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Shock-wave Distortion Cancellation using Ultra-high-speed Phase-conjugate Digital In-line Holography

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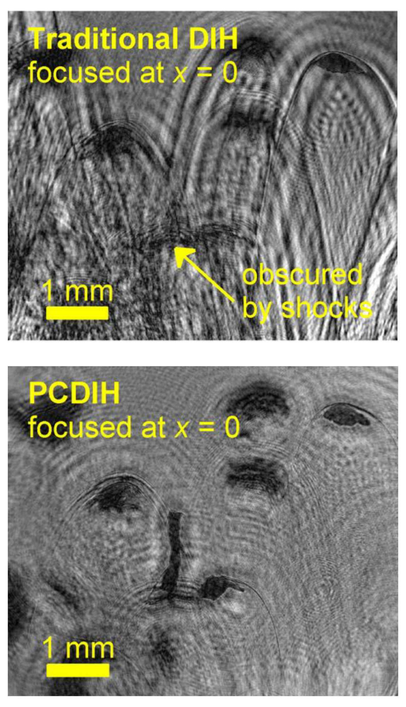
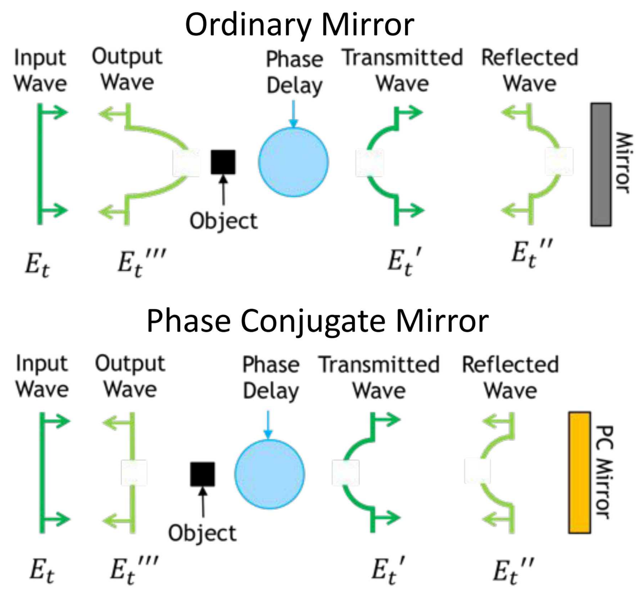
Motivation & Approach

