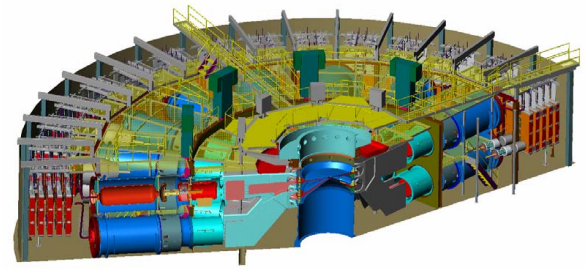
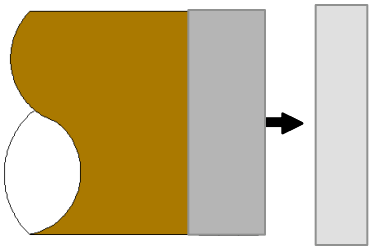
PDV measurements of structured wave profiles at modest velocities (< 1km/s)

2009 Photonic Doppler Velocimetry (PDV) Workshop

November 5-6, 2009
Austin, TX

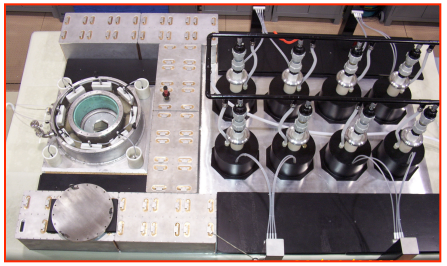
Z Accelerator





Gas Gun

Veloce



T. Ao and D.H. Dolan

Sandia National Laboratories, Albuquerque, NM, USA

1646 Dynamic Material Properties

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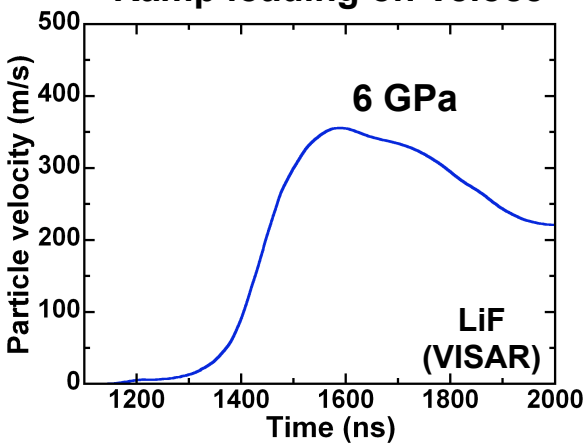
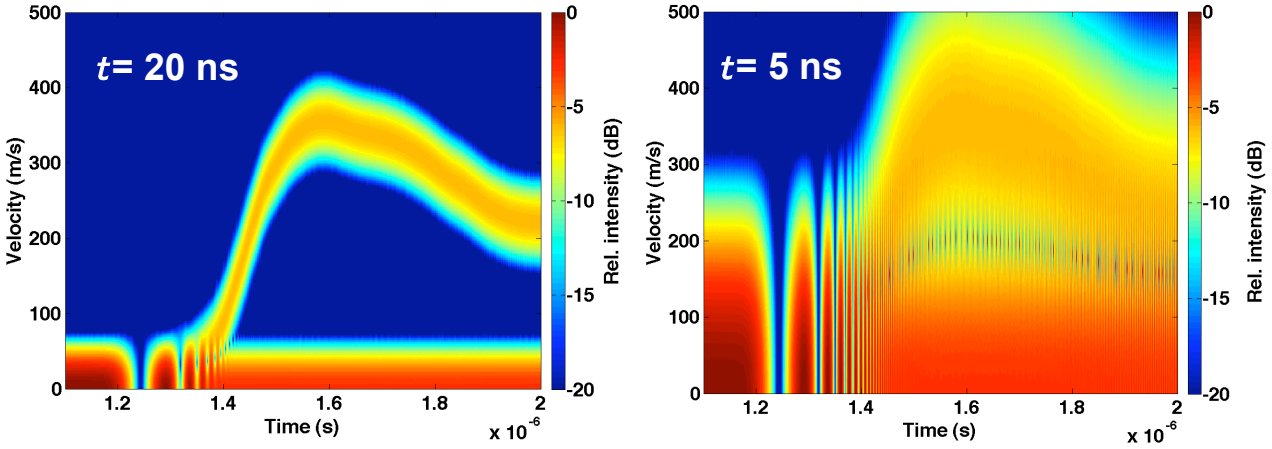
Purpose of Work

- **Background**
  - PDV beat frequency: $f = \frac{2v}{\lambda_0}$; uncertainty product: $(\delta v)(\tau) \geq \frac{\lambda_0}{8\pi}$, $\tau = \frac{\lambda_0}{8\pi\delta v}$
- **Motivation**
  - Achieve both optimal velocity & time precision
  - Where does this matter?
    - $l_0 = 1550$ nm, $v = 100$ m/s, $f = 0.13$ GHz
    - $\delta v \leq 10$ m/s, $\tau = 6$ ns
  - "Modest" velocity (<1km/s) transients
    - Structured waves (ramps and multiple shocks)
    - Elastic precursor, phase transition

