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Measurements of Transient Phenomena in a Shock Tube using Pulse-Burst PIV

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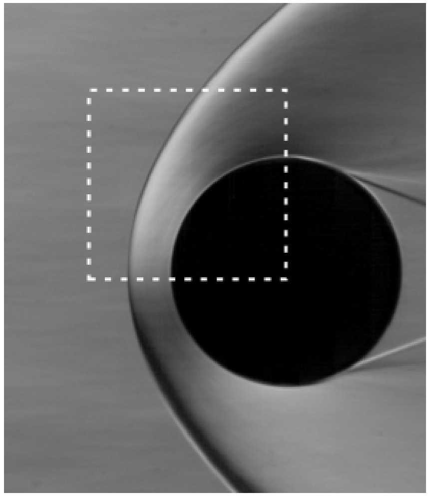
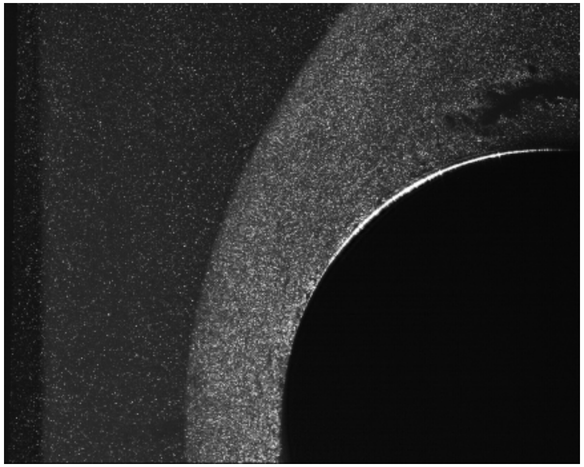
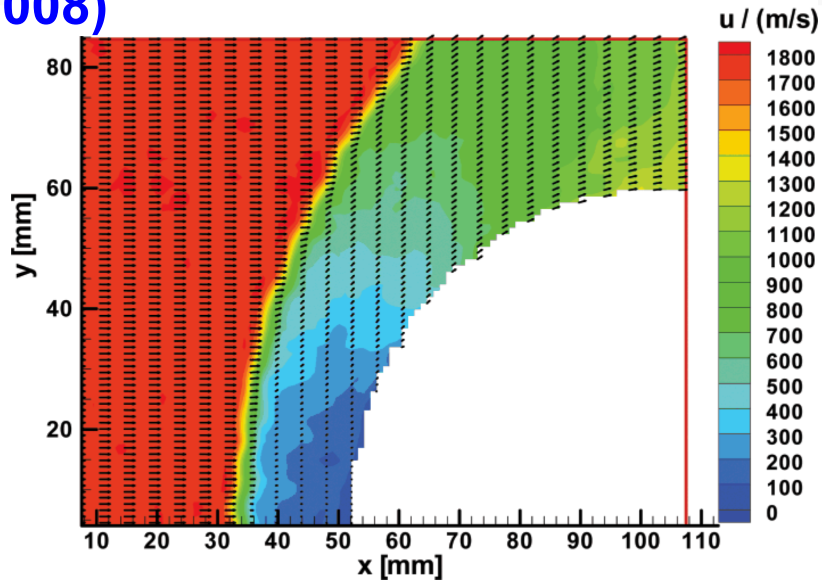
Previous PIV in Shock Tubes and Shock Tunnels

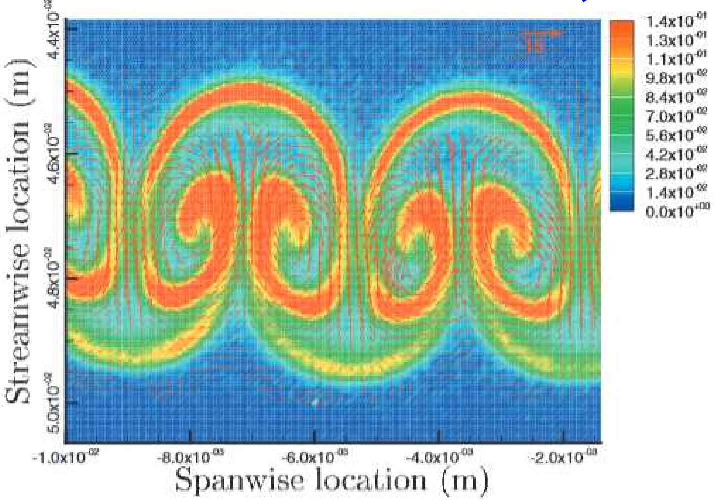
Cylinder Flow at ISL, Havermann et al. (2008)







Richtmeyer-Meshkov Interaction at LANL, Balakumar et al. (2008)



Insightful results, but conventional PIV gives only one realization in the ~ 1 ms test time of a shock tube.

Also: Bonazzo et al at Wisconsin, Jacobs et al at Arizona, Vorobieff et al at New Mexico

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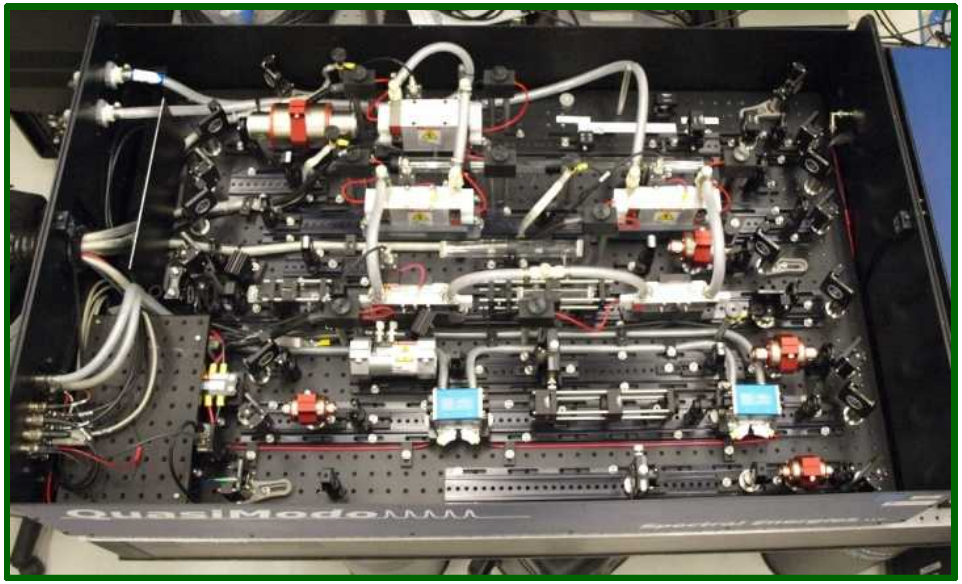
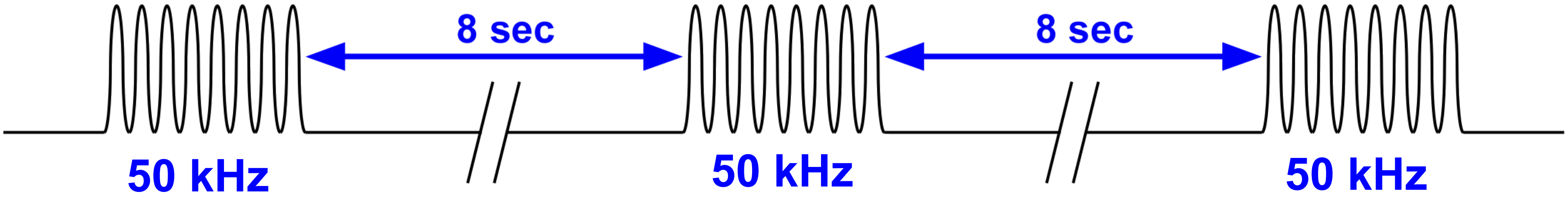
Pulse-Burst PIV

