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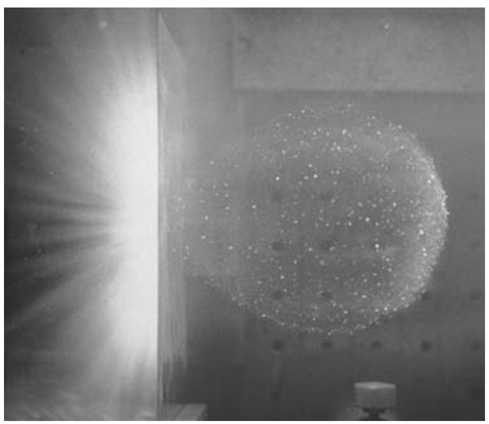
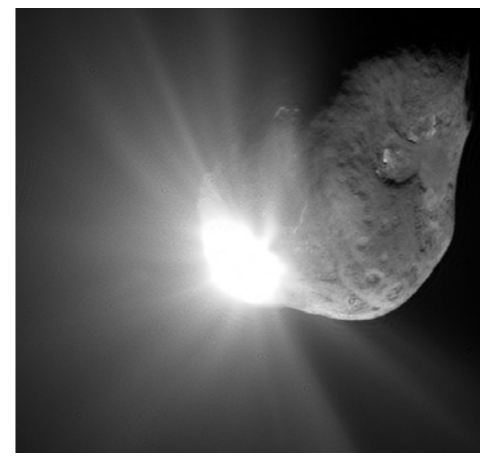
STAR
Shock Thermodynamics Applied Research

CHARACTERIZATION OF IMPACT FLASH SIGNATURES USING HIGH SPEED BROAD-BAND DIODE DETECTORS

10th Hypervelocity Impact Symposium
Williamsburg, Virginia
Sept. 23 – 27, 2007





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NNSA National Nuclear Security Administration

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Outline

- motivation for this work
- experimental layouts
  - CTH model of Comp-B experiment
- diagnostics (photo-diodes)
- experimental results and discussion
  - temperature measurement
  - impact flash scaling laws, titanium impacting aluminum, and lexan impacting Comp-B
  - Comp-B shock/detonation velocity from prompt impact flash
- conclusions

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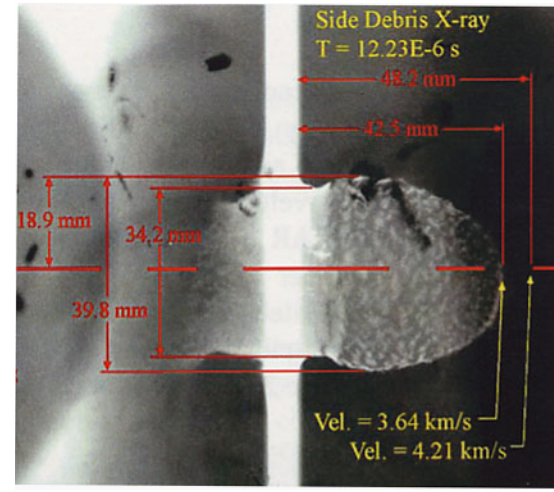
Motivation

Understanding and modeling impact debris physics



Reinhart et. al. Temperature measurements of expansion products from shock compressed materials using high-speed spectroscopy, *HVIS2007*

Chhabildas et. al. Shock-induced vaporization in metals, *Int. J. Impact Engng, 2005*

Chhabildas et. al. Debris propagation phenomenology from hypervelocity impacts on aluminum from 6 to 11 km/s, *Int. J. Impact Engng. 2003*

Space structure hit detection, initial testing at SNL-STAR

Starks et. al. Seeking radio emissions from hypervelocity micrometeoroid impacts: early results from the ground, *Int. J. Impact Engng*. 2005

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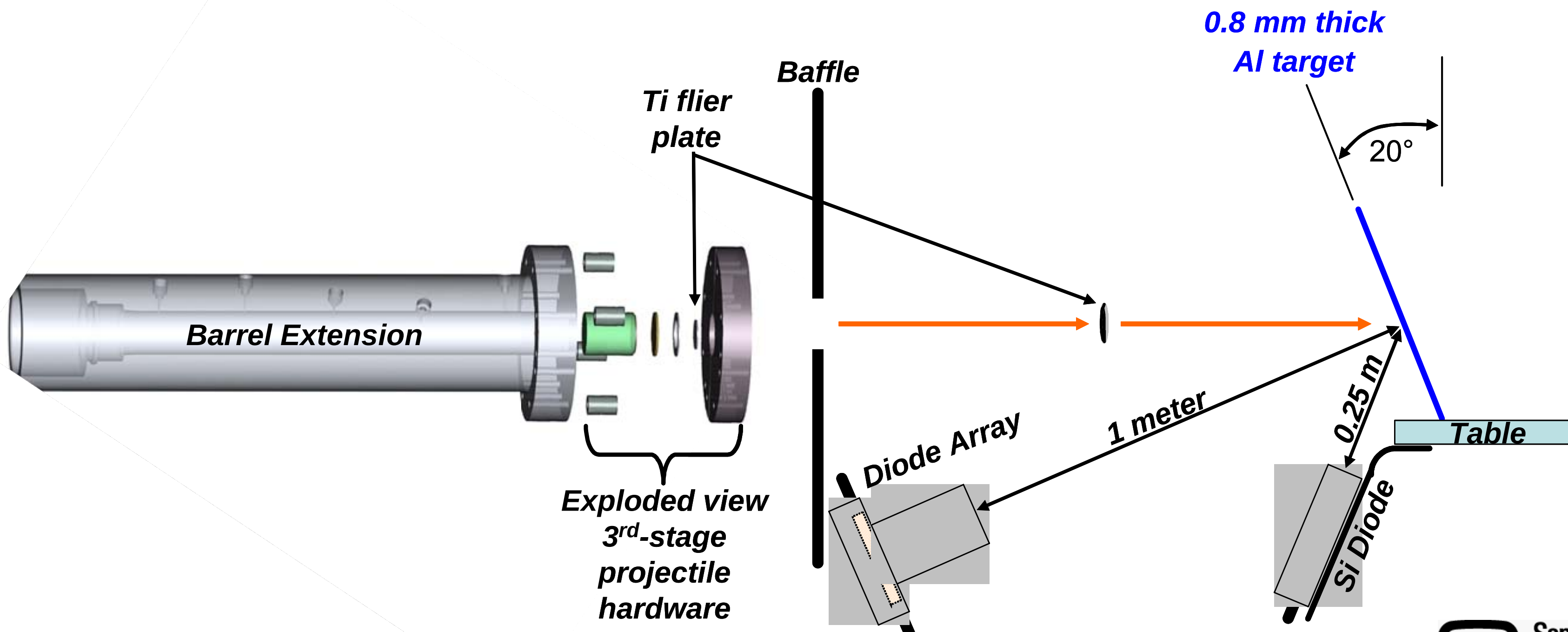
Experimental Layout - Impact Surface Diagnostics