Ramp loading on Veloce[1]



STFT analysis



[1]T. Ao *et al.*, RSI **79**, 013903 (2008)

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PDV Analyses

- **Detector measures output intensity**

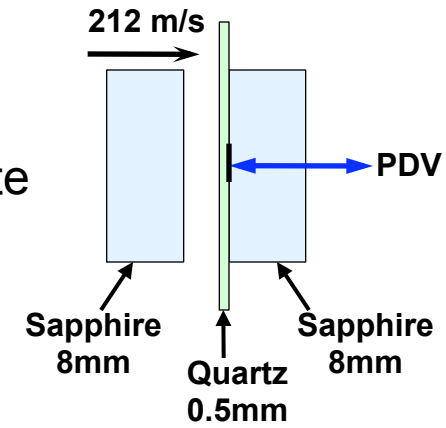
$$D(t) = aI_R + bI_T(t) + 2\sqrt{I_R I_C(t)}\cos\left[\Phi(t_i) + 4\pi\frac{x(t) - x(t_i)}{\lambda_0}\right]$$

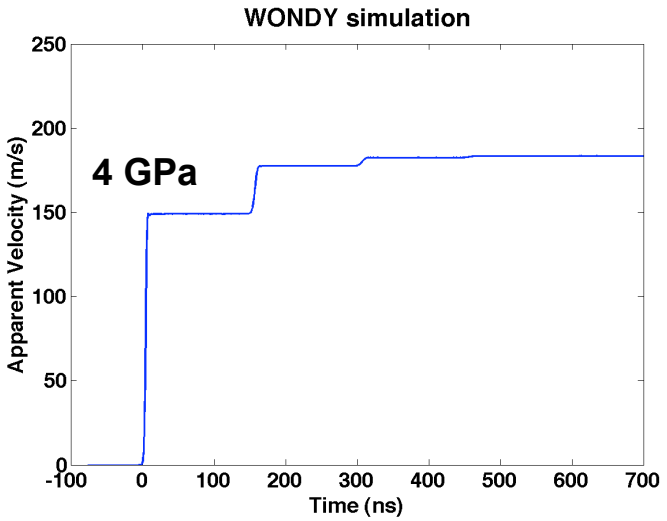
- **Short-time Fourier Transform (STFT)**
  - Finite time window, usually over several fringes
  - Velocity from Gaussian fitting of power spectrum
- **Three-phase analysis (THRIVE[1])**
  - Three signals shifted by 120°
  - Displacement from quadrature reduction (similar to VISAR analysis)
  - Velocity from differentiation of displacement
- **Local sinusoid**
  - Similar to STFT, less robust to transients

[1]D.H. Dolan and S.C. Jones, RSI **78**, 076102 (2007)
D.H. Dolan and S.C. Jones, SAND2008-3871

