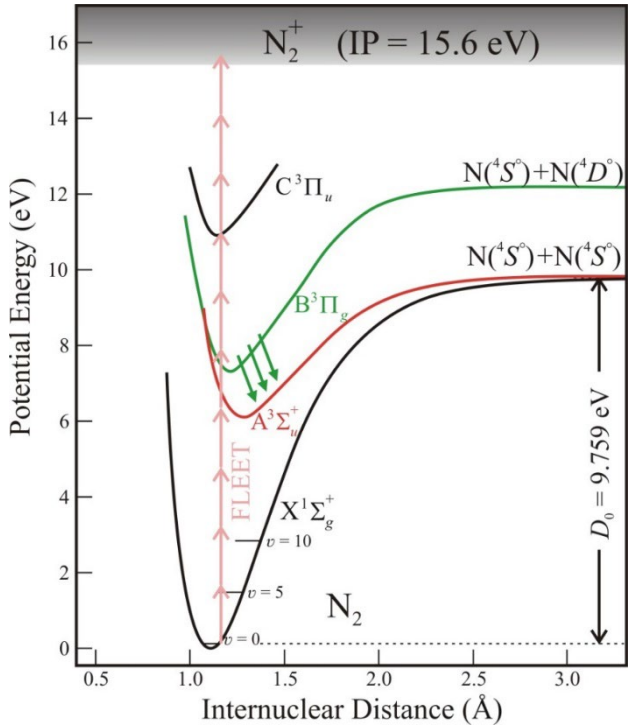


Schneider (2004)

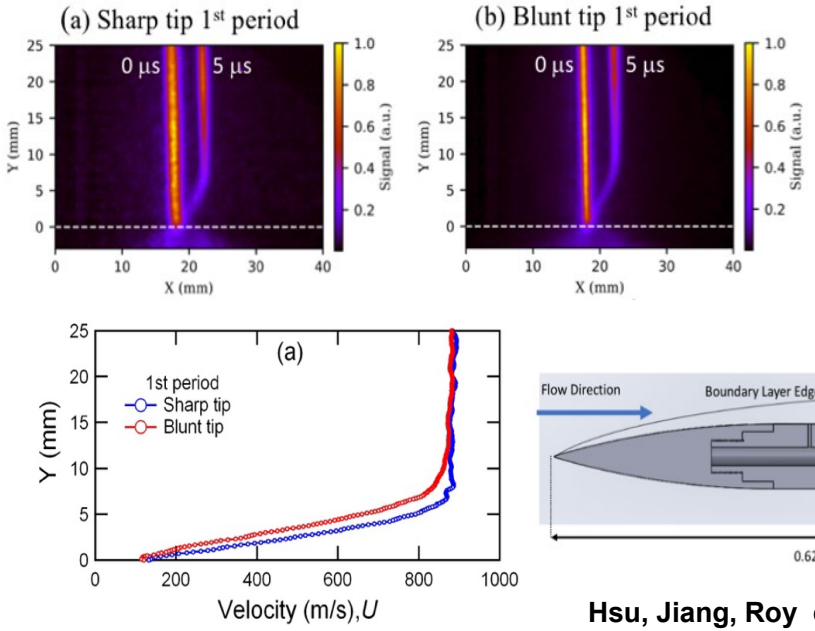
Molecular Tagging Velocity (MTV) Diagnostics and their Challenges for Hypersonic Flows

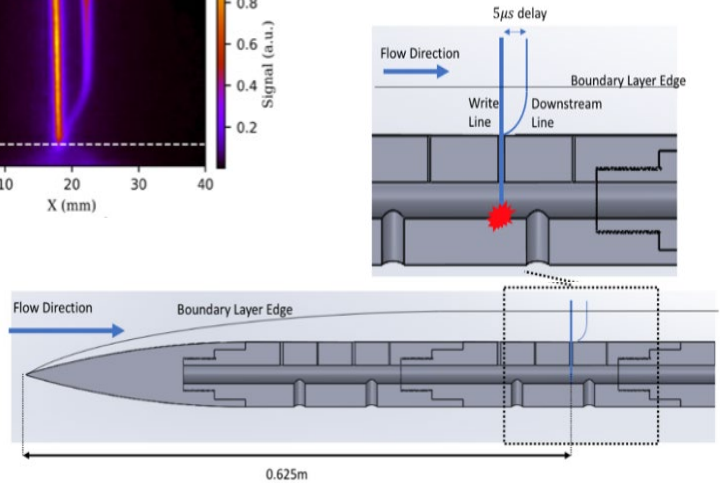
***F**emtosecond **L**aser **E**lectronic **E**xcitation and **T**agging (*FLEET*): Unseeded MTV*

