Computer Models of Micrometeoroid Impact on Fused Silica Glass Mirrors

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Presented by David Davison

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Summary of Presentation

- Objectives/Strategy/Outcome
- Validation of computer model for glass
- Results of cratering analysis
- Analysis and Auburn University/Hypervelocity Impact Facility (AU/HIF) data in the context of historical data
- Surface displacements
- Conclusions/Recommendations

Objectives

- Review data on hypervelocity impact on glass.
- Develop a computer model for glass suitable for analysis of impacts at high velocities.
- Match the crater and spall parameters for impacts into glass from low-energy tests at AU/HIF.
- Blindly predict the crater and spall parameters for impacts into glass (to be compared to results from high-energy tests at AU/HIF).
- Damp the calculations to static solutions at late time for further analysis of the influence of impact on mirror optics.

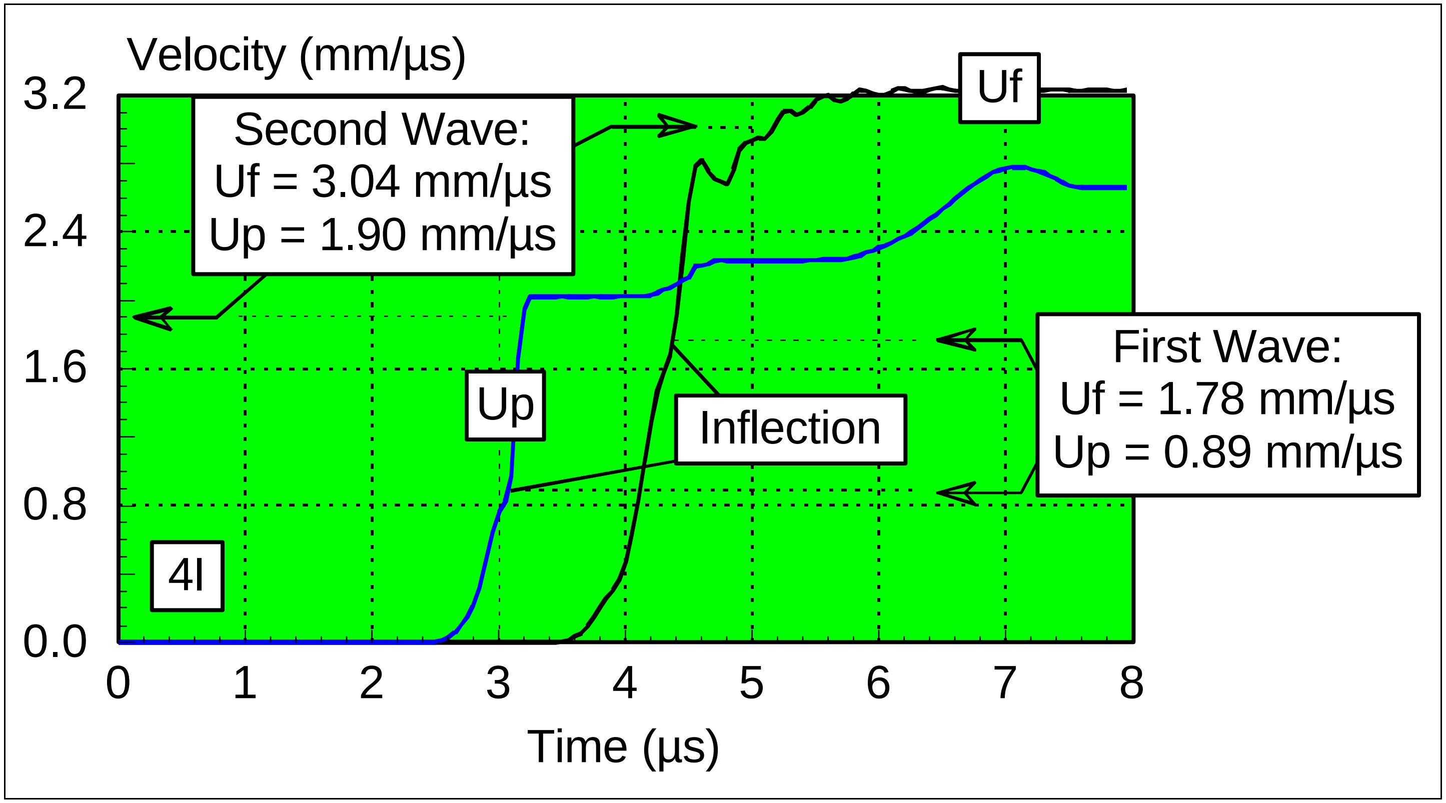
Strategy for Impact Analysis