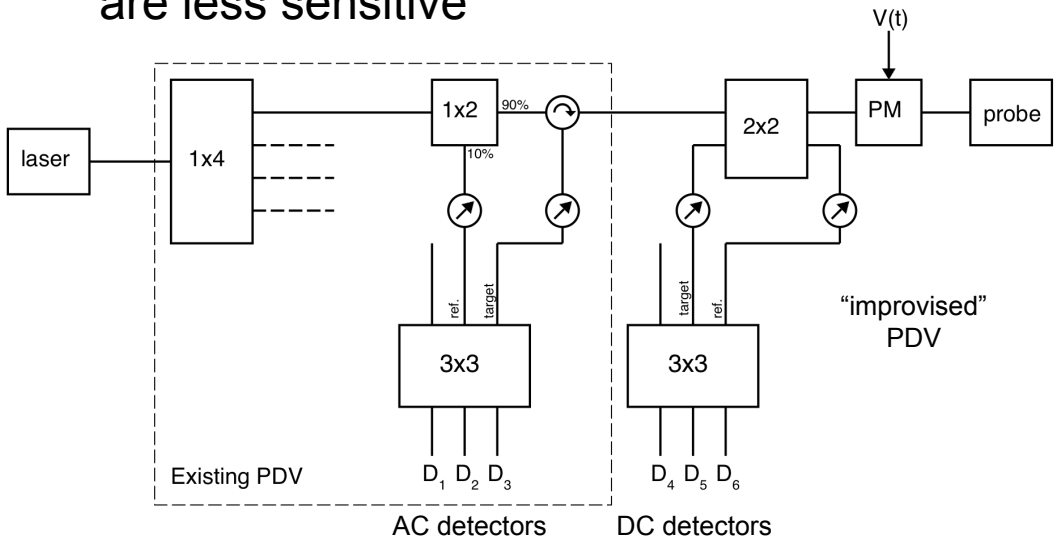
Experimental Configuration

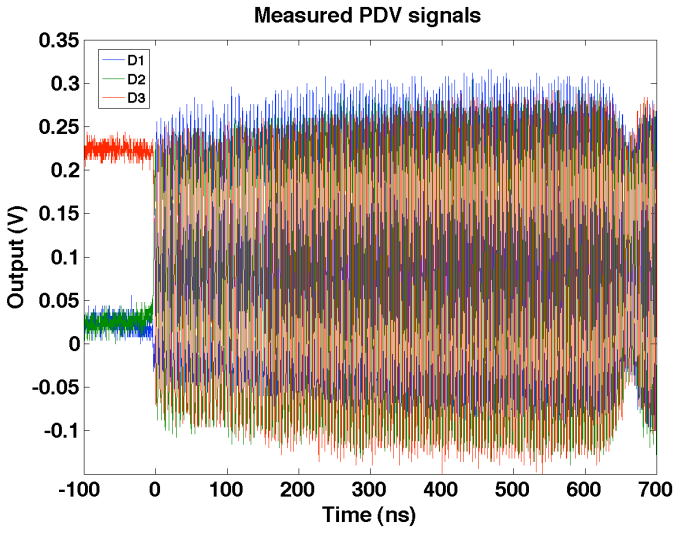
- **Gas gun**
  - Ring-up to shock state
  - Comparable target geometry to pulsed power loads





- **Three-phase PDV measurement**
  - Focusing probe (f = 12 mm)
  - DC detectors cleaner than AC detectors but are less sensitive





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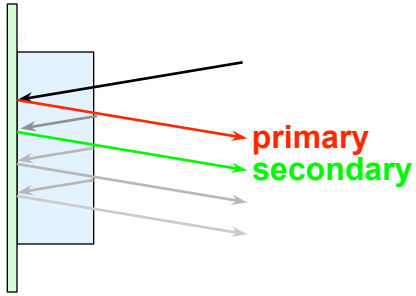
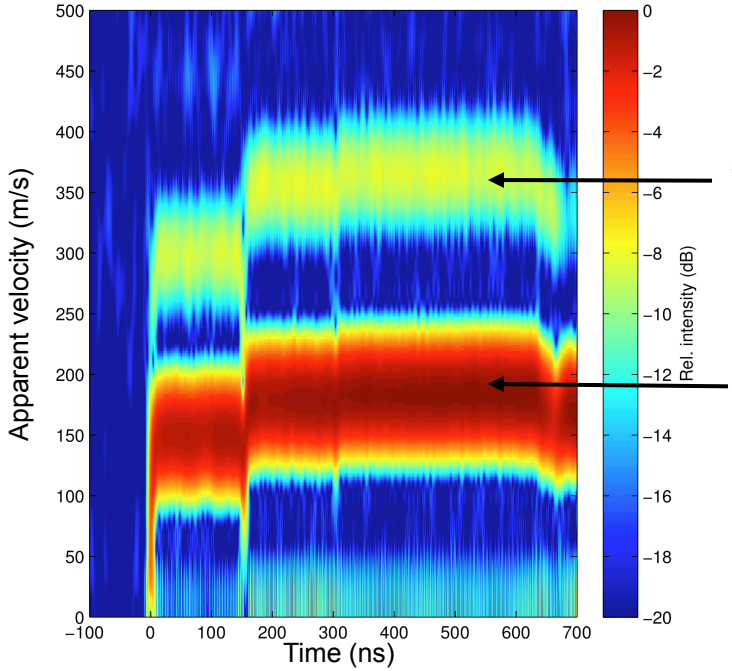
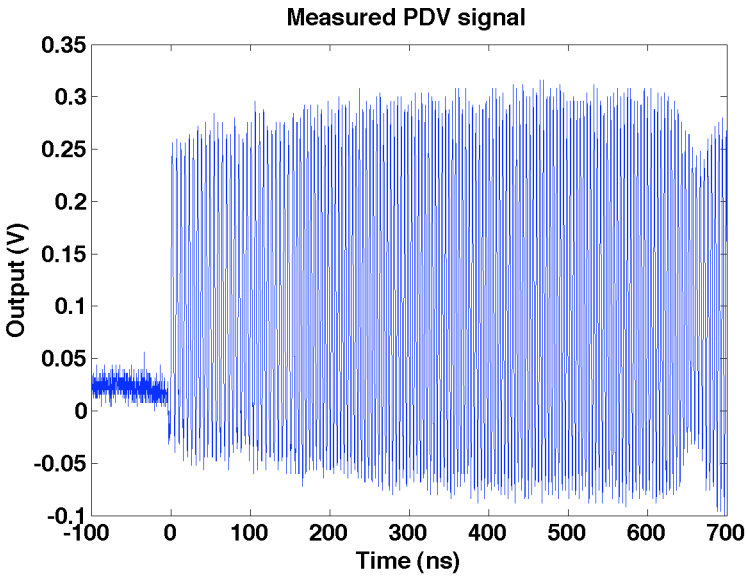
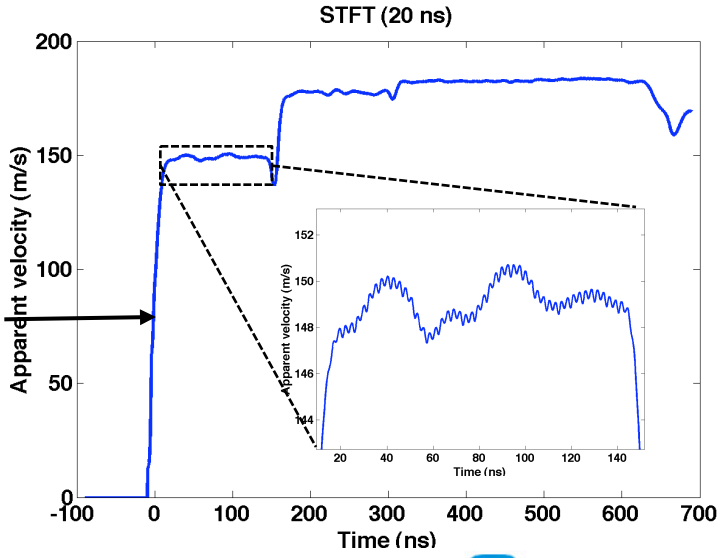
PDV01 – STFT Analysis