BL Velocity Profile Measured by 1-kHz FLEET in AFRL Mach 6 Ludwieg Tube



J. Michael, R. Miles et al, Appl. Opt. 50, 5158, 2011.



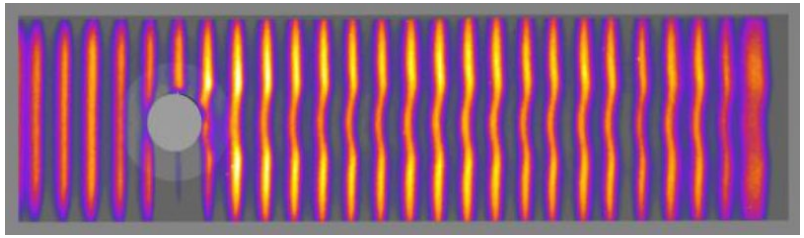


Hsu, Jiang, Roy et al., Applied Optics Vol. 60, pp. C38-C46 (2021)

- Limited to 1 kHz
- High-power laser pulse can cause model damage

Molecular Tagging Velocity (MTV) Diagnostics and their Challenges for Hypersonic Flows (Cont'd)

Nitric Oxide (NO) and Krypton (Kr) MTV

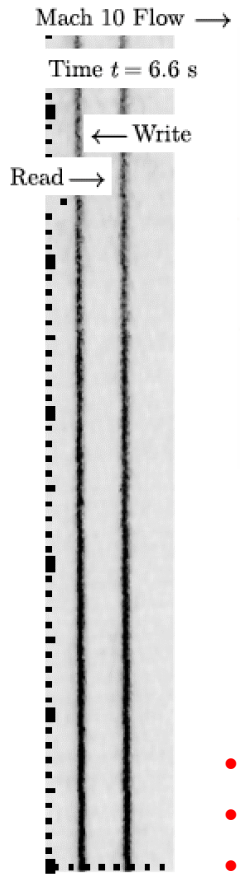


NO MTV in Mach 10 Tunnel at NASA Langley

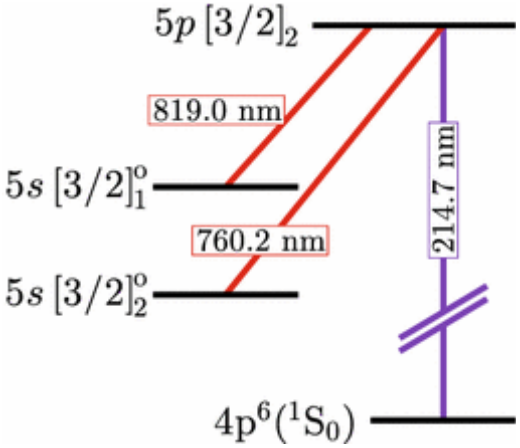
BF Bathel, PM Danehy, et al, AIAA J. 2011.

- Short fluorescence lifetime ~ 200 ns *only* in low-pressure hypersonic flow – cannot measure velocity at higher densities where BL transition occurs (need microsecond lifetime)