- Develop a context for the impact analysis and testing by examining data from terrestrial experiments.
- For the fused silica model, include data from experiments at very high pressures, the first-order phase transformation to Stishovite, and a strength model that depends on pressure and strain rate.
- Use coupled smooth particle hydrodynamics (SPH) and Lagrange representations of objects.
- Vary the spall parameter to match the crater from the impact test at low-energy.
- Use the same settings for the impact analysis at high energy.
- Run to late time for both low and high energy impacts.

Outcome

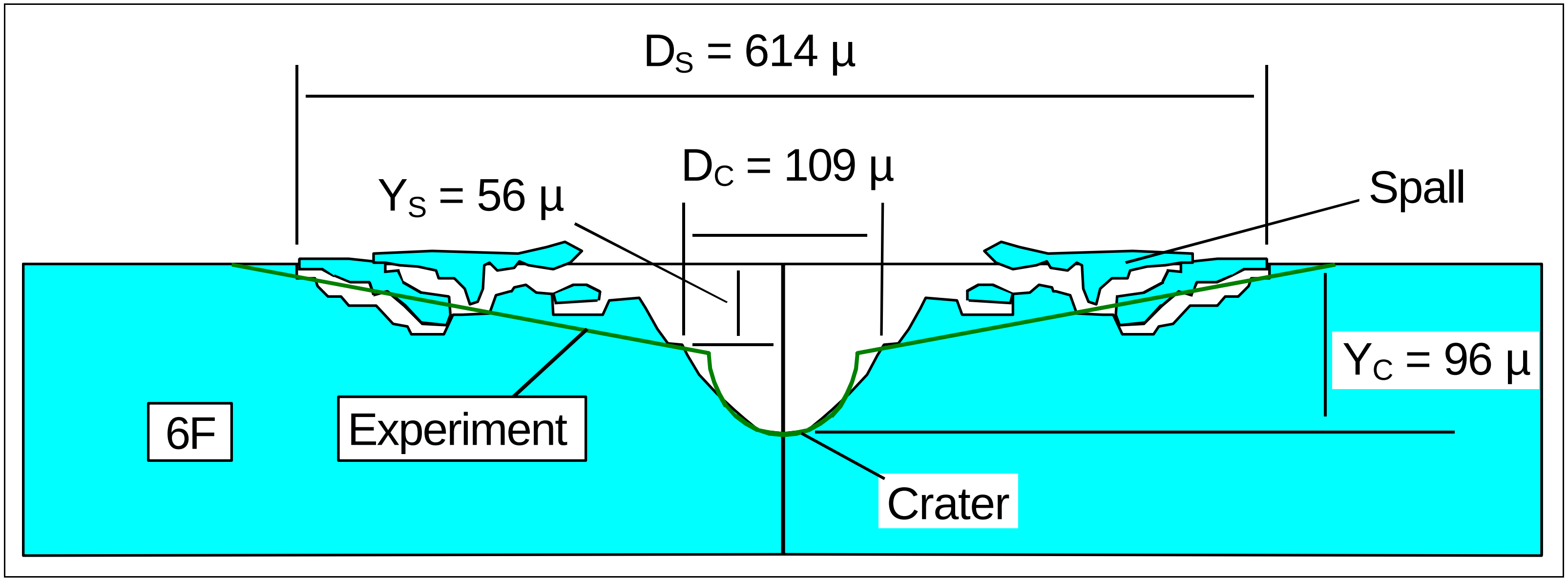
- Obtained new fits to historical data on crater and spall in glass
- Validated the computer model for the glass
- Matched the low-energy impact calculation to historical trends and to the averaged result of tests at AU/HIF
- Matched the high-energy impact calculation to historical trends but *not* to the averaged result of tests at AU/HIF
- Predicted the effect of low-and high-energy impacts on the shape of the mirror