- **STFT power spectrum**
  - 20 ns Hamming window
  - Gaussian fitting of peaks







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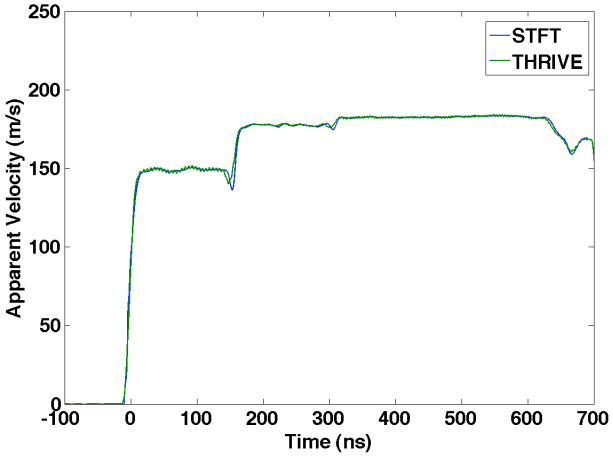
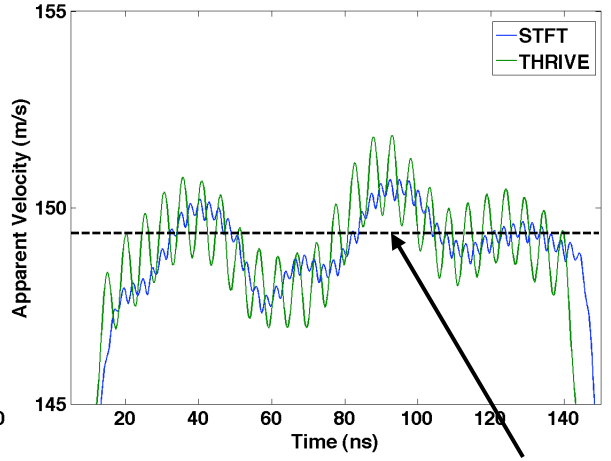
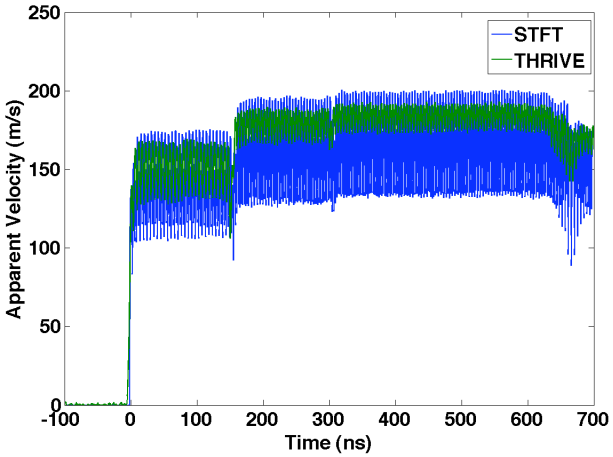
PDV01 – THRIVE Analysis

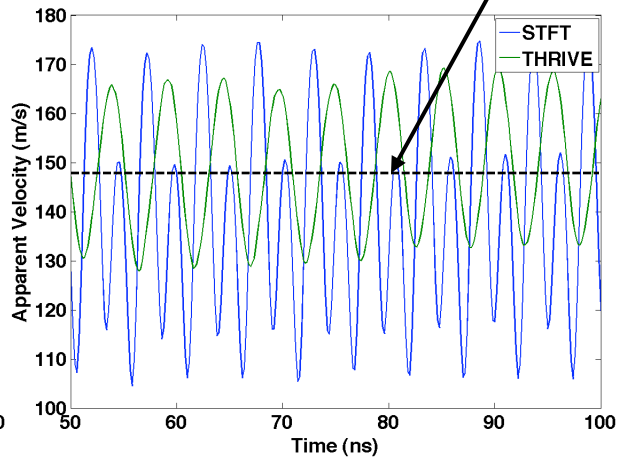
- ***t*= 20 ns**
  - THRIVE & STFT agree with WONDY prediction
  - Smaller oscillations with STFT





