Window effects in PDV measurements

Corrections and dispersion

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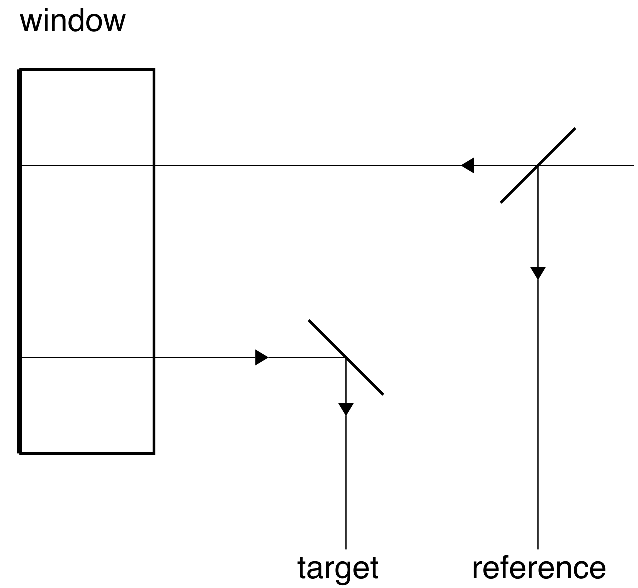
Are PDV windows effects different from VISAR?

- **Different operating wavelength**
- **Window is now interferometer "etalon"**
  - **Refractive index correction**
  - **Variable density/thickness**
  - **Dispersion?**
- **Multiple reflection capabilities**



- **Window characterization lacking**
  - **Brian Jensen will address this...**

Ambient index changes

- VISAR
  - 632.8 nm
  - 514.5 nm
  - 532 nm (most common)
- PDV
  - 1550 nm

	VISAR			PDV		
Material	n_0	δ	correction (published)	n_0	δ	correction (estimated)
sapphire	1.772	0.039	1.785	1.746	0.027	1.759
quartz	1.547	0.028	1.083	1.528	0.021	1.064
LiF	1.393	0.015	1.280	1.383	0.013	1.269
fused silica	1.461	0.025	-	1.444	0.019	-

Optical phase difference (PDV)

- **Definition:**

$$\Phi(t) = \phi_1(t) - \phi_2(t)$$
$$= \omega_0 T(t)$$

- **Transit time:**
  - **"Displacement interferometer"**

$$T(t) \approx \frac{x_r - x(t)}{c_0}$$

- **Real-apparent equivalence:**

$$v^*(t) = v_s(t) - \frac{d}{dt}\left[\int_{x(t)}^{x_s(t)} \frac{n(x,t) + n'(x,t)}{2} dx'\right]$$

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Window correction

- **Linear window:**

$$n(x,t) = a(\lambda) + b(\lambda)\frac{\rho(x,t)}{\rho_0}$$

- **Doppler shifting:**

$$n' \approx n + 2\delta\frac{v}{c_0} \qquad \left(\delta = -\lambda_0 \left.\frac{dn}{d\lambda}\right|_{\lambda=\lambda_0}\right)$$

- **Total correction:**

$$v^*(t) = v_w(t) - \frac{\delta}{c_0}\frac{dv^*(t)}{dt}\left(x_s(t) - x(t)\right) - \left(a(\lambda_0) + \delta\frac{v(t)}{c_0}\right)\left(v_s(t) - v(t)\right)$$
$$\approx a(\lambda_0)v(t) - \left(a(\lambda_0) - 1\right)v_s(t)$$

  - **Assumes static dispersion**
  - **Corrections significant at high acceleration**
    - **~0.01 m/s for 1 km/s over 100 ns in 10 mm window**
  - **Result not PDV specific...**

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System dispersion

- **VISAR (etalon):**
  - Fiber dispersion doesn't affect interference

$$\Phi = \omega\tau$$

$$\omega \approx \omega_0(1 + 2v/c_0) \qquad \tau \approx \tau_0(1 + 2\delta v/c_0)$$

$$\Phi \approx \Phi_0 + \frac{4\pi\tau_0(1+\delta)}{\lambda_0} v$$

- **PDV (fiber):**
  - No effect in steady motion
  - Dispersion critical during acceleration
  - Critical time scale
    - 0.1 ns/m of silica fiber

$$T = \frac{2}{c_0}\left[\frac{\delta L v}{c_0} + (x_r - x(t))\right]$$

$$t_c = \frac{2\delta L}{c_0}$$

Dispersion summary: acceleration bad

- **Window dispersion**
  - **Negligible except in shock front**
- **System dispersion**
  - **Keep interferometry runs short**

- **Velocity analysis limited by uncertainty principle (PDV)**
  - **Velocity-time tradeoff**
  - **Can be avoided in displacement mode**
    - **Numerical derivative required**
    - **Multiple velocities are a problem**

$$(\delta v)(\delta t) \geq \frac{\lambda_0}{8\pi}$$

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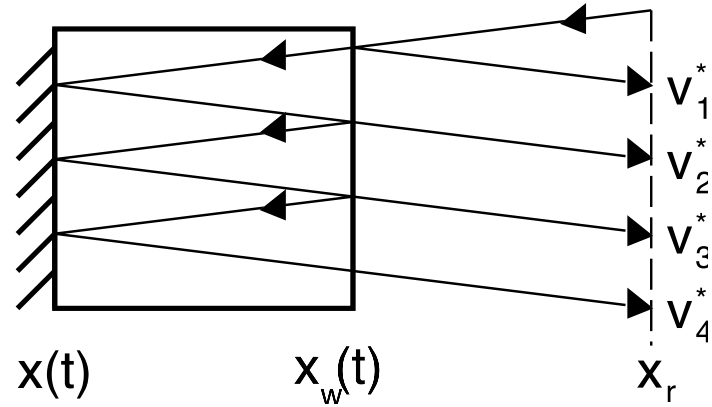
Windows introduce a plethora of reflections