Validation of Computer Model for Fused Silica



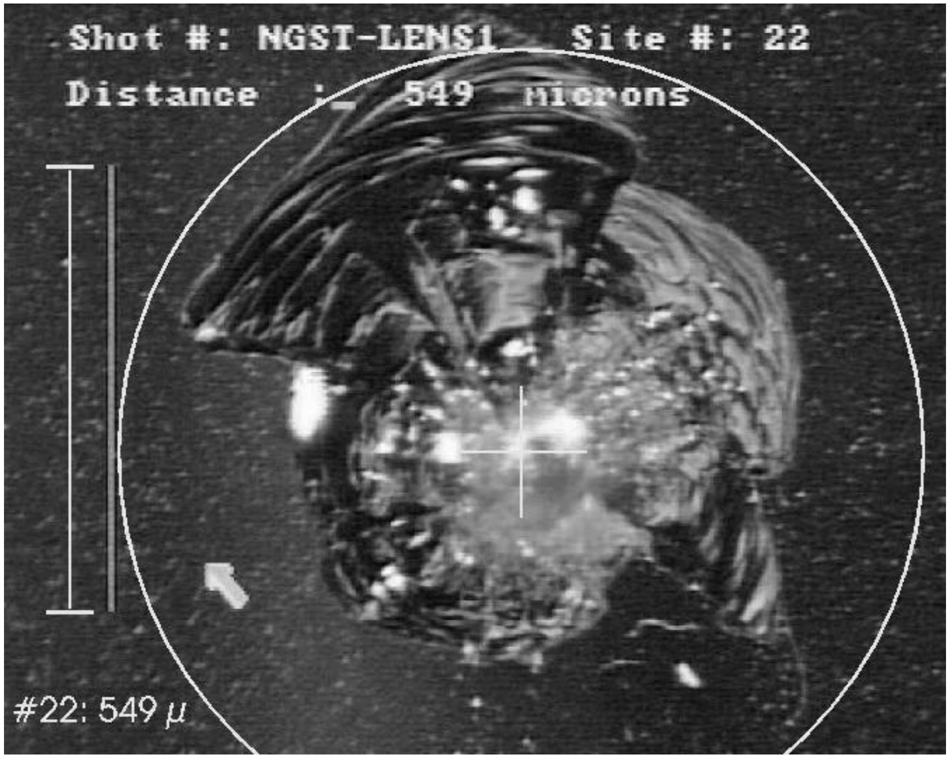
The computer model for the fused silica reproduced the first and second waves observed in impact experiments by Wackerle (*J. Appl. Phys.*, p.922, March 1962).