Spectral Energies Quasi-Modo Laser



Burst-Mode Laser Specs:

- CW beam chopped & amplified by diode and flash lamp stages
- Rep rate: 5 kHz – 500 kHz *doublets* with adjustable Δ*t*
- Pulse energy: up to 500 mJ
- Burst duration: 2.6 – 10.2 ms



Bursts of high repetition rate pulses last up to 10.2 ms, *plenty long in a shock tube flow.*

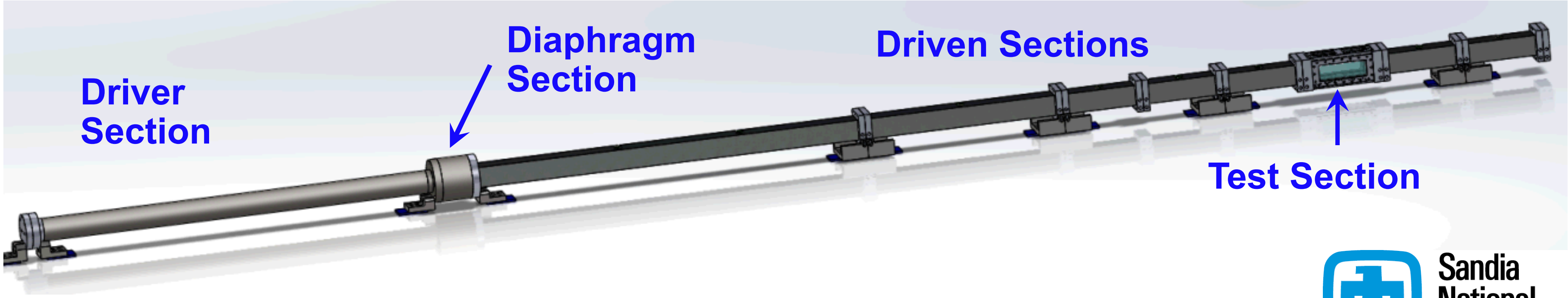
Multiphase Shock Tube (MST)

Shock Mach numbers M_s up to about 2.

Driven section is air initially at atmosphere.

Test section width D = 76 mm.

MST typically used for shock-particle interaction and liquid breakup experiments.



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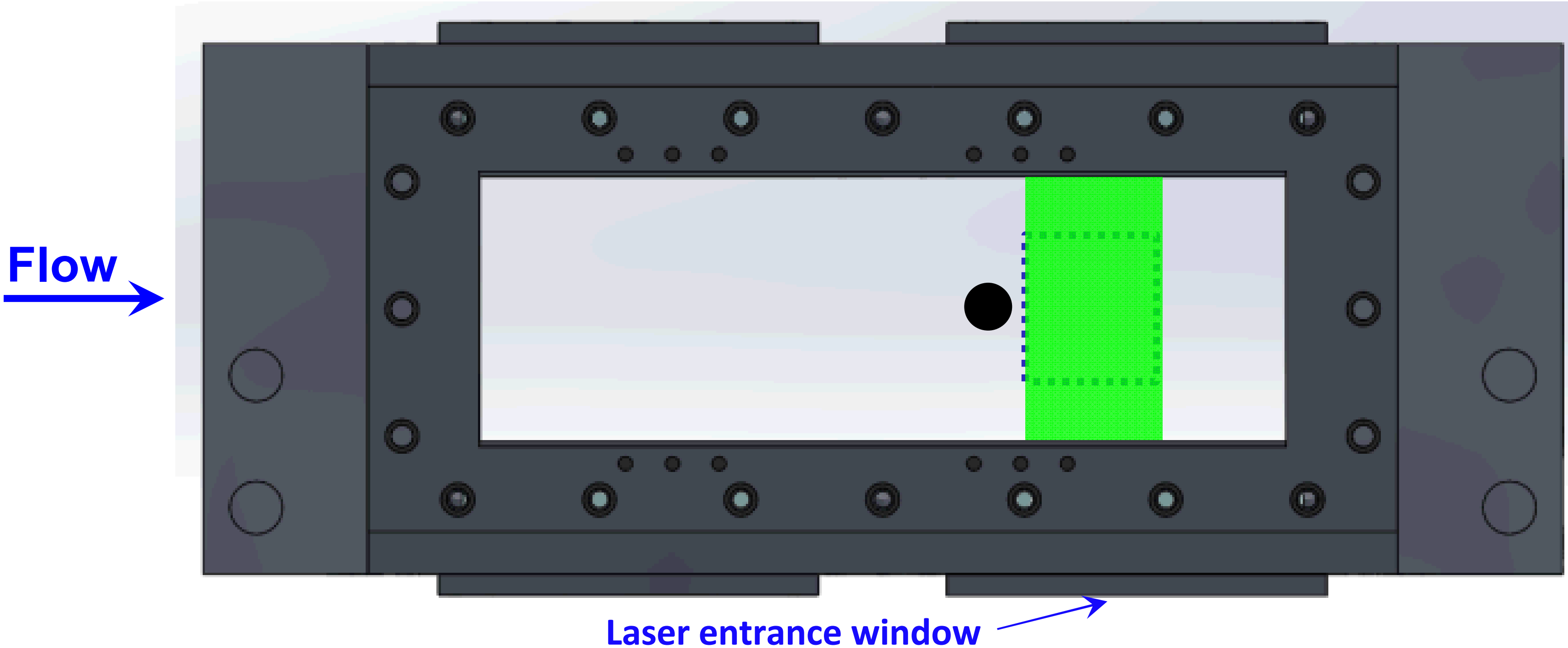
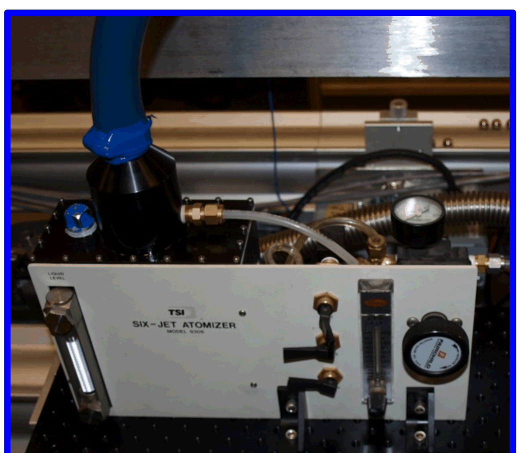
Cylinder Wake Flow