- **Collimated probe picks up multiple Fresnel reflections**
  - **Relative amplitude scales with field electric field (n-1)/(n+1)**
  - **"Weak" components show up easily on a logarithmic scale**



- **Extra beat frequencies**
  - **Direct beats from reference signal**
  - **Cross beats between reflections**
  - **N(N+1)/2 beats for N reflections**
    - **Often degenerate!**

$$\bar{\omega}_{j0} = \frac{4\pi}{\lambda_0} \left| v_j^* \right|$$

$$\bar{\omega}_{jk} = \frac{4\pi}{\lambda_0} \left| v_j^* - v_k^* \right| \qquad j \neq k$$

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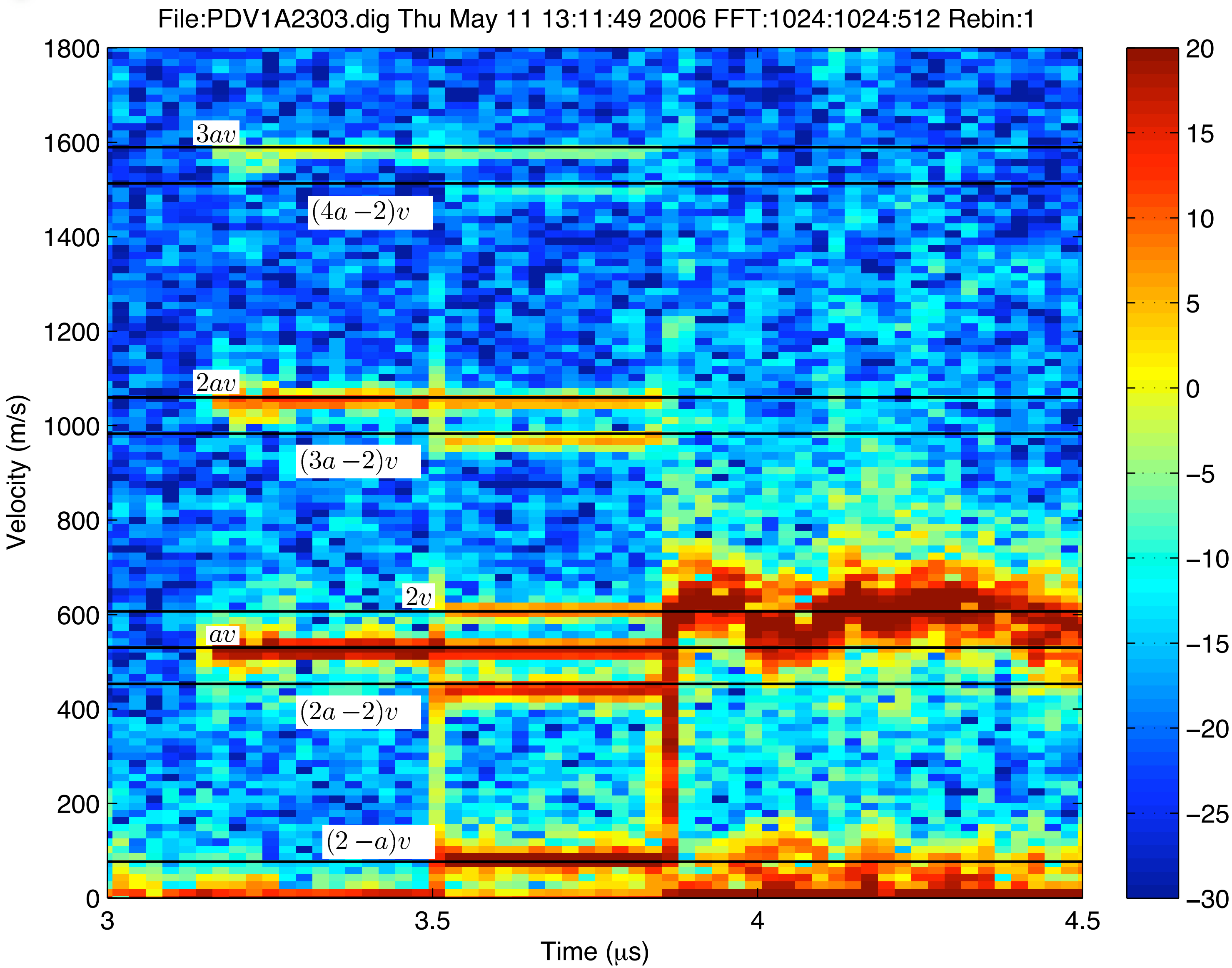
Example: symmetric sapphire impact (LANL)



303.3 m/s impact

a ~ 1.75

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Summary

- **Similar window corrections for VISAR/PDV**
  - Minor difference due to operating wavelength
- **Dispersion play a minor role in the window correction at moderate acceleration (ICE, etc.)**
  - PDV system dispersion is a larger problem during acceleration
- **Basic PDV probe picks many reflection**
  - Good news: lots of redundant information
  - Bad news: complex power spectra