10-Hz KTV



Two-line KTV



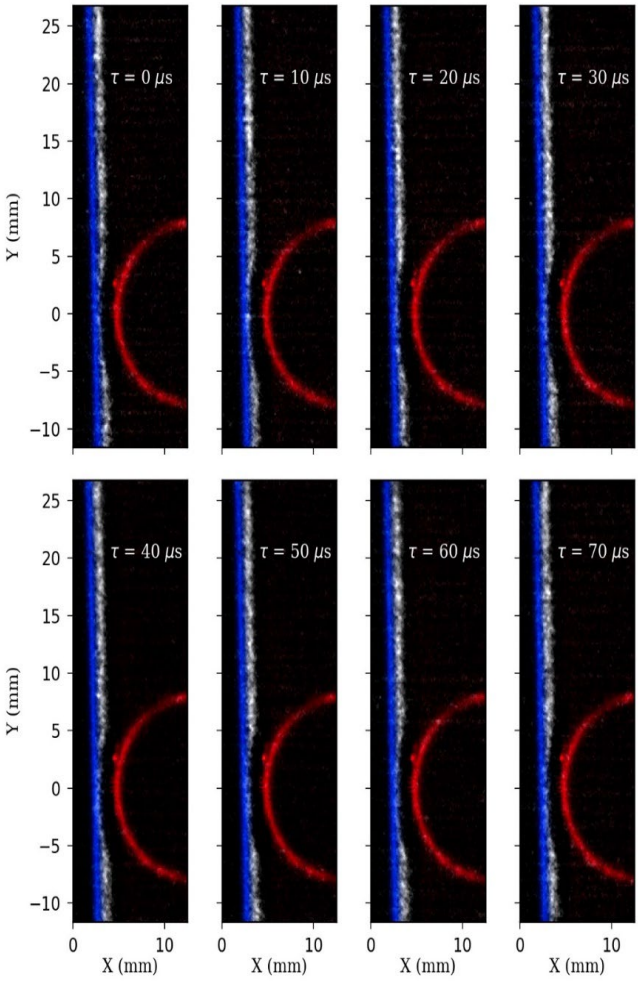
N. Parziale, et al.
AIAA Scitech 2015.

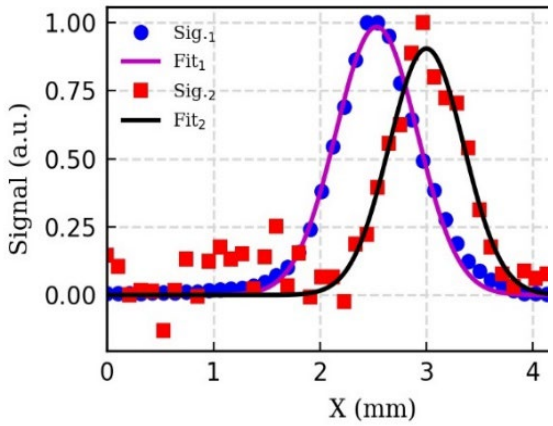
- Complex laser system
- Kr gas is very expensive
- Slow data acquisition speed

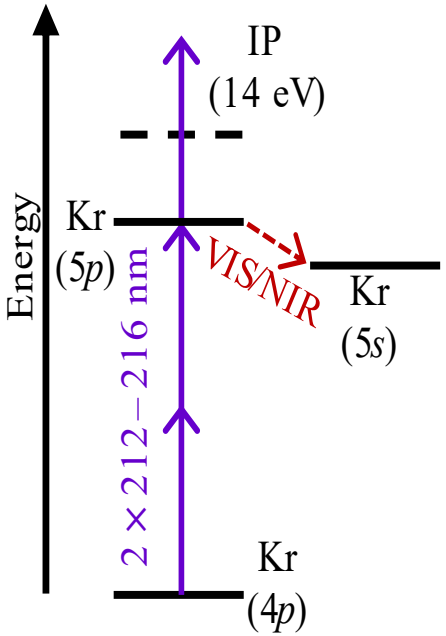
Molecular Tagging Velocity (MTV) Diagnostics and their Challenges for Hypersonic Flows (Cont'd)