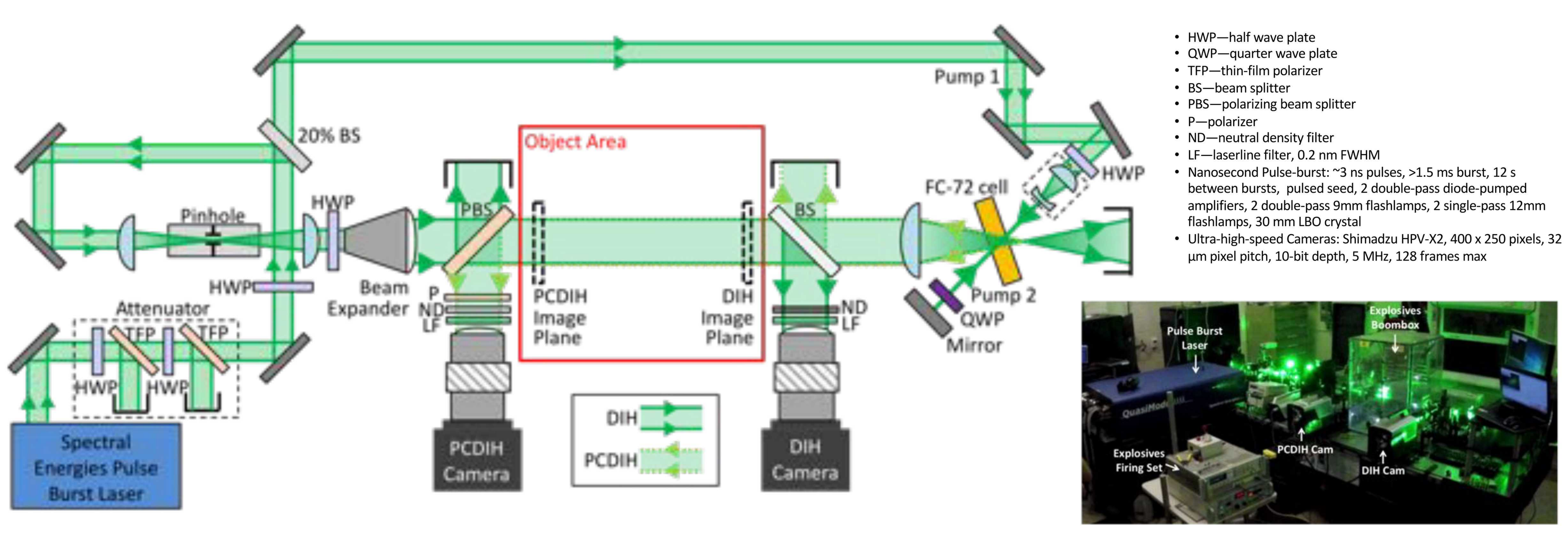


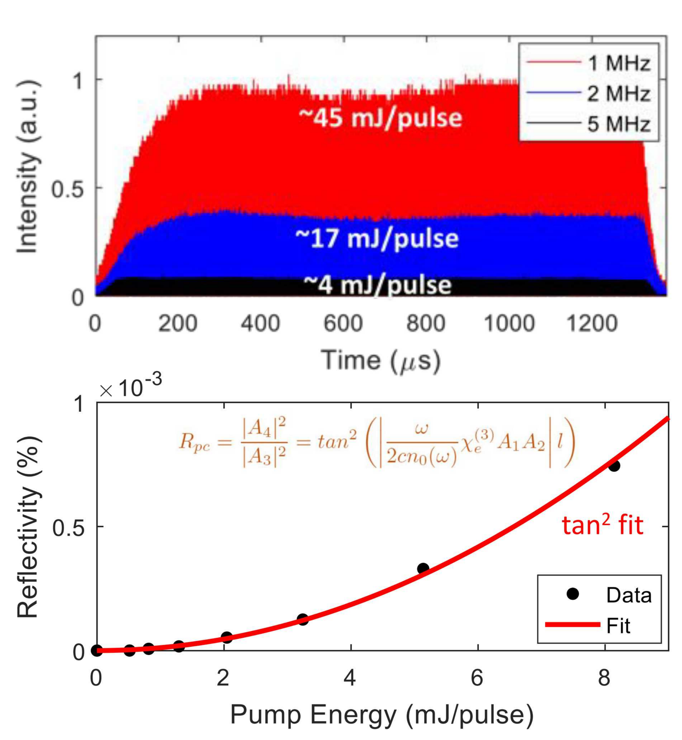
- Shock-wave distortions in coherent imaging prevent accurate 3D interrogation in supersonic, hypersonic, and explosive environments.
- Existing approaches use synchrotron x-rays and experimental repetition to reconstruct 3D motion.
- We propose to **cancel distortions** using ultra-high-speed phase conjugate digital in-line holography (PCDIH).
- We aim to increase acquisition rate from 10 to 20 Hz (limitation of conventional high power pulsed lasers) to 2 to 5 MHz, an increase by > 5 orders of magnitude.

Concept & Apparatus

- When coherent light passes through a shock-wave, it accumulates phase distortions.
- If this light is passed through a phase conjugate (PC) mirror and back through the shock-wave, the phase distortion cancels.
- Ultra-high-speed PCDIH is implemented in a four-wave-mixing topology with a pulse burst laser and Shimadzu cameras from 0.5 to 5 MHz imaging rates and 0.5 to 1.5 ms burst durations.