Transient wake growth of a cylinder after an impulsively started flow.

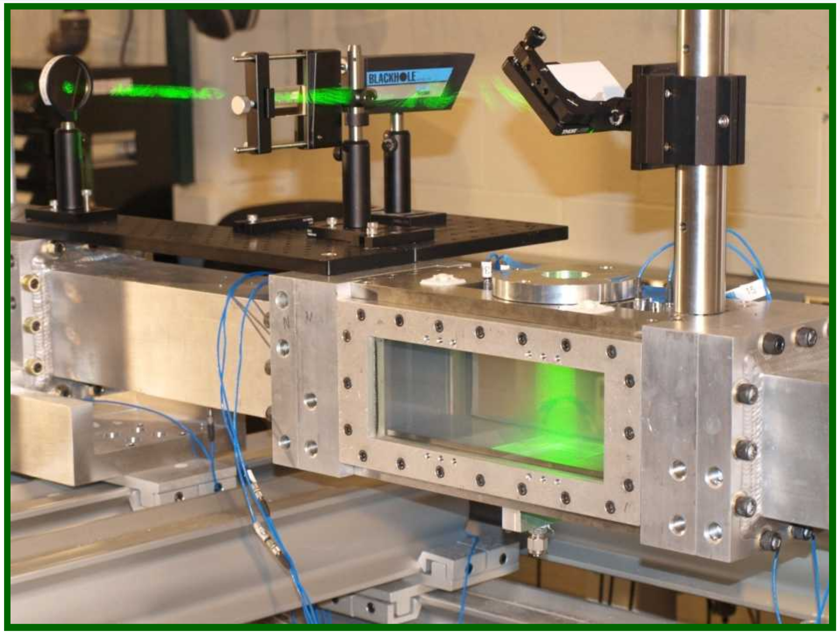




Particle seeding:

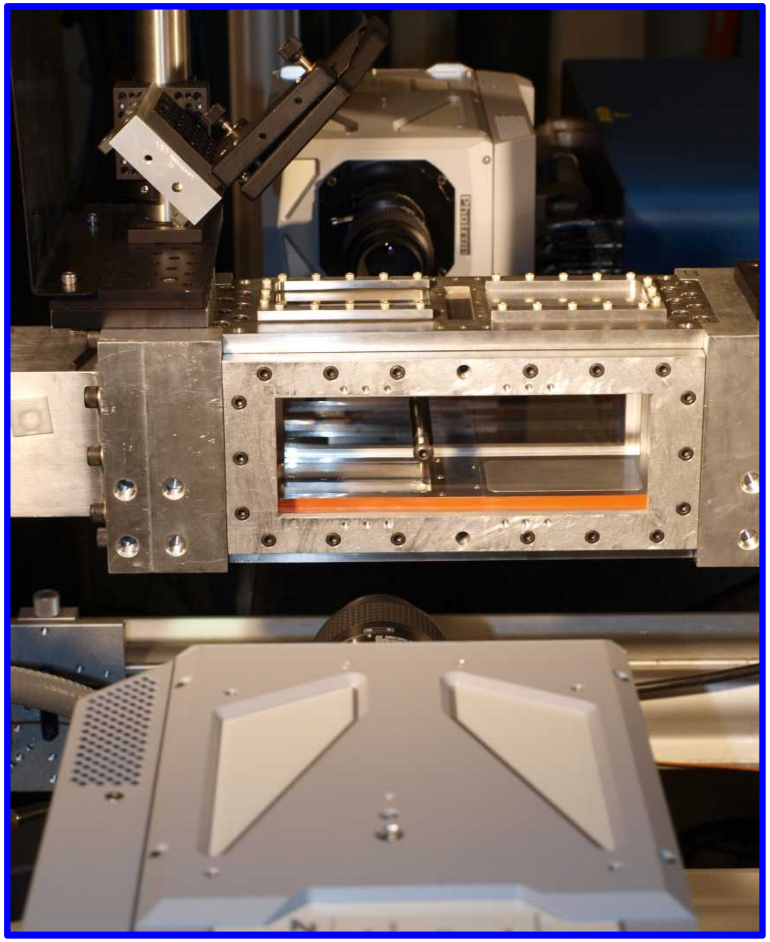
- TSI Six-Jet Atomizer
- Particles mixed into driver section prior to run
- Particle size: d_p = 1.6 μm
- Stokes Number: 0.05 – 0.50

Imaging Details



Pulse-Burst Laser Settings:

- 50 kHz rep-rate
- Δt = 2 – 4 μs
- 20 mJ per pulse
- Burst duration = 10.2 ms

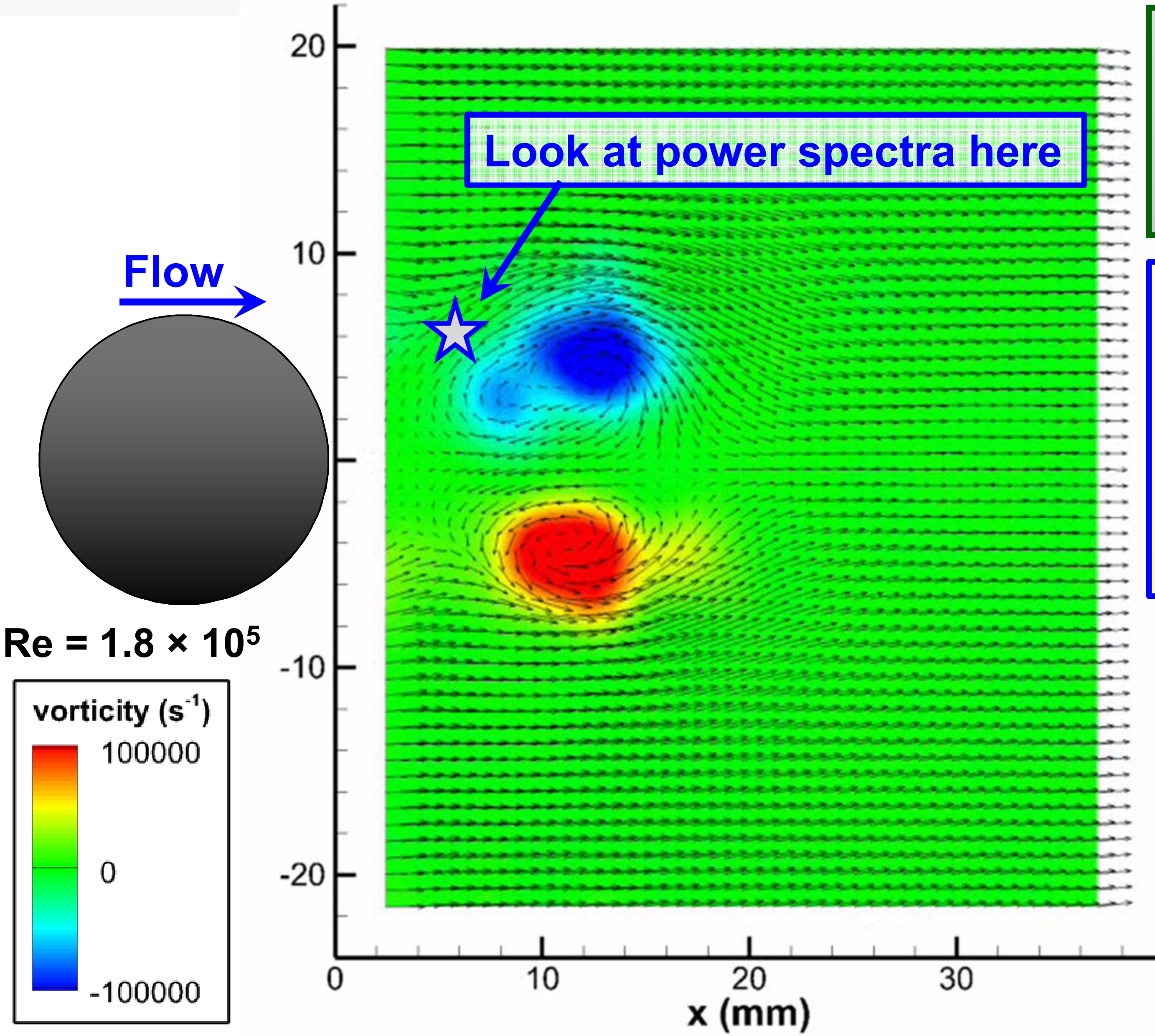


Cameras

- Two *Photron SA-Z's* placed adjacent to extend field of view
  - Each 680 × 340 pixels
  - Two-component vectors
- 100 kHz framing rate to frame straddle 50 kHz pulse pairs

Laser and cameras triggered off shock passage at upstream location.

Transient Wake Vorticity (M_s = 1.32, M_2 = 0.43)



50 kHz frame rate

Final interrogation window: 24 × 24 pix ($1.8 \times 1.8\ mm^2$)

Vortex shedding starts symmetric, then becomes a von Kármán streeet.

Some historical precedent exists.

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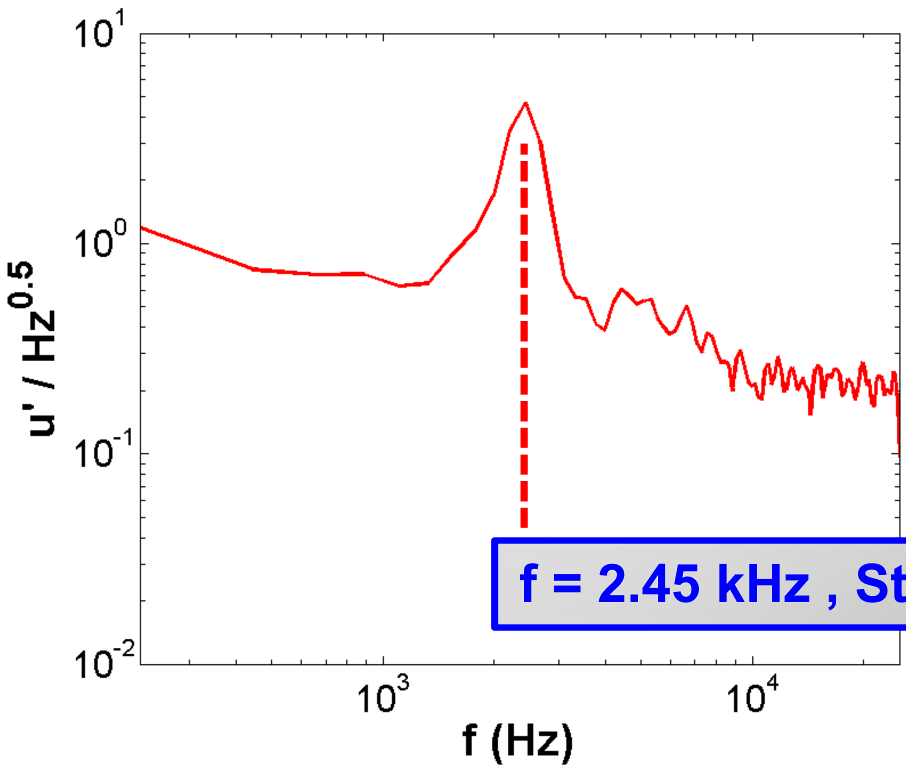
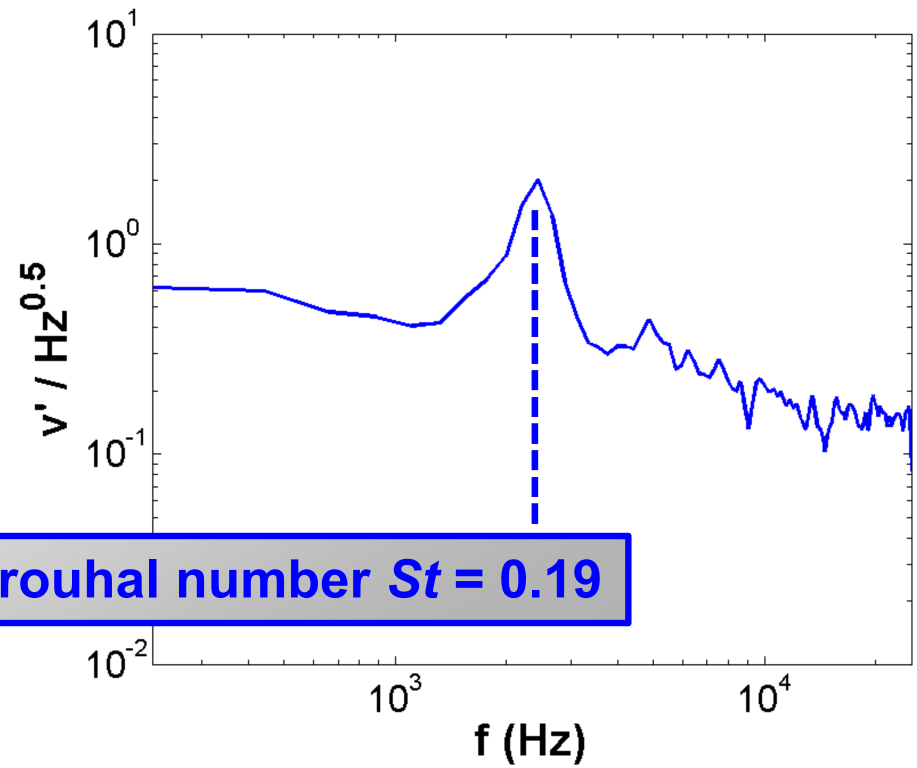
Power Spectra of Vortex Shedding