100-kHz single beam KTV using burst-mode OPO

Applied Optics Best Paper Prize of 2022

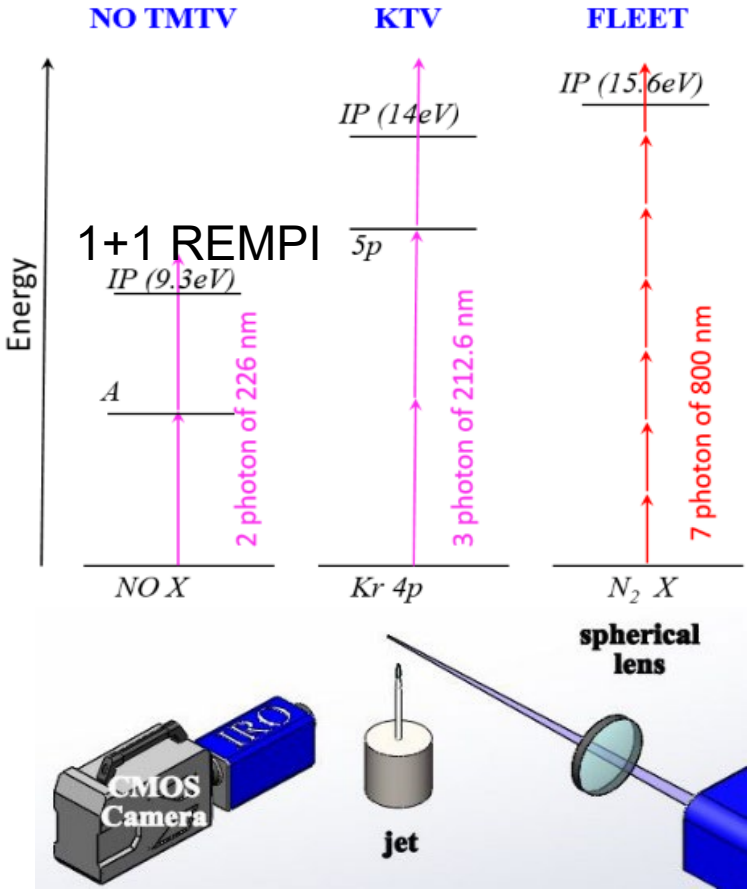




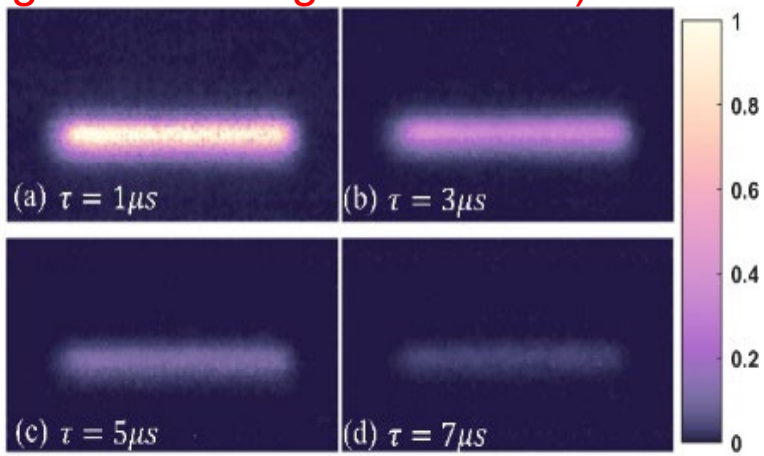


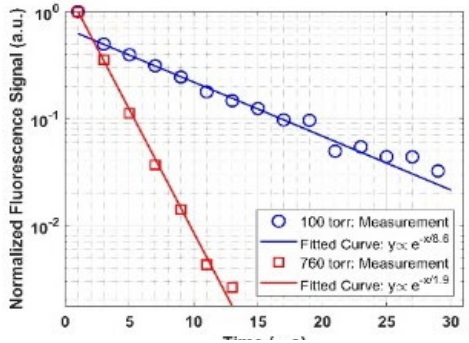
- Kr gas is very expensive
- Still need ~5-7 mJ/pulse in deep UV for KTV (3-photon Kr ionization)