- ***t*= 5 ns**
  - Deviation between THRIVE & STFT
  - STFT's average velocity biased systematically lower than WONDY
  - Smaller oscillations with THRIVE





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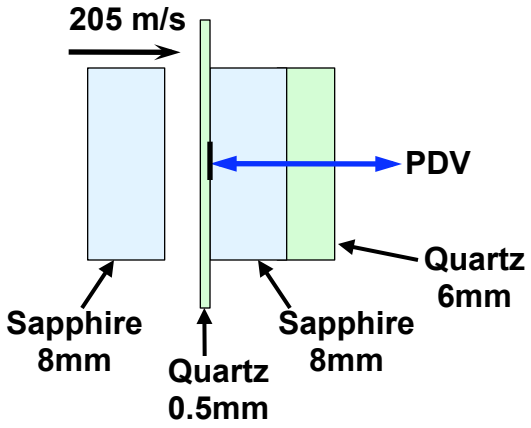
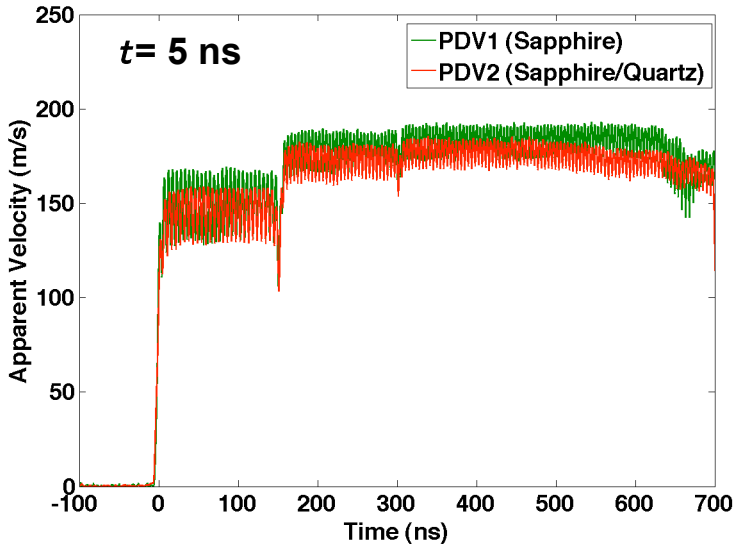
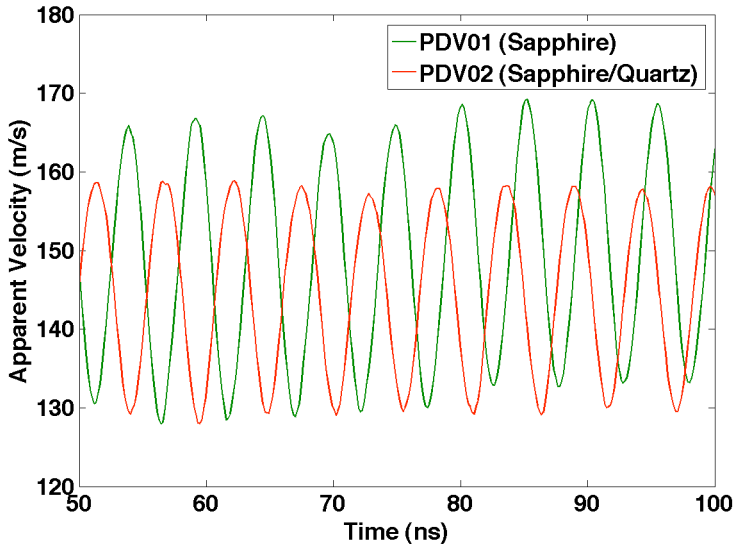
PDV02

- **Attempt to reduce secondary reflection**
  - Focusing probe insufficient
  - Add Quartz window to diminish multiple window transit effect