Sandia three-stage launcher, Ti6Al4V plate projectile impacting aluminum at 7, 9, and 11 km/s, or 2nd-stage projectile at 1.5 to 7 km/s.

Four color photo-diode array.

Broadband impact flash intensity photo-diode.



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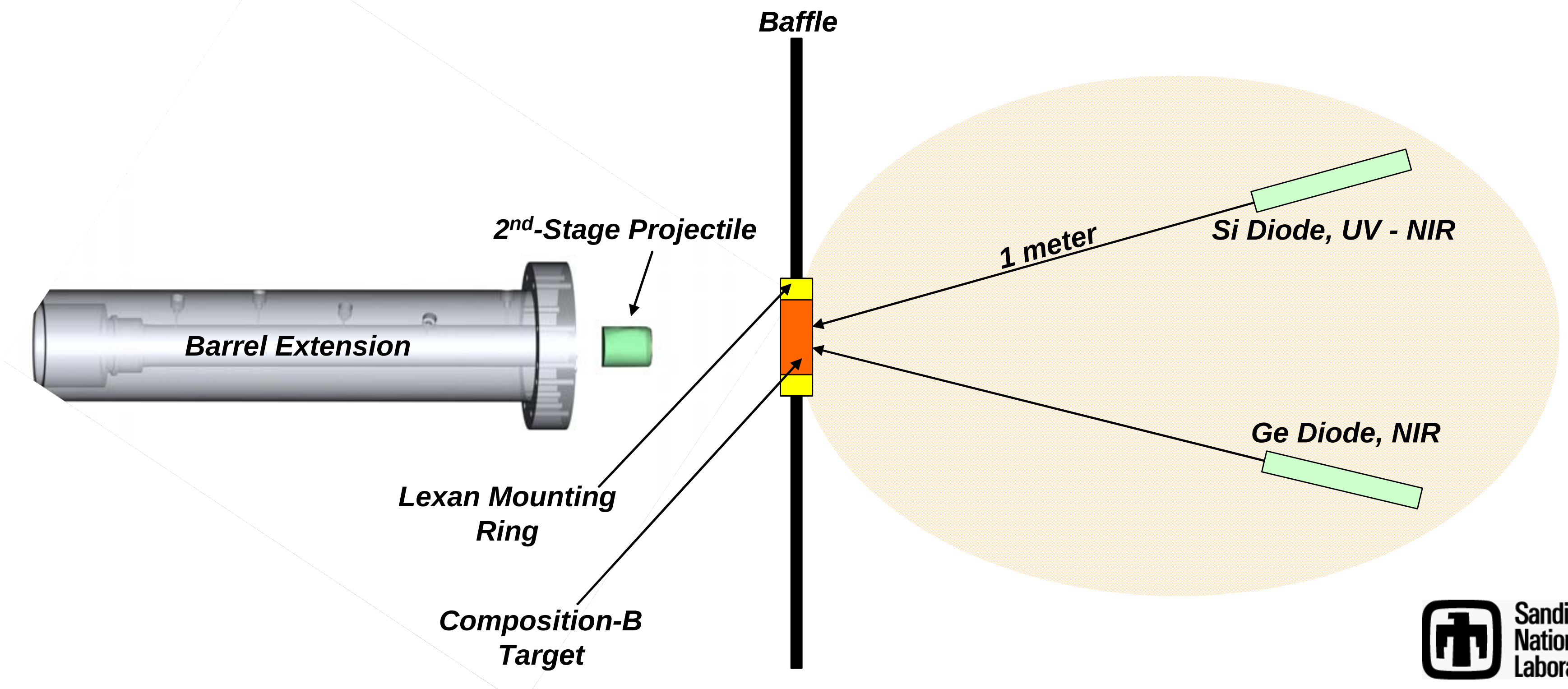
Experimental Layout – Rear Surface Diagnostics

Sandia two-stage launcher, lexan projectile impacting Comp-B target at 5.5, 7, and 7.5 km/s.

Broadband photo-diodes (NIR, visible spectrum) looking at rear of target and radiating impact debris.