New Method: Microsecond Lifetime Nitric Oxide MTV with 1+1 REMPI



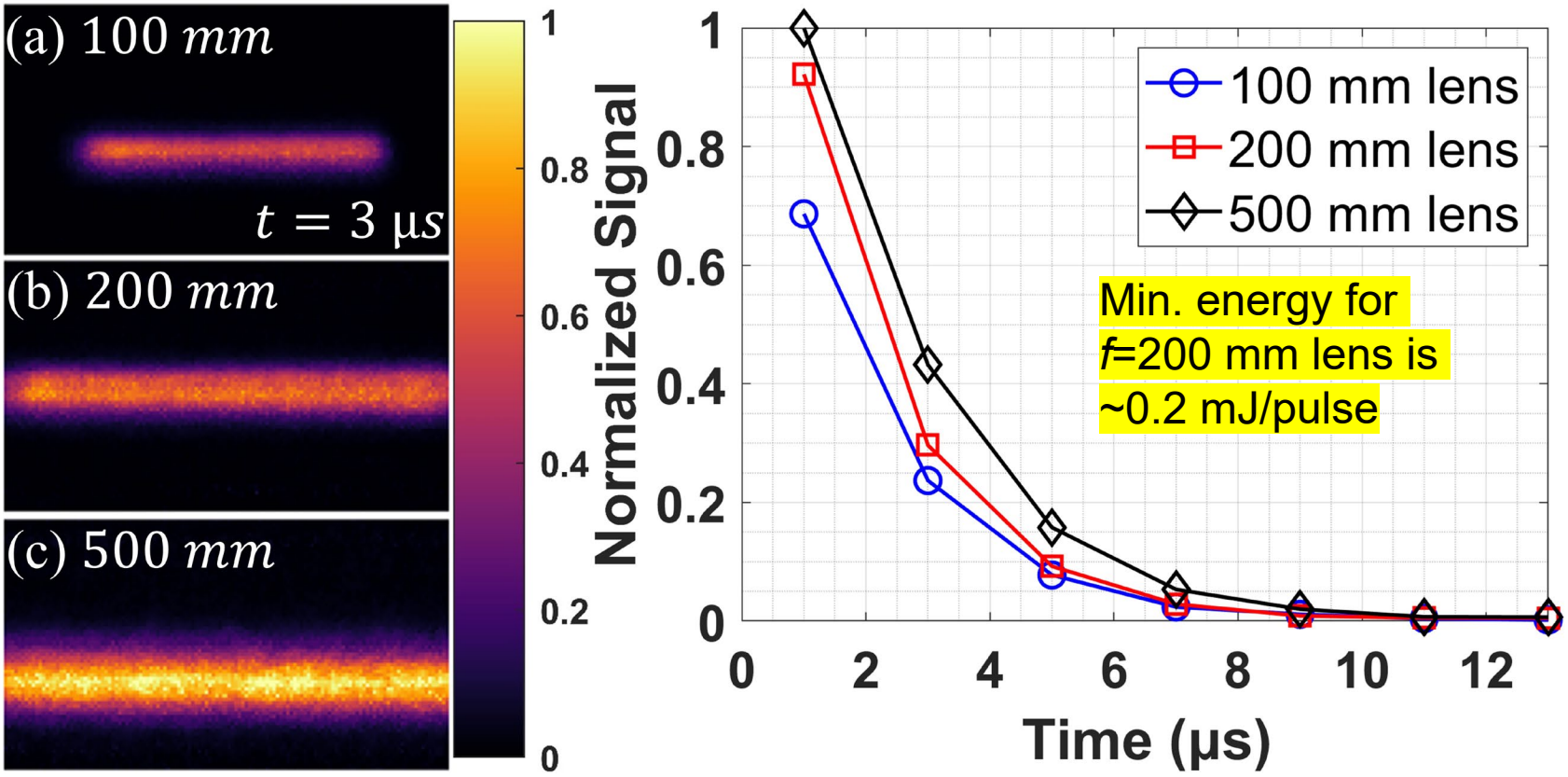
Evidence of long-lived NO fluorescence (Signal wavelength < 300 nm)