Streamwise Velocity



Wall-Normal Velocity



f = 2.45 kHz , Strouhal number *St* = 0.19

Similar *St* to previous studies at this Re (Roshko, 1961).

This is a time average. How does the frequency of vortex shedding change in time?

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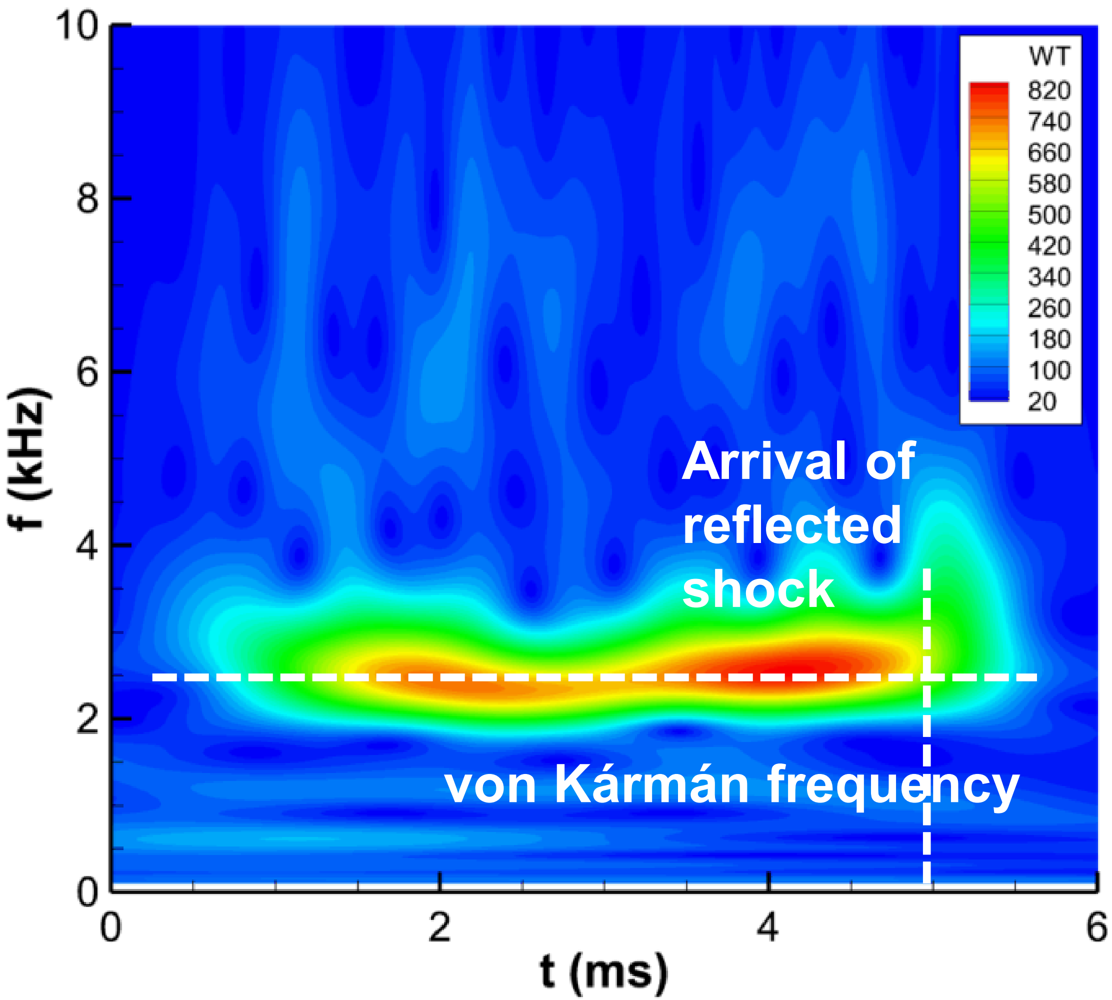
Joint Time Frequency Analysis (JTFA)

<u>Wavelet Transform of Wall-Normal Velocity</u>



- **It takes ≈ 0.5 ms for vortex street to become active.**
- **Street reaches local max at ≈ 2 ms, remains near maximum until ≈ 5 ms**
- **After the reflected shock at 5 ms, it takes ≈ 0.5 ms for shedding to dampen.**

Pulse-burst PIV quantifies the transient nature of vortex shedding in a shock tube.