$$D(t) \propto \sqrt{I_R I_{C1}(t)}\cos\Phi_1 + \sqrt{I_R I_{C2}(t)}\cos\Phi_2$$



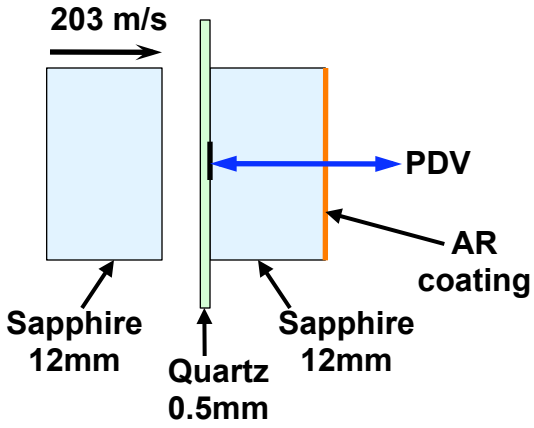


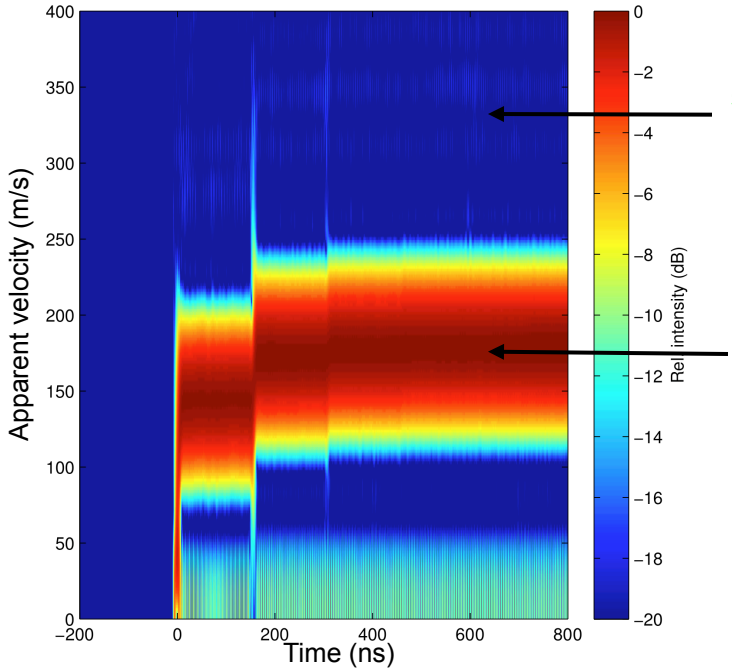


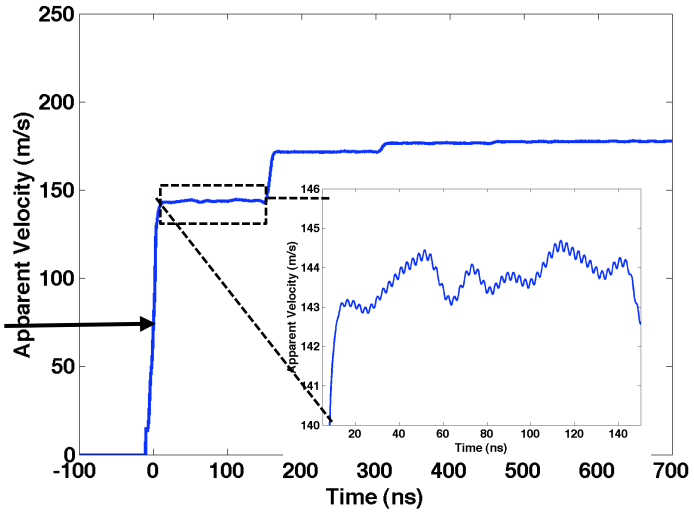
- **Oscillations smaller than with only Sapphire window but remains**
  - Need anti-reflective coating at free surface

PDV03 – STFT Analysis

- **Anti-reflective coating on Sapphire**
  - Reflectivity < 0.05% at 1550 nm
- **STFT power spectrum**
  - 20 ns Hamming window
  - Gaussian fitting of peaks







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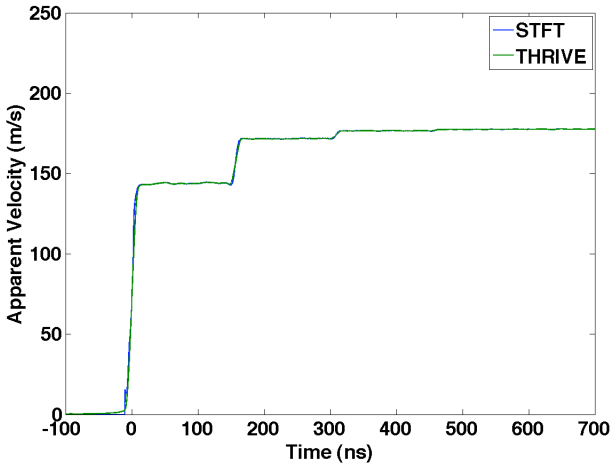
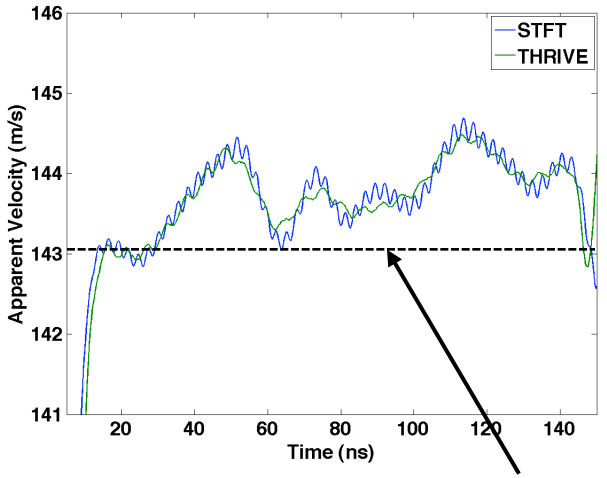
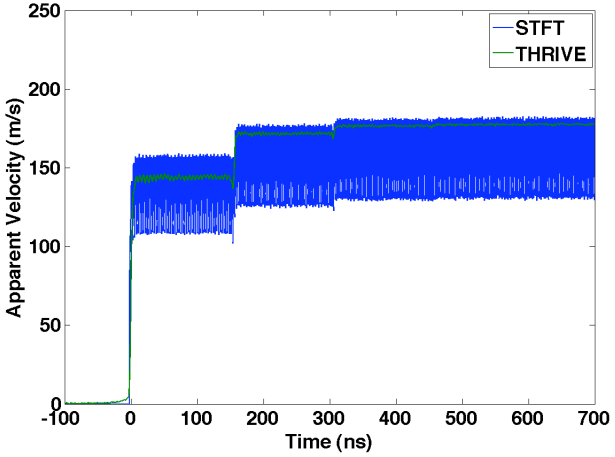
PDV03 – THRIVE Analysis