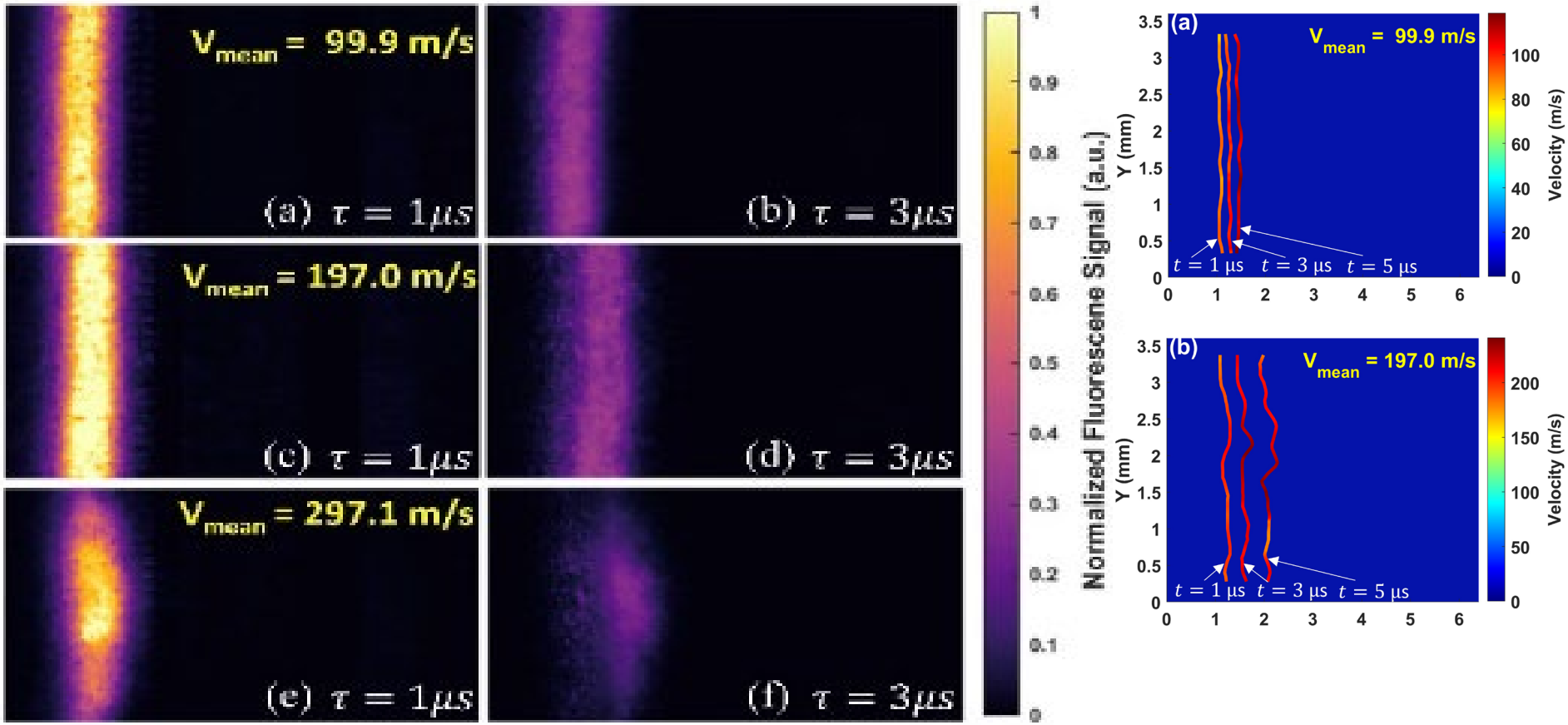
- NO is naturally occurring in many facilities (arc jets, arc-heater tunnels, and shock tunnels) but must be seeded into other tunnels and is toxic and corrosive
- Microsecond long-lived signal – ideal for hypersonic freestream and BL flow
- Capable to be operated at high and low pressure conditions

Impact of Focal Length on NO REMPI MTV Signal



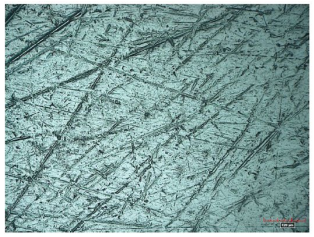
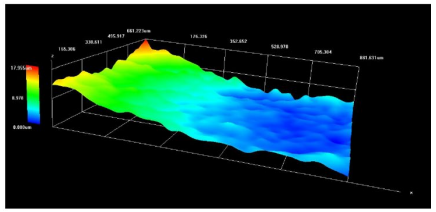
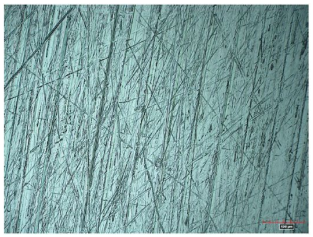
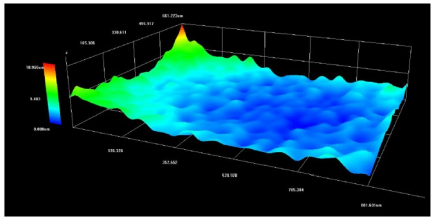
- No noticeable differences were observed in the lifetime of the NO MTV signal
- NO MTV signal exhibits greater signal strength with longer focal length lenses. This phenomenon serves as evidence that the NO MTV process does not necessarily requires high-energy laser pulses.