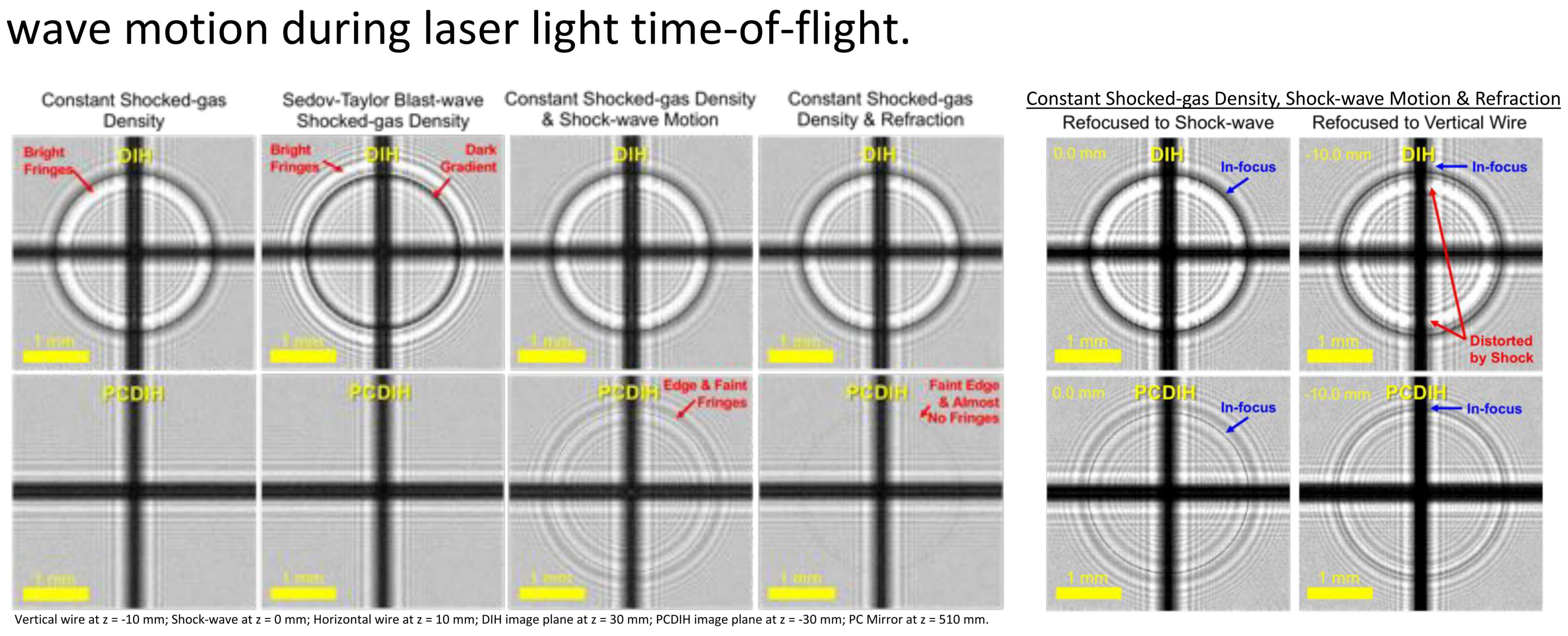




- The energy per pulse from the laser decreases as repetition rates increase due to the fixed amount of energy in the flashlamps and the decrease in wavelength conversion efficiency due to lower irradiance.
- As the energy per pulse decreases, the PC mirror reflectivity decreases.
- These factors increase the difficulty of obtaining ultra-high-speed PCDIH images.
- Alignment of a four-wave mixing system with one burst every 12 seconds is also complex.

Simulations

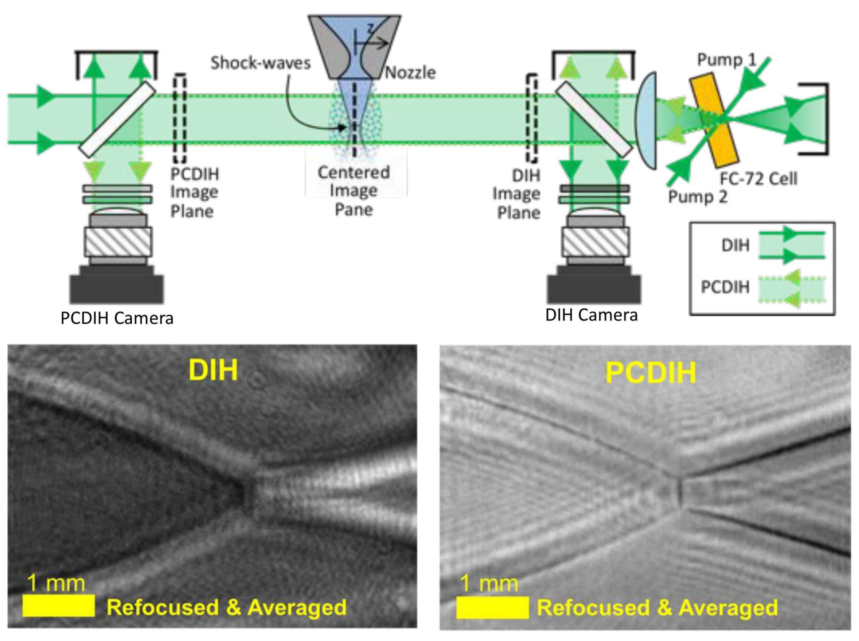
- Simulations aim to understand the physics that produce unknown features in DIH and PCDIH images. Results show that shock-waves distort DIH images.
- Fainter shock-wave edges are visible in PCDH due to refraction and shock-wave motion during laser light time-of-flight.