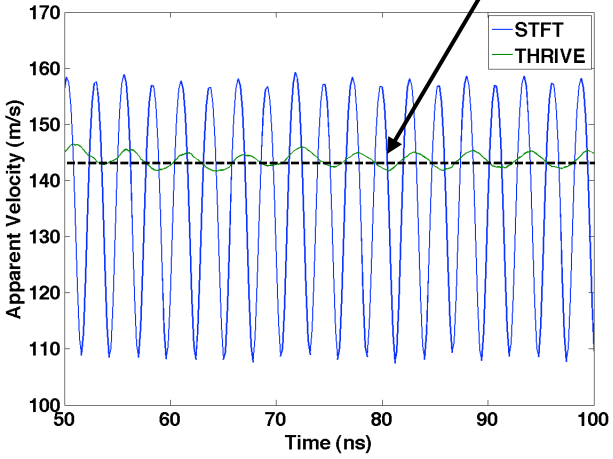
- ***t*= 20 ns**
  - THRIVE & STFT agree with WONDY prediction
  - Smaller oscillations with THRIVE





- ***t*= 5 ns**
  - Deviation between THRIVE & STFT
  - STFT's average velocity biased systematically lower than WONDY
  - Smaller oscillations with THRIVE





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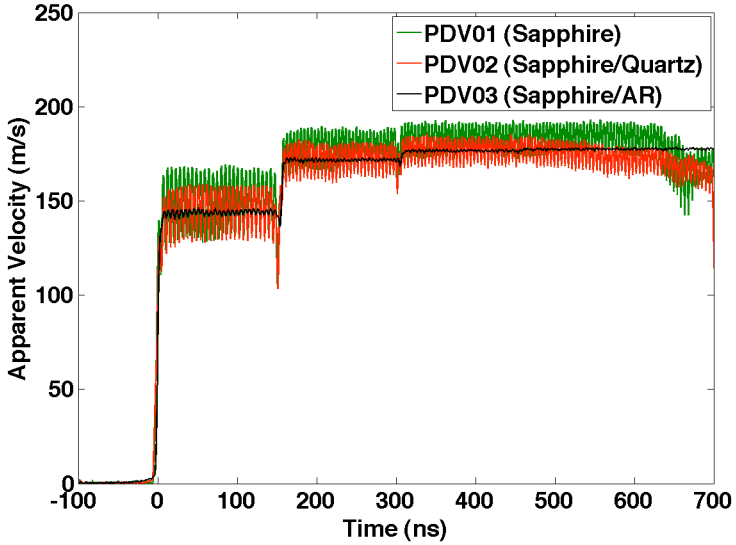
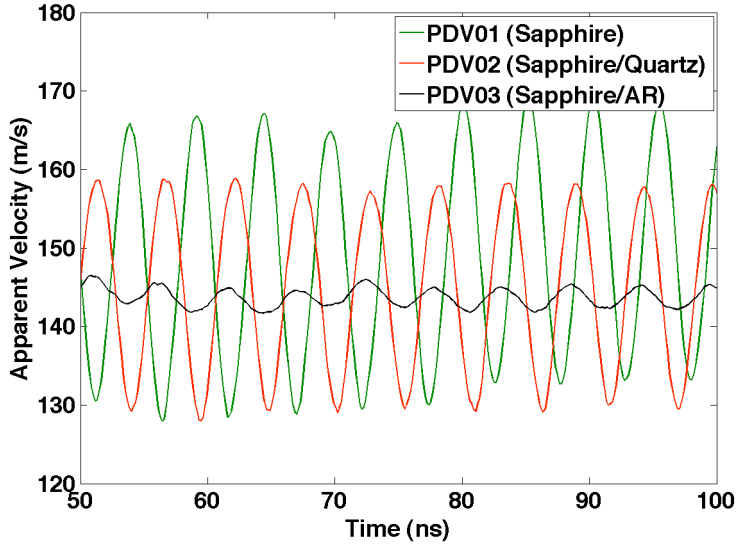
Mitigation of secondary reflection

- **Anti-reflective coating with THRIVE analysis**
  - Velocity oscillations of $dv/v \approx 1\%$ (1s) and $t = 5$ ns
  - Comparable to velocity and time precision of VISAR