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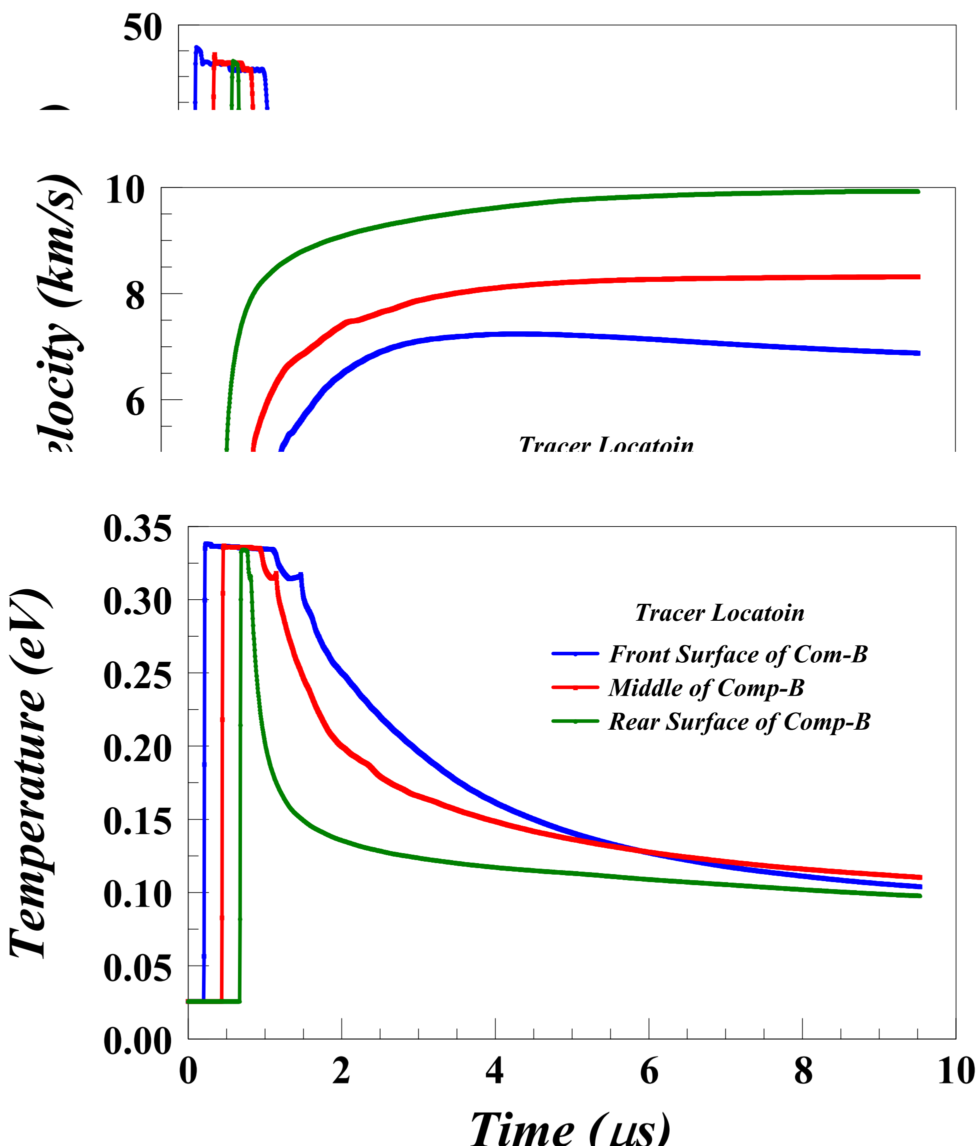
CTH Simulation – Comp-B Pressure, Expansion Process

- 2-D problem using experiment geometry
  - automatic mesh refinement
- EOS
  - lexan and acrylic represented by Mie-Gruneisen EOS
  - Comp-B represented by history variable reactive burn model (default parameters)
    - Mie-Gruneisen EOS for unreacted Comp-B
    - SESAME table data for reaction products
- material strength
  - high temperatures upon shock arrival in materials
    - strength both elastic and spall were not included

CTH Results



Comp-B is loaded to ~47 GPa and rapidly releases to almost zero pressure in 4 µs.

The loading profile imparts a velocity distribution from 6 to 10 km/s from front to back respectively.

CTH result indicates a peak temperature of 4350 K rapidly cooling to 1400 K.

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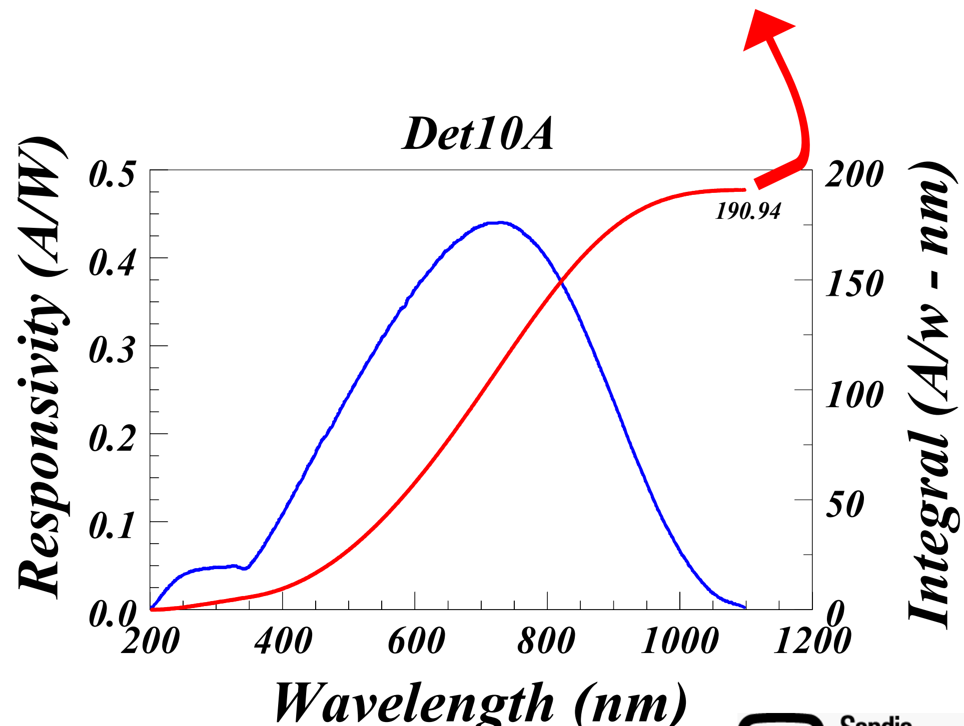
Diagnostics – Broadband Photo-Diodes

Model No.	Diode Type	Active Area (cm²)	Wavelength (nm)	Bandwidth (MHz)	Sensitivity (nm:Amps/Watt)
DET10A	Si	0.008	200-1100	350	191
DET10C	InGaAs	0.008	700-1800	50	683
DET50B	Ge	0.196	800-1800	1.6	523

- ThorLabs commercial detectors
- reverse-biased PIN photo-diode circuit with internal battery
- diodes inside Ø50mm steel pipe (armor), collimates viewing area
- diodes looking through fused silica window (armor)