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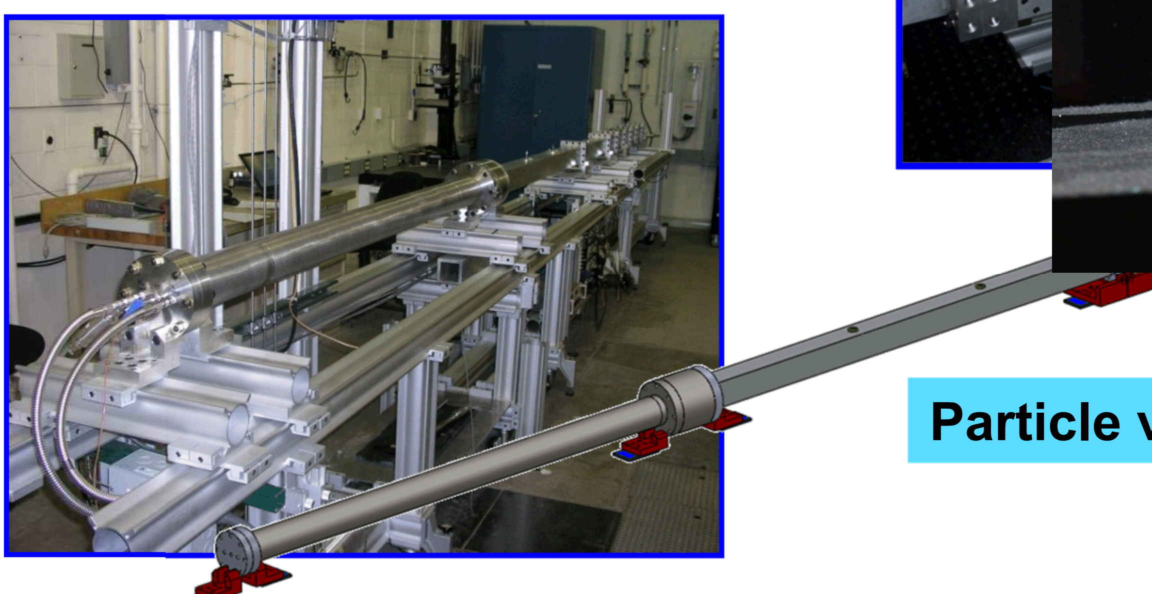
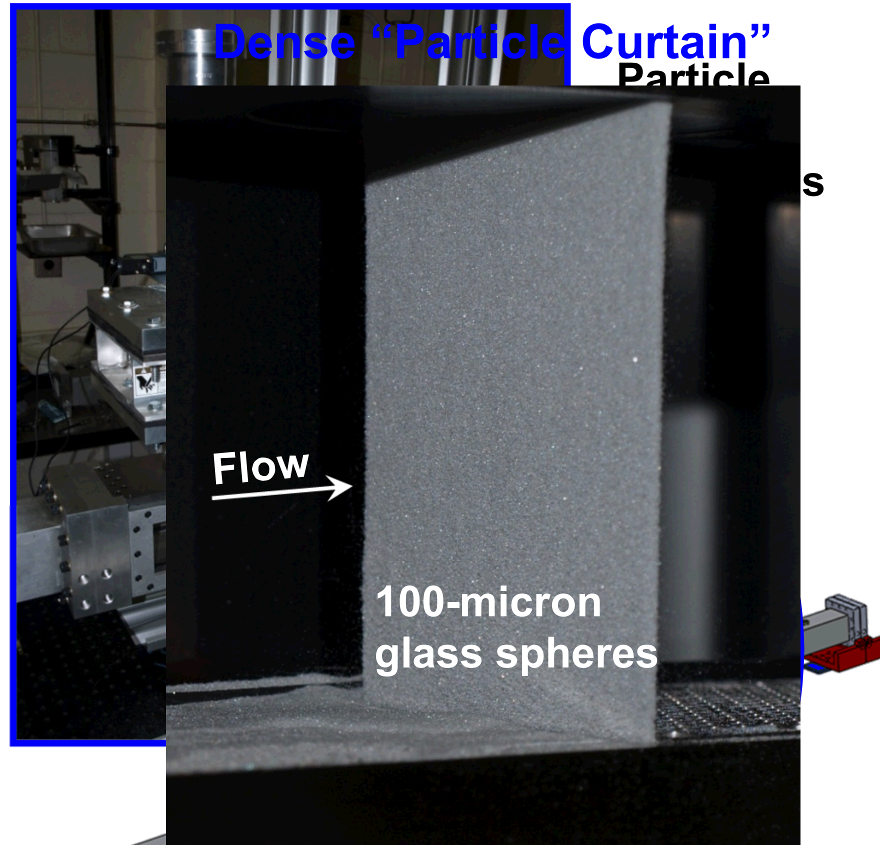
Particle Curtain Experiments in MST

Multiphase shock tube facility

- MST allows study of shock-particle interactions in dense gas-solid flows.
- Shock Mach #s up to about 2, driven section at atmosphere
- 76 mm × 76 mm test section