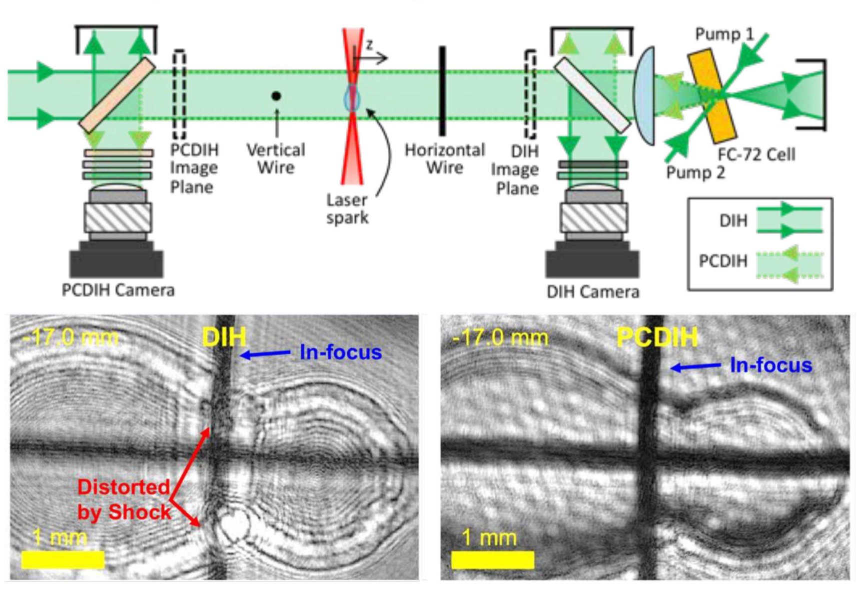
Vertical wire at z = -10 mm; Shock-wave at z = 0 mm; Horizontal wire at z = 10 mm; DIH image plane at z = 30 mm; PCDIH image plane at z = -30 mm; PC Mirror at z = 510 mm.