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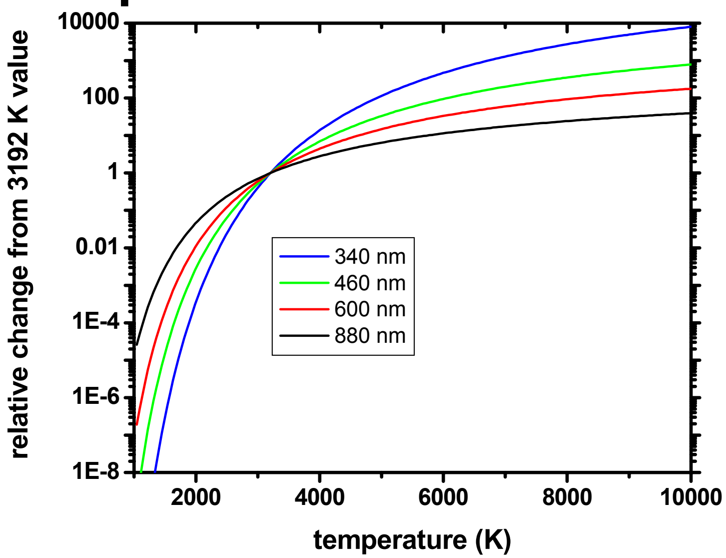
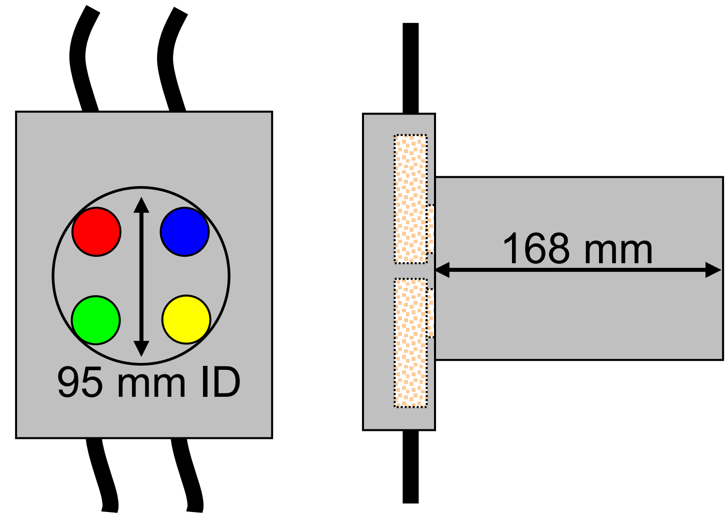
Diagnostics – Temperature Array

Expected Calibration Results





- **simplified four color pyrometer**
- **band pass filtering (+/- 10nm) at 340, 460, 600, and 880 nm**
- **impact flash irradiance is 10^5-10^6 times greater than 1 kw calibration lamp**
- **Three calibration runs with a quartz-tungsten halogen calibration lamp for absolute calibration showed too much scatter, and unrealistic calibration curves**

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Temperature Measurement Result

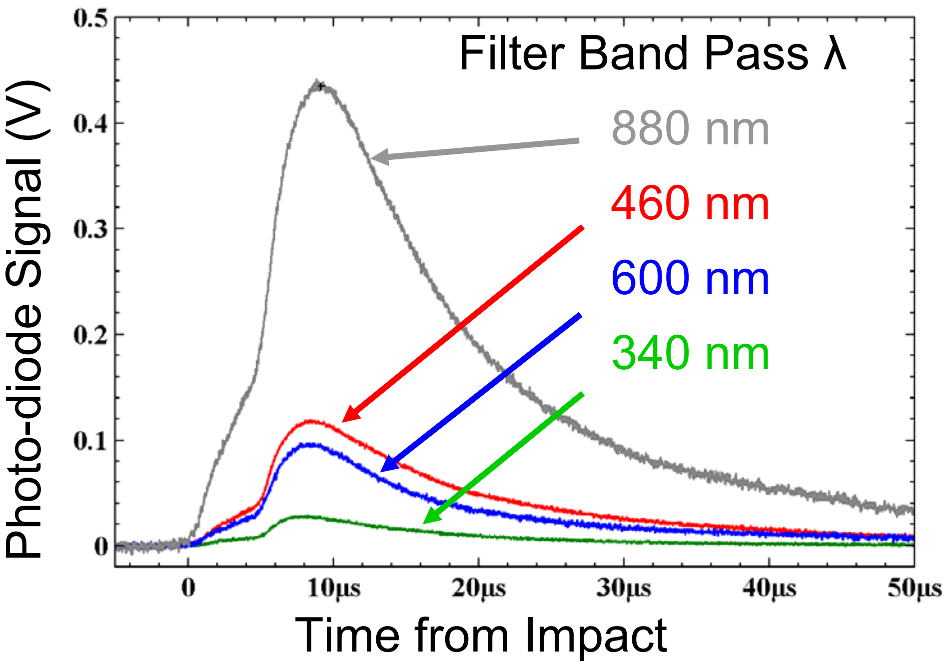
IV (km/s)	*Impactor Material / Thk. (mm)*	*Target Material / Angle / Thk. (mm)*	*Impact Pressure (GPa)*
10.9	**Ti6Al4V / 0.90**	**Al / 20° / 1.0**	**225**

$$I(\lambda,T)=\varepsilon\frac{2hc^2}{\lambda^5}\frac{1}{e^{c_2/\lambda T}-1}$$

Assuming:
emissivity is constant
diodes are viewing the same flash area
graybody/blackbody radiator
equivalent sensitivity from diode to diode

$$\frac{1}{T}=\frac{\lambda_1\lambda_2}{c_2(\lambda_2-\lambda_1)}\left[\ln(I_2/I_1)+5\ln(\lambda_2/\lambda_1)\right]$$

Raw Intensity vs Time



Wavelength filtered profiles from the four color photo-diode array suggest a simplified analysis based on consistent shape.