Summary

- **Transient wave profiles at modest velocities (< 1km/s)**
  - Require optimization of both velocity and time precision
- **Short time Fourier Transform analysis (STFT)**
  - Robust and “simple”
  - Reliable over many fringes (large t) but suspect for small number of fringes (small t)
- **Three-phase analysis (THRIVE)**
  - More complicated (3 detectors/probe), more characterizations
  - Better for rapid transients
  - Consistent with STFT over many fringes (large t)
- **Must mitigate secondary reflection at window free surface**
  - Anti-reflective coating < 0.05%
  - Wedged window

Acknowledgements

- Sheri Payne
- Aaron Bowers
- Jesse Lynch
- Andy Shay
- Randy Hickman

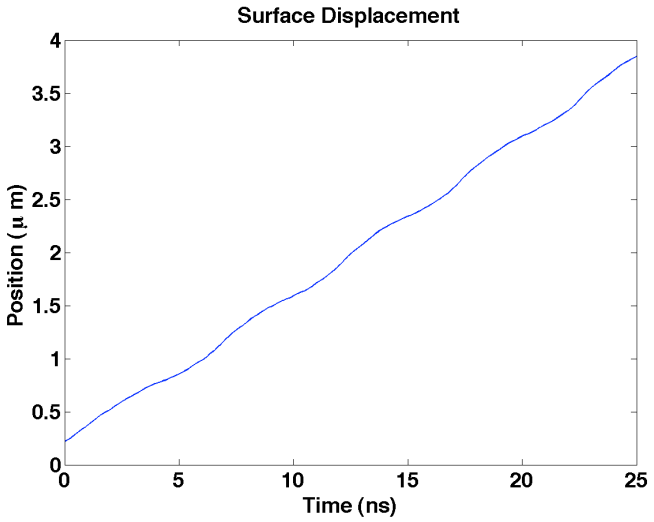
Extra Slides

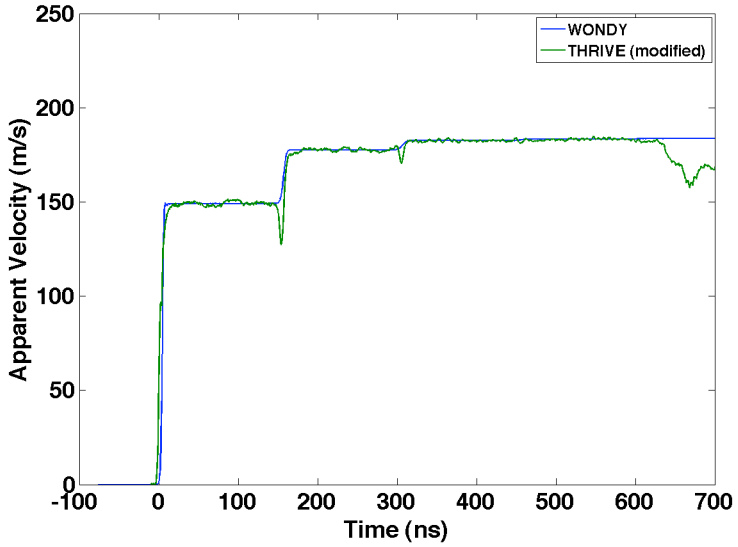
PDV01 – Displacement Analysis

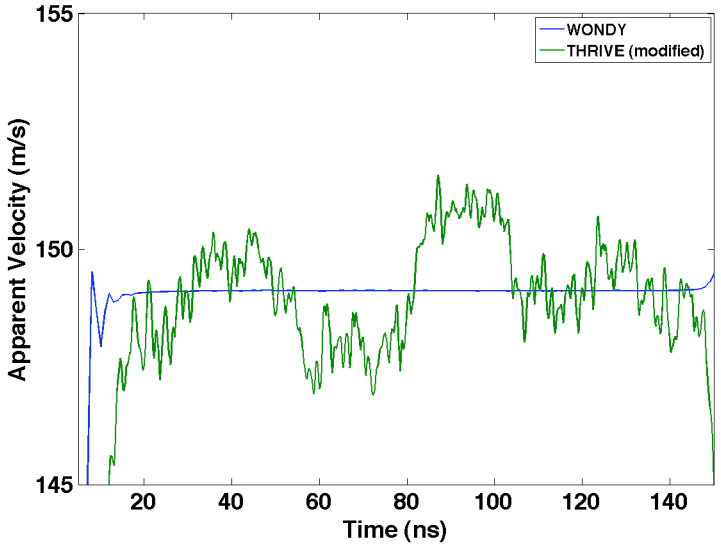
- **Examine displacement profile**
  - Sinusoid riding on linear ramp

$$x(t) = x(t_i) + vt + A\cos\left(\frac{4\pi}{\lambda_0}vt\right) + B\sin\left(\frac{4\pi}{\lambda_0}vt\right)$$

  - Iteratively solve for velocity
    - Use time window covering at least one wavelength of sinusoid (t = 6 ns)







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