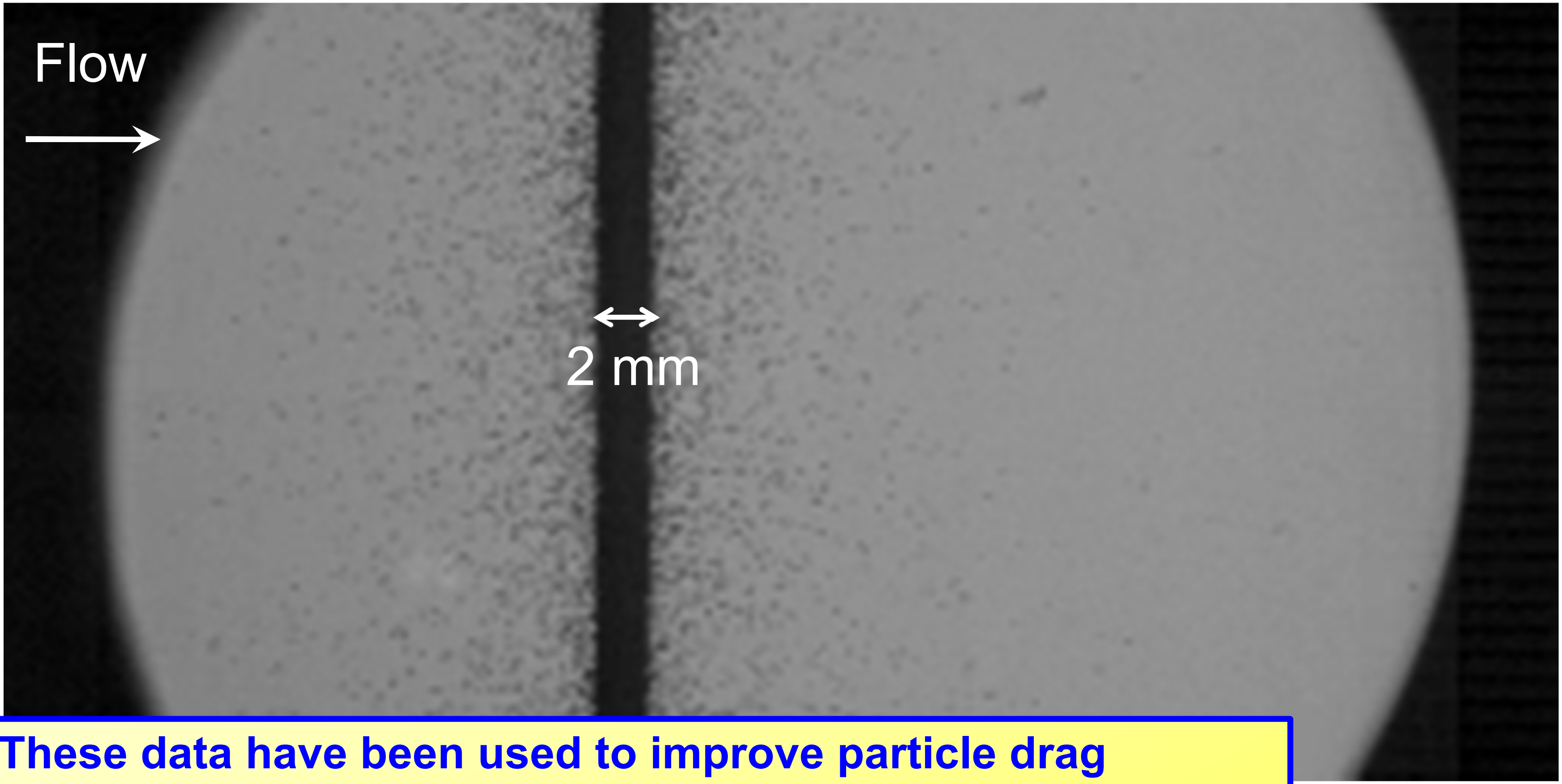




Particle volume fraction ≈ 20%

High-Speed Schlieren (130 kHz)

Interaction at shock Mach number = 1.67



These data have been used to improve particle drag models for prediction of explosive processes.

But we need *gas-phase velocities* to accurately provide drag coefficients.

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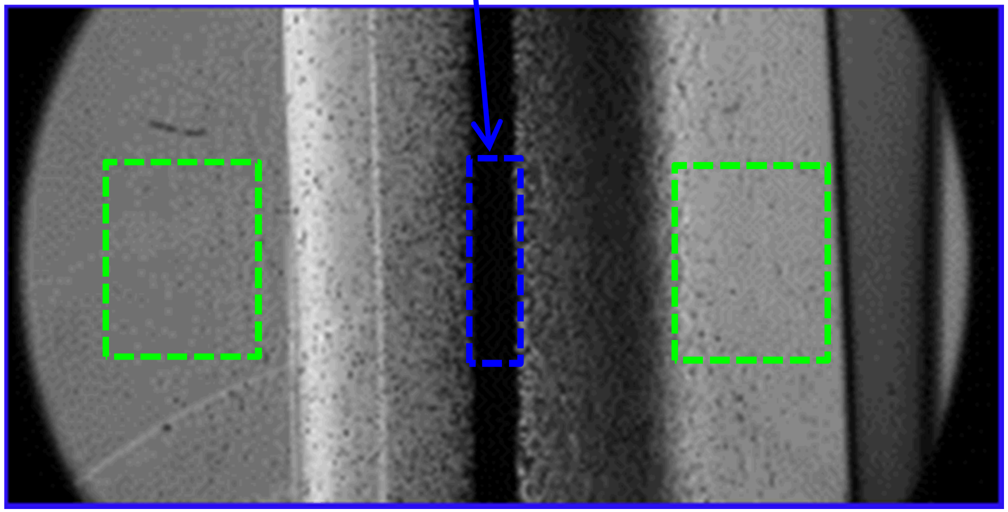
Pulse-Burst PIV can probe much deeper physics.

We've previously focused on the solid particles.

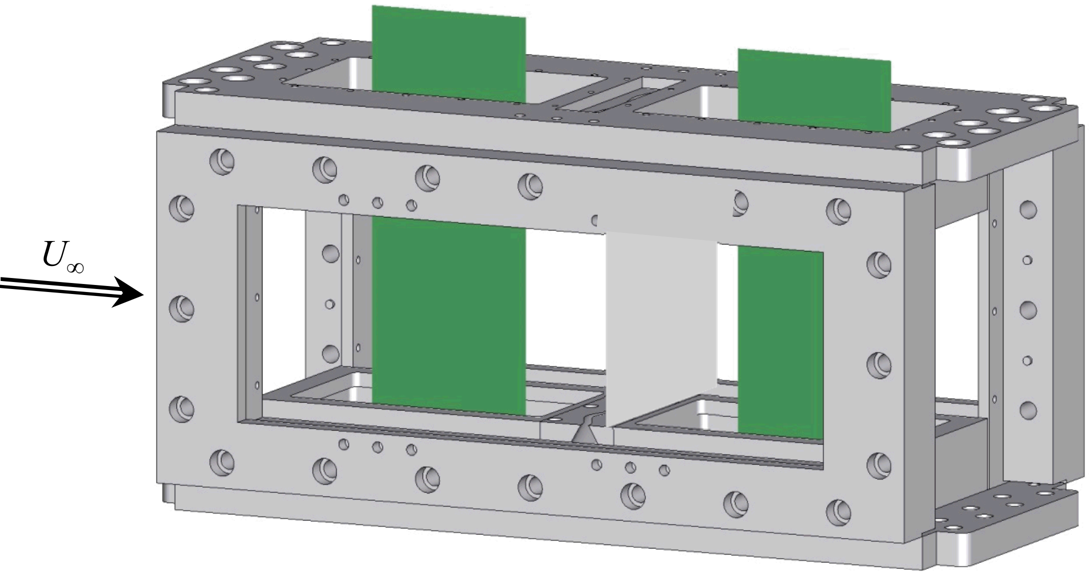


A conventional PIV system allows only one realization in the millisecond test times of a shock tube.