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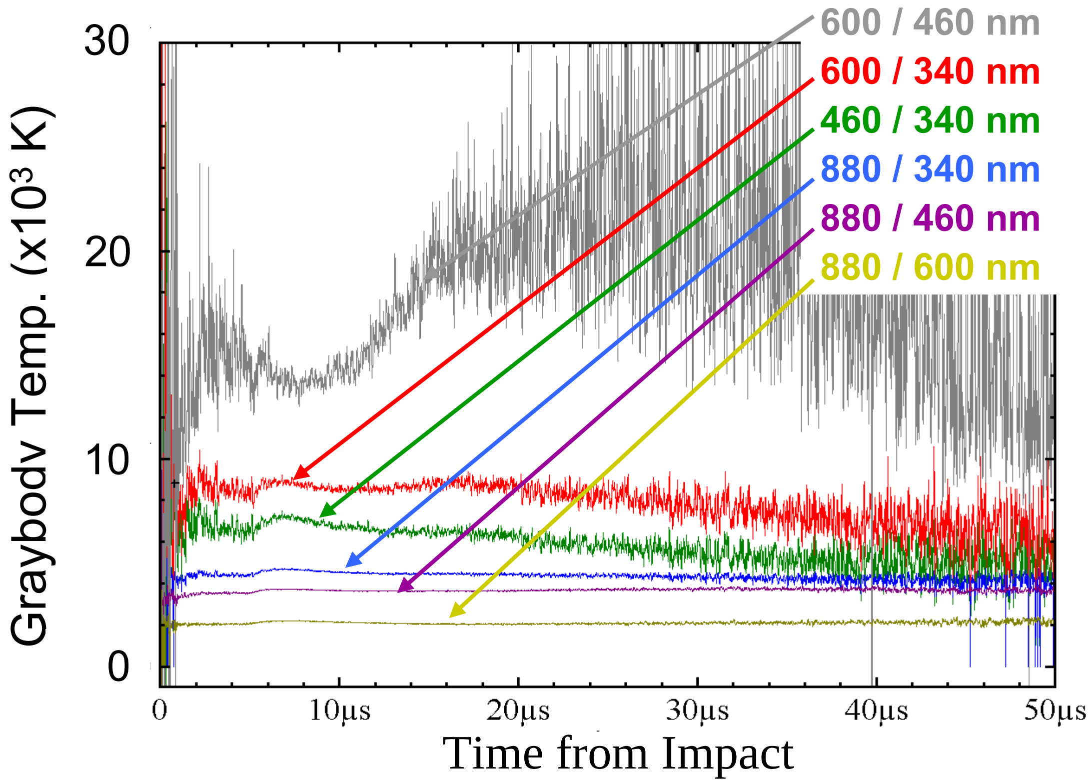
Temperature Measurement Result

Little faith is placed in absolute calculated graybody temperatures. However, the lack of rapid cooling in the profiles supports previous work which demonstrates time-dependent shock induced vaporization.

Calculated temperatures from photo-diodes.



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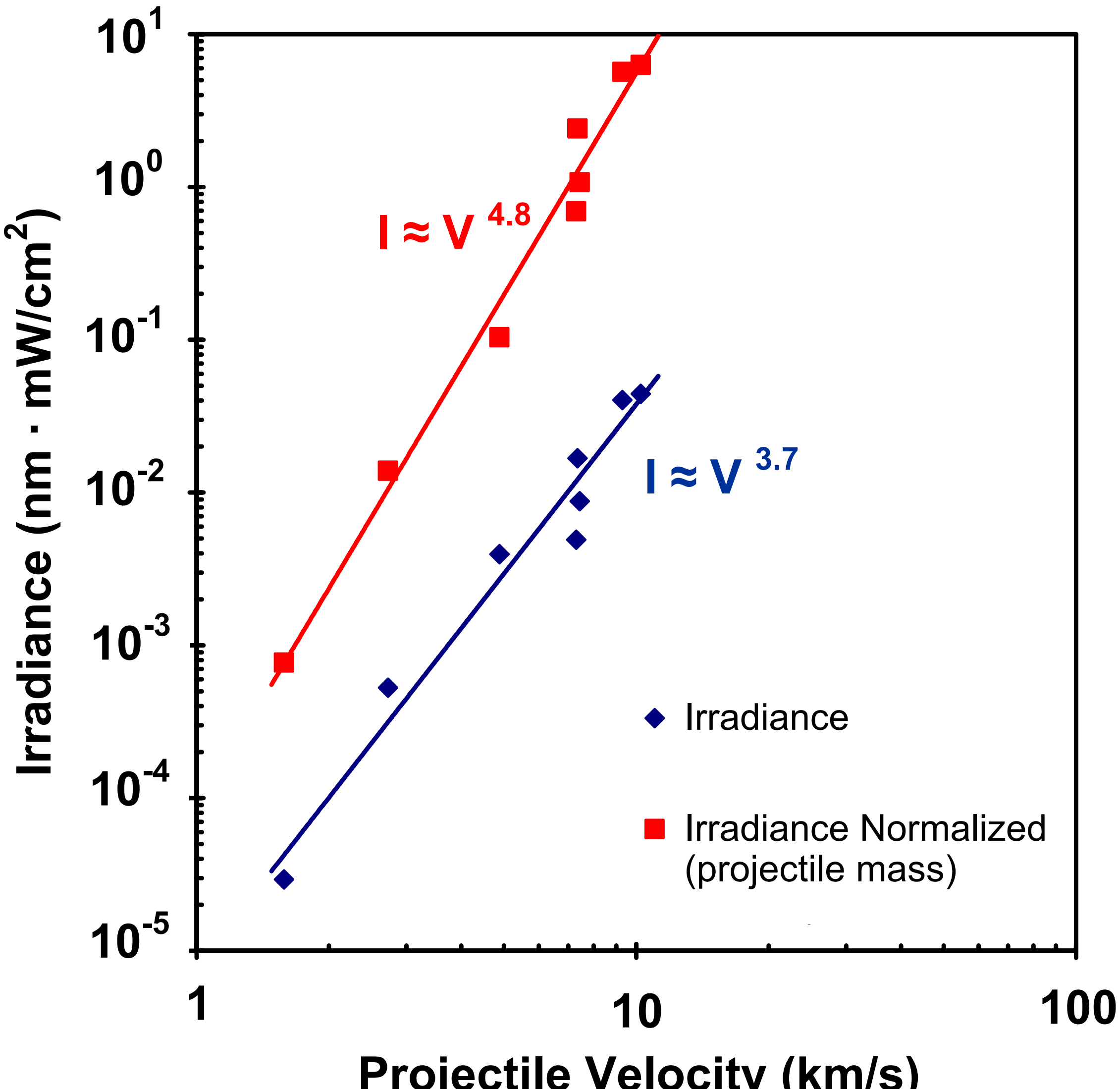
Front Surface Aluminum Impact Flash Intensity