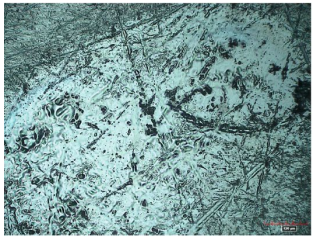
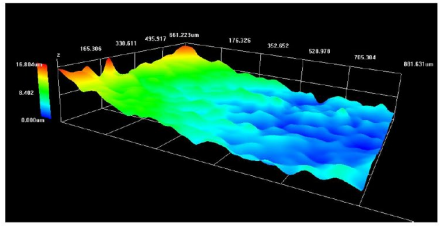
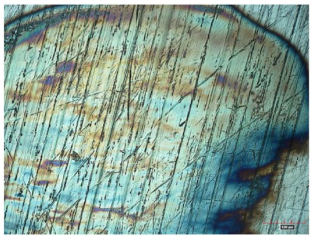
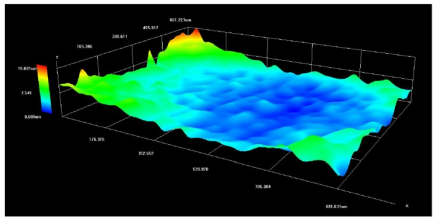
NO REMPI MTV for Transonic Flow Condition

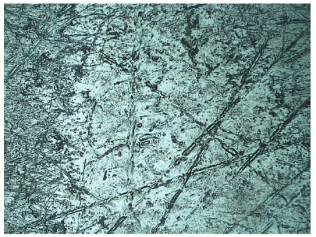
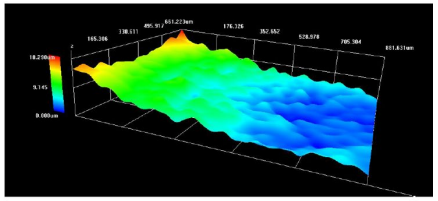


Material Damage Test (Polished Samples)

Aluminum ~2 mJ/pulse, 500 pulses Stainless Steel 316



Original surface





F=+300 mm

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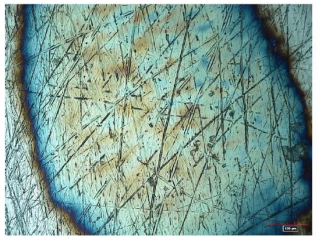
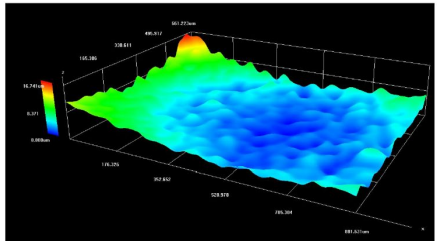

- **No major deviation from typical surface (discoloration but no damage)**

Summary

- Successfully demonstrated the long-lived NO MTV with 1+1 REMPI method employing a single laser beam.
- NO MTV with only two photons offers advantages over processes requiring three or more photons, such as KTV or FLEET. Additionally, this approach demands significantly less laser pulse energies.
- We measured the REMPI MTV fluorescence lifetime under various pressures and have proposed an underlying mechanism based on experimental evidence. We believe that the observed REMPI MTV signal originates from NO fluorescence rather than nitrogen emission. The technique was demonstrated in jet flows for velocimetry and has broad applicability for both reacting and non-reacting flow velocity measurements.
- The required UV laser pulse energy/intensity for NO REMPI MTV *does not damage* polished aluminum and stainless steel surface (even with high intensity using F=+300 mm lens)

Acknowledgement

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Thank you for your attention!!