Ultra-High-Speed Experiments

Supersonic Air Jet

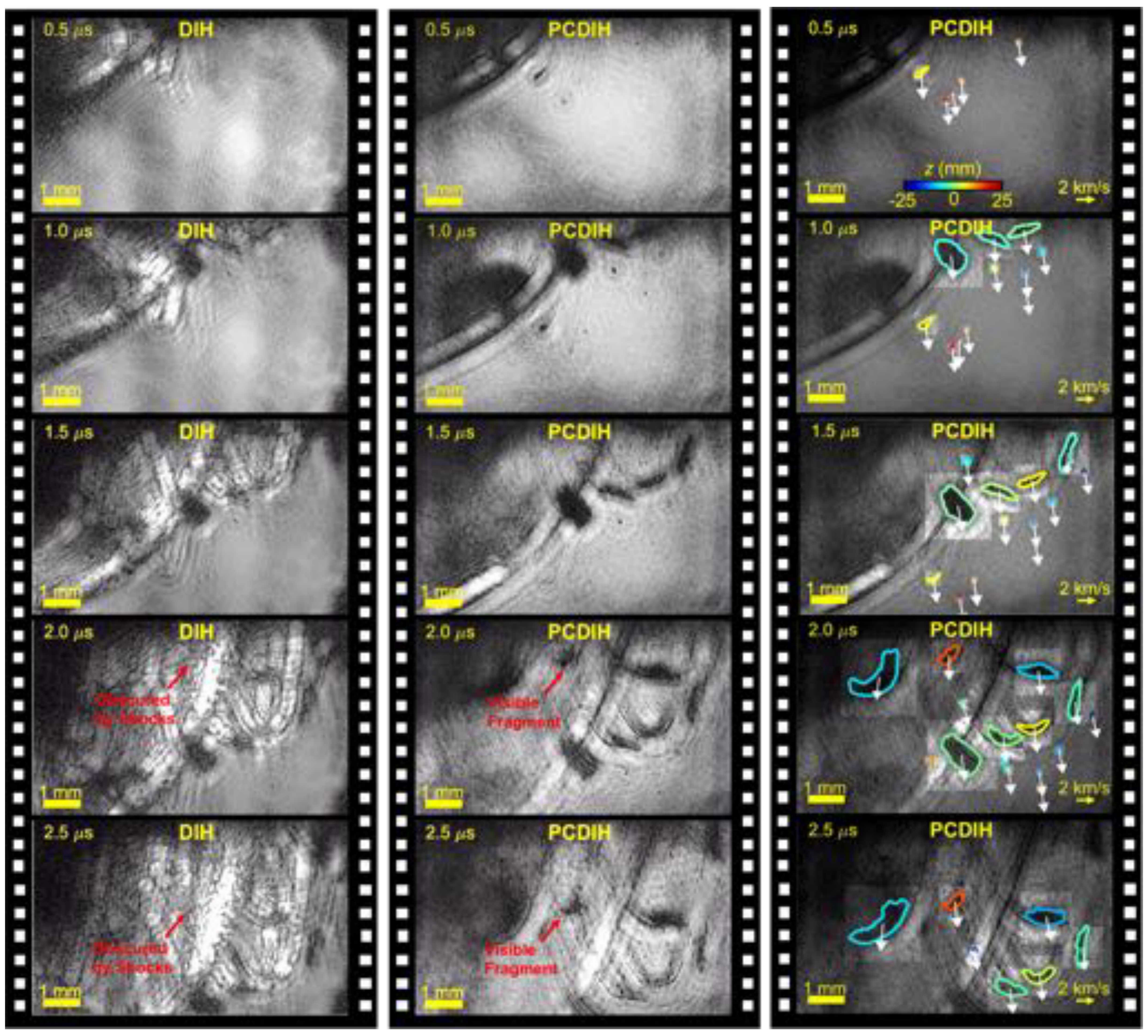


Laser-spark Plasma-generated Blast-waves



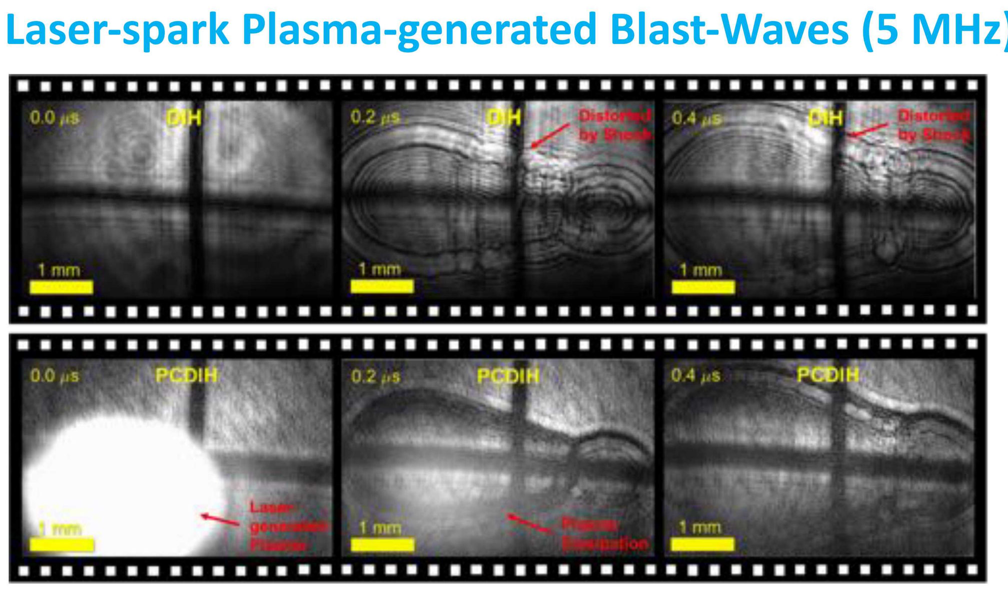
- Phase distortion cancellation experiments were conducted in supersonic air jets, blast-waves generated by laser-spark plasmas, and explosively generated fragments.
- Stationary supersonic shock-waves show how PCDIH enables refocusing of the entire shock-wave to a single plane, which is not possible with DIH.
- PCDIH can be refocused to shock-wave edges, which enables measurements of multiple shock-waves at multiple depths simultaneously.
- Measurements show severe distortions in DIH and minimized distortions in PCDIH.
- Experiments with explosive bridge-wire detonators generate fragments traveling at up to 2.5 km/s that can be tracked in three-dimensions using PCDIH images captured at 2 MHz.

Explosively Generated Fragments (2 MHz)



Conclusions & Future Work

Laser-spark Plasma-generated Blast-Waves (5 MHz)



- Ultra-high-speed PCDIH successfully minimizes phase distortions for improved 3D tracking up to 5 MHz in supersonic, hypersonic, and explosive environments.
- Future work focuses on measurement of phase effects.
- We also aim to study alternative topologies for holography and PC mirror concepts to improve signal to noise and further minimize distortions.

References

- **Y. Chen**, J. D. Heyborne, D. R. Guildenbecher, M. E. Smyser, and M. N. Slipchenko, "Ultra-high-speed Pulse-burst Phase Conjugate Digital In-line Holography for Imaging Through Shock-wave Distortions," 57th AIAA SciTech, AIAA 2019-1602, 2019.
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- J. D. Yeager, P. R. Bowden, D. R. Guildenbecher, and J. D. Olles. "Characterization of Hypervelocity Metal Fragments for Explosive Initiation," Journal of Applied Physics, vol. 122, 035901, 2017.

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