Ti6Al4V projectile impacting MLI/aluminum



- targets are 1-3 mm thick aluminum plate
- 75% of experiments used a multilayered insulation (MLI) blanket over the face of the aluminum target plate.
- normalizing to projectile mass tightens up fit. (Fiichtenicht et. al. 1963, Rosen et. al. 1965,)
- projectile mass varies from 0.8 – 5 grams
- peak irradiance taken from prompt flash peak (<4 μs after impact)

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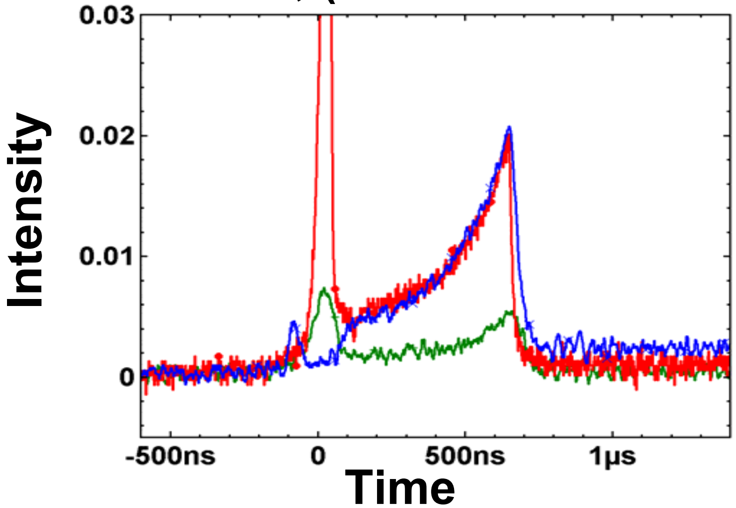
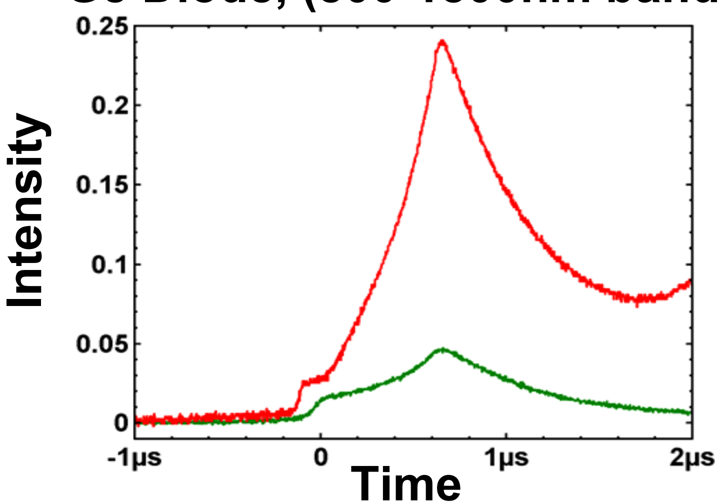
Rear Surface Comp-B Impact Flash Intensity

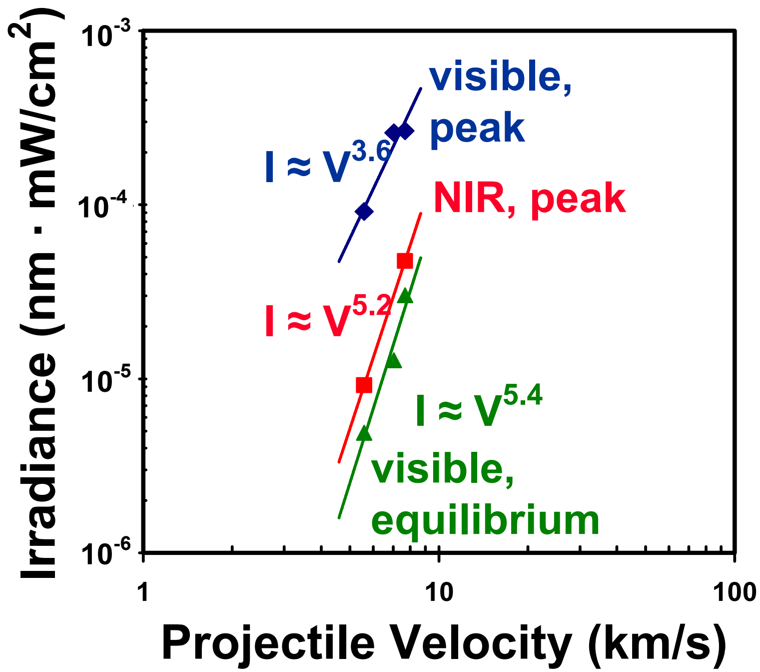
Si Diode, (200-1100nm band)



Ge Diode, (800-1800nm band)



Lexan projectile impacting Comp-B



- impact velocities of 5.5, 7, 7.5 km/s
- peak irradiance is from prompt flash, equilibrium data is steady state irradiance after shock transit through Comp-B