Time-resolved gas phase data can measure:

- Interaction Unsteadiness
- Interphase Momentum Transfer
- Particle-Induced Turbulence

Particle Curtain Pulse-Burst PIV

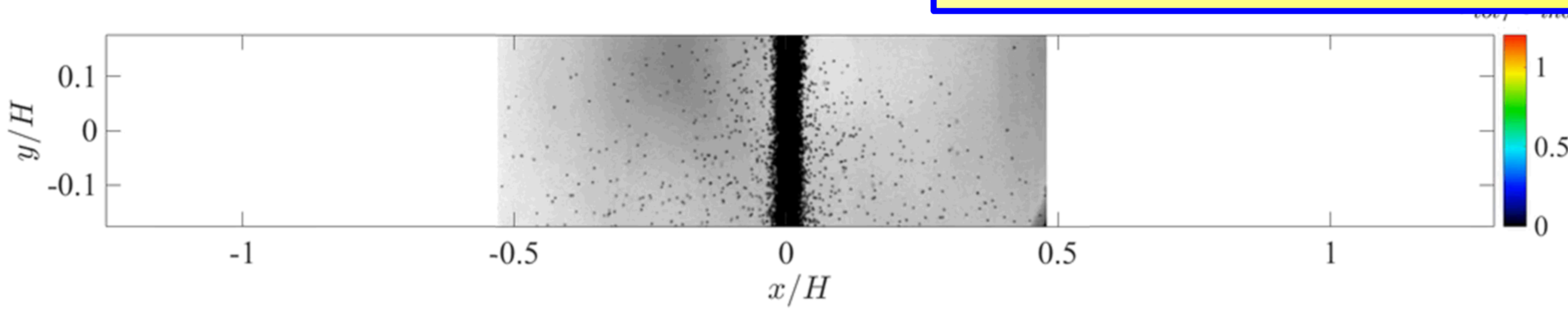


Split the laser into upstream and downstream sheets.

Image each using synchronized cameras.

Data capture gas jetting through the curtain and angled shock waves.

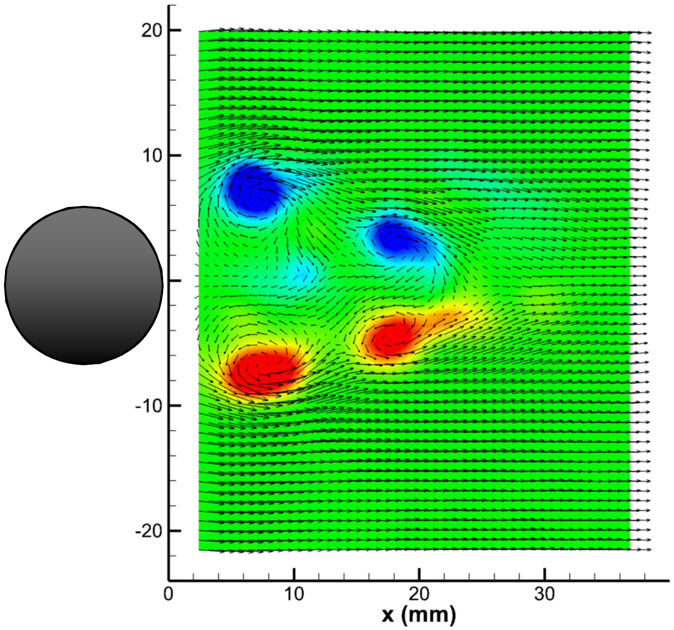
Control volume analysis is ongoing to determine the particle drag.

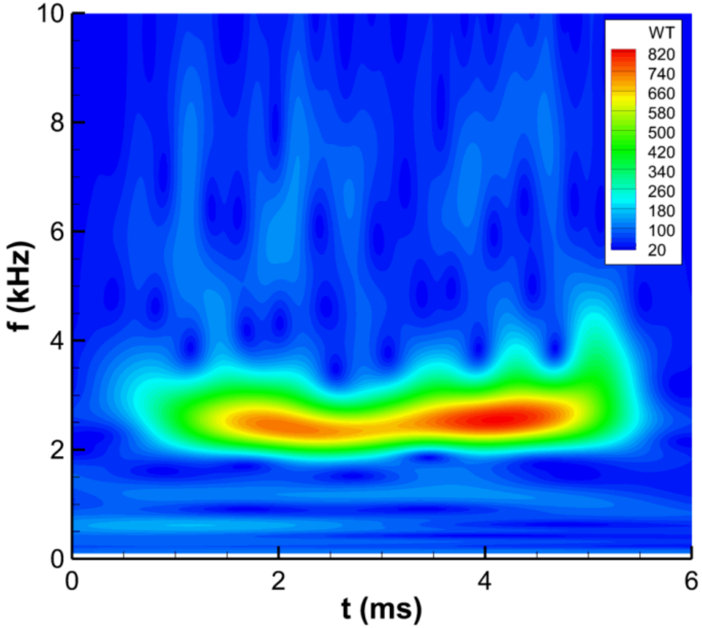


Upstream PIV | **Schlieren Imaging** | **Downstream PIV**

Conclusions

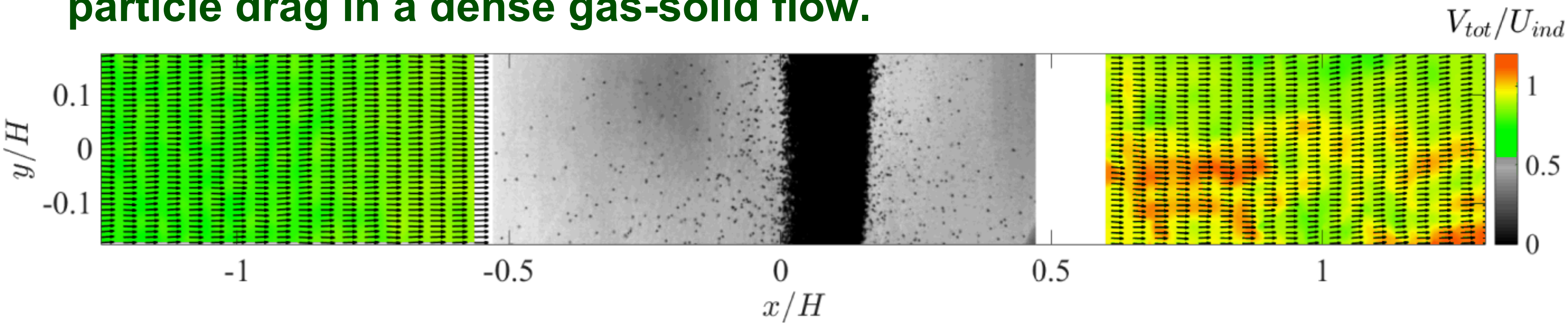
We've demonstrated TR-PIV in a shock tube using a pulse-burst laser.





Shock tube data reveal the transient start of cylinder vortex shedding.

Shock-particle interaction data can be used to determine particle drag in a dense gas-solid flow.



More physics to be revealed as we continue to analyze these data sets!