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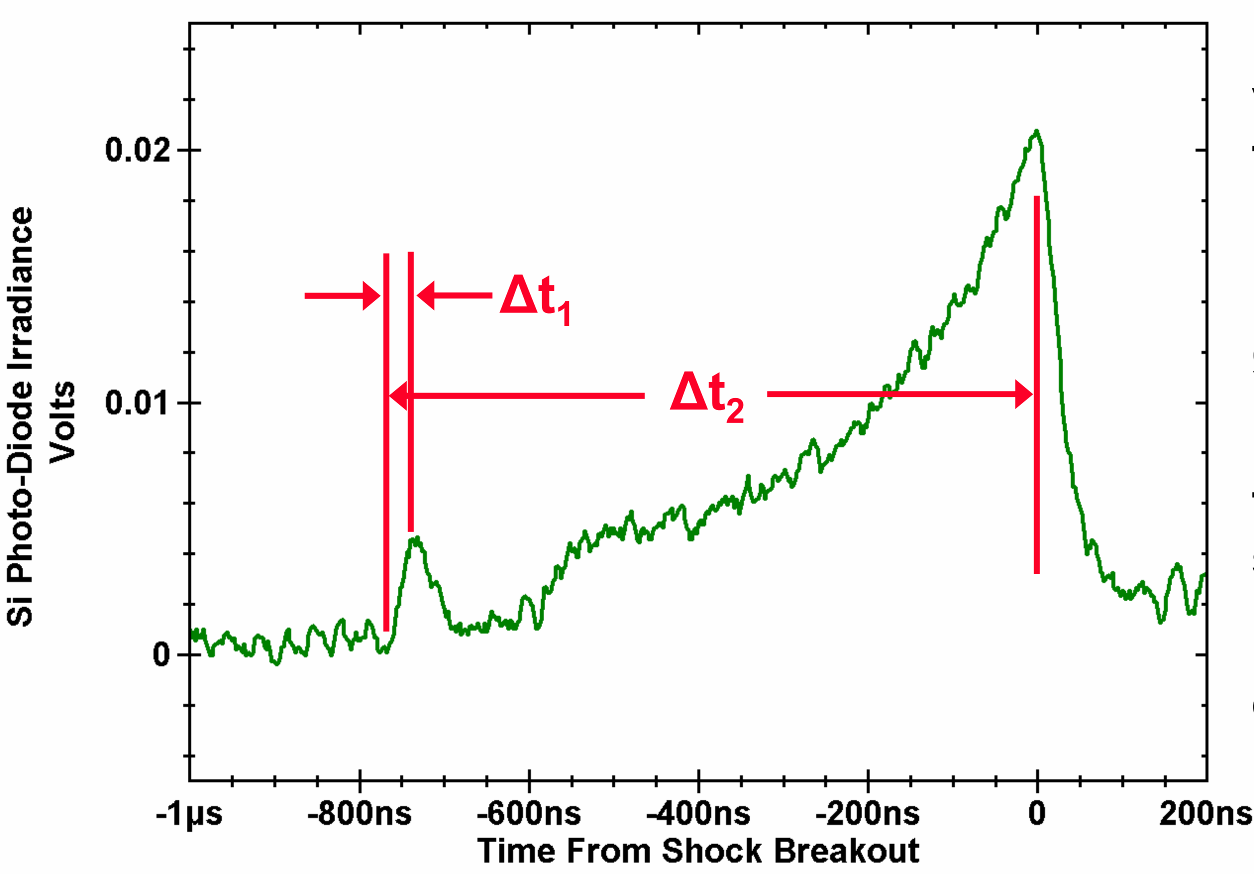
Rear Surface Photo-Diodes Signal Structure

Typical Rear Surface Signal Characteristics



- rear surface photo-diodes view impact through acrylic target mounting ring
- Δt_1 corresponds to impact planarity (28ns across Ø28.6 mm, 0.12 mrad)
- Δt_2 corresponds to shock transit through the target sample
- impact flash structure evident in both visible and NIR signals

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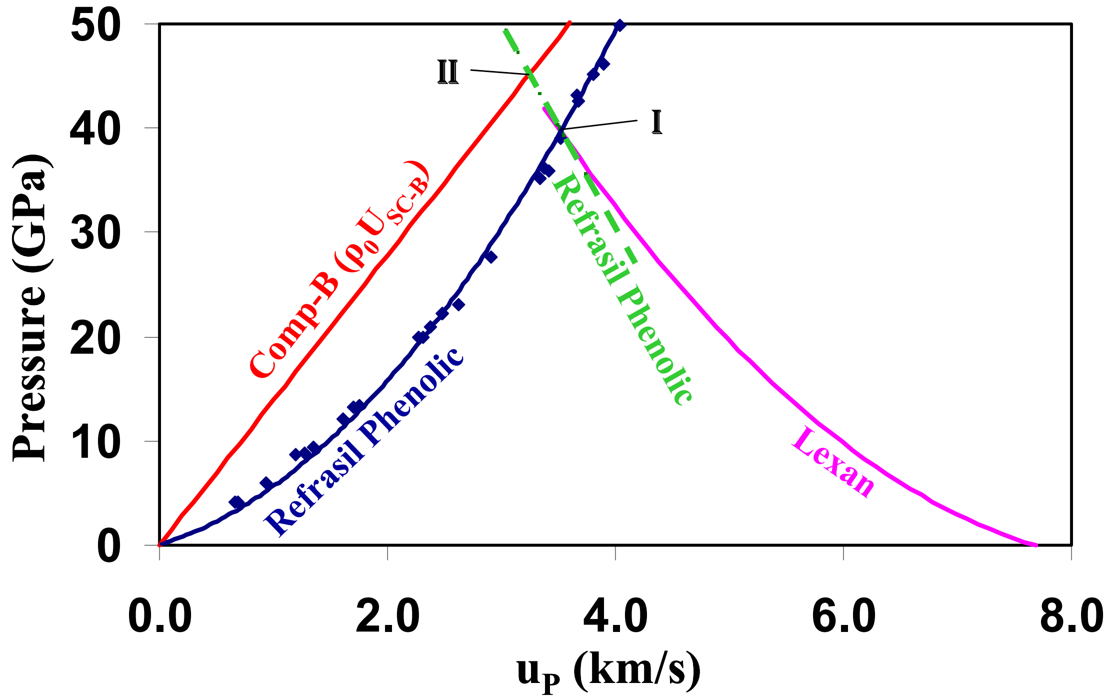
Comp-B Shock/Detonation Velocity

IV (km/s)	Photo-Diode Type	Calculated Composition-B Target Hugoniot State				
		ρ_0 (g/cc)	ρ (g/cc)	P (GPa)	U_S (km/s)	u_P (km/s)
5.59	Si	1.713	2.58	26.7	6.82	2.29
5.59	Ge	1.713	2.60	26.6	6.75	2.30
7.04	Si	1.712	2.88	37.6	7.36	2.99
7.68	Si	1.712	2.85	45.2	8.13	3.25
7.68	Ge	1.712	3.02	43.6	7.66	3.32

- two of three experiments are lexan impacting Comp-B
- calculated hugoniot from measured apparent shock velocity, Rankine-Hugoniot jump equations and LASL shock hugniot data (Marsh et. al.)



- third experiment is Lexan impacting refrasil phenolic backed by Comp-B
- calculated hugoniot from apparent shock velocity, and impedance matching based on LASL shock hugoniot data

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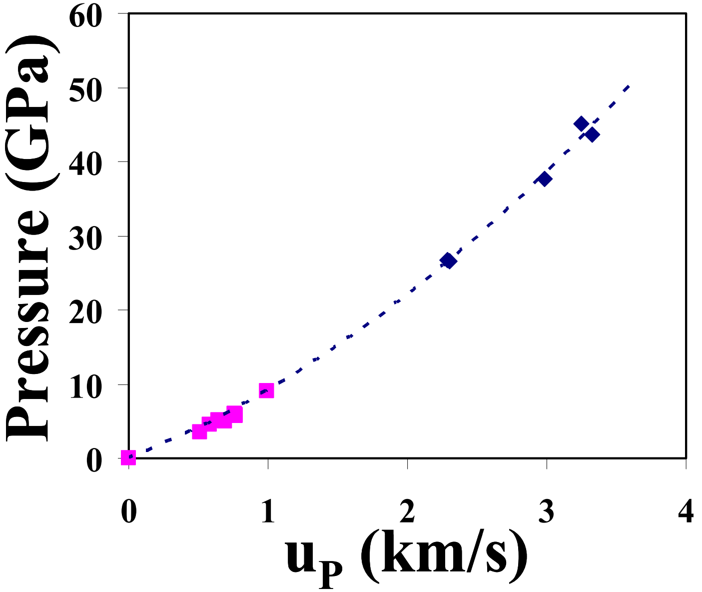
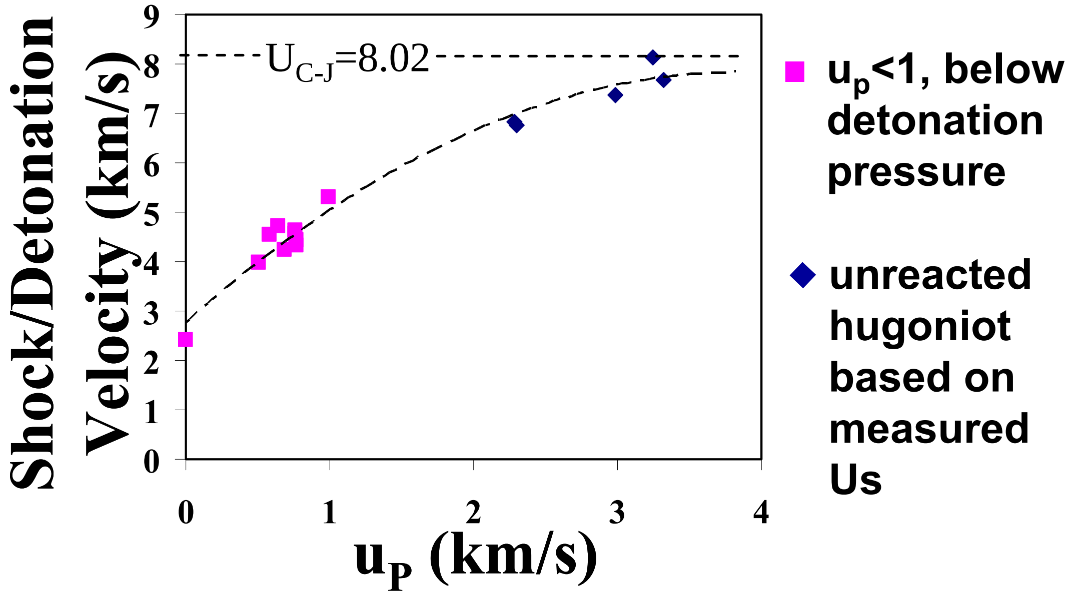
Comp-B Apparent Shock/Detonation Velocity

Hugoniot analysis performed treating Comp-B as unreacted.

All experiments are above the detonation threshold pressure.

The distance to detonation for the low pressure shot based on pop plot slope and critical diameter is 1.2mm





Comp-b pressure behind shock front before detonation is established.

Apparent shock/detonation velocity appears to be asymptotic to the Chapman-Juoguet velocity.

Comp-B reference – LASL Explosive Compendium (Gibbs, Popolato)

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Conclusions

- Temperature measurements of radiating impact debris did not performed well.
  - Improve viewing area , use telescope and beam splitters to ensure uniform detector exposure.
  - Resolve photo-diode calibration issues.
  - Time resolved response is encouraging.

- Impact flash intensity vs. velocity scaling was performed for several materials and experimental geometries.
  - MLI on aluminum indicates same response as aluminum only target.
  - Larger scale experiments for titanium into aluminum provide scaling powers in agreement with micron scale experiments for glass impacting aluminum.

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Conclusions

- Application of rear surface photo-diodes on Comp-B shows details of shock loading and initiation process.
  - Hugoniot analysis of data provides empirical EOS results.
  - CTH model impact pressure agrees with pressures based on photo-diode results.

- Use of off the shelf photo-diodes provides unique insight into the phenomena and physics associated with impact flash, and has the potential to provide measurement of opaque target shock velocity using properly designed experimental configurations.