Matching of Crater and Spall, Low-Energy Impact



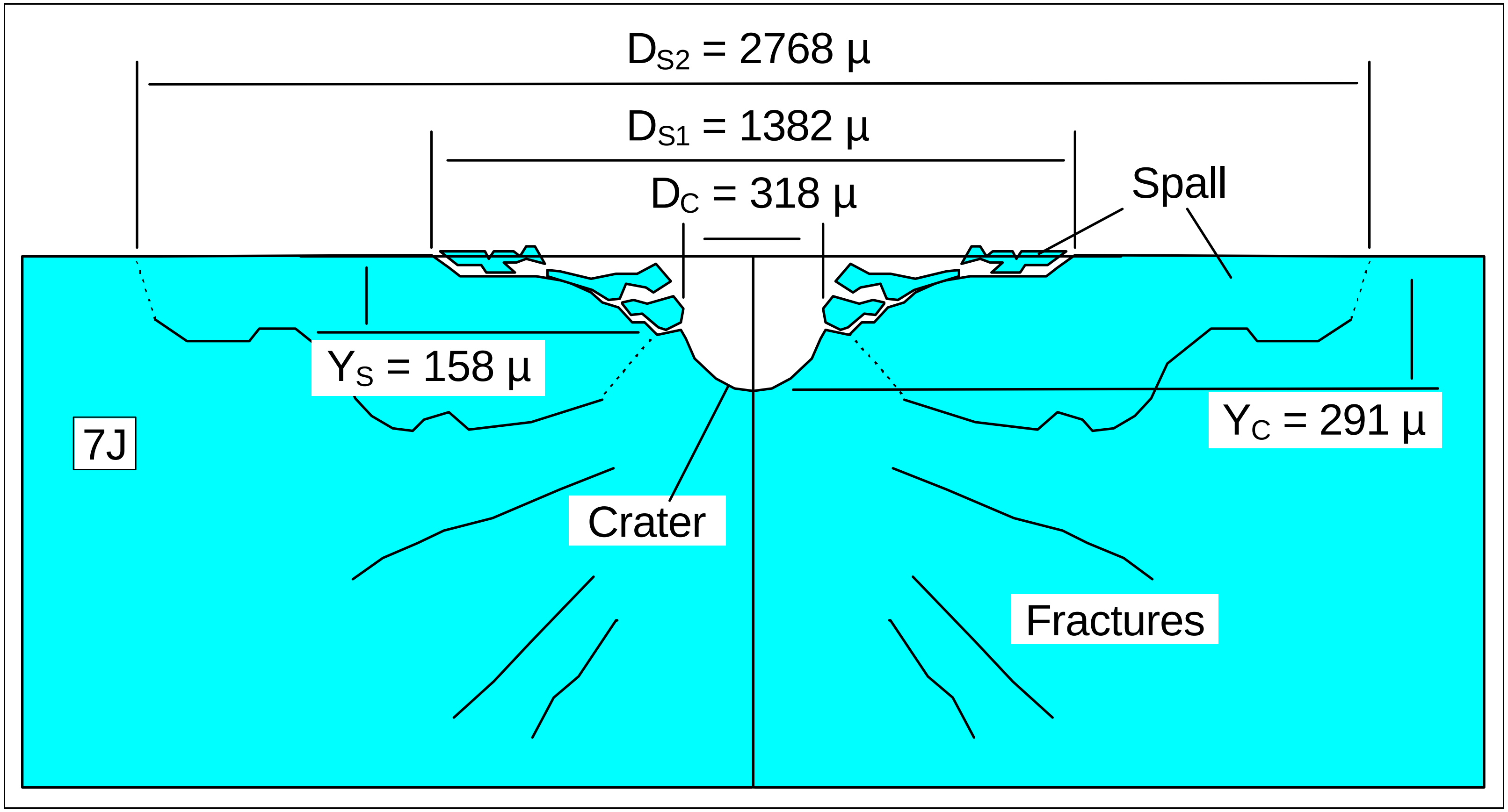
The calculation (shaded) matched the crater depth (Y_C) and diameter (D_C) and the spall depth (Y_S) and diameter (D_S).

AU/HIF Test of Low-Energy Impact in Fused Silica



For this test the particle velocity was 5.6 km/s and its diameter, 57 µ. The crater and spall were nonsymmetric. The crater and spall dimensions were: Y_C = 103 µ, D_C = 63x90 µ, Y_S = 51 µ, and D_S = 740x780 µ.

Crater and Spall, High-Energy Impact



The impact analysis showed a large region of incipient front-surface spall. Not shown is aft surface spall also predicted by the analysis.

Crater and Spall Dimensions

Energy	Type	Y_C (μ)	D_C (μ)	Y_S (μ)	D_S (μ)
Low	AU/HIF*	97	91	51	681
Low	AUTODYN	96	109	56	614
High	AU/HIF*	74	68	34	516
High	From Fit	234	243	-	3,356
High	AUTODYN	291	318	158	2,768

*Average of three

Definition of Low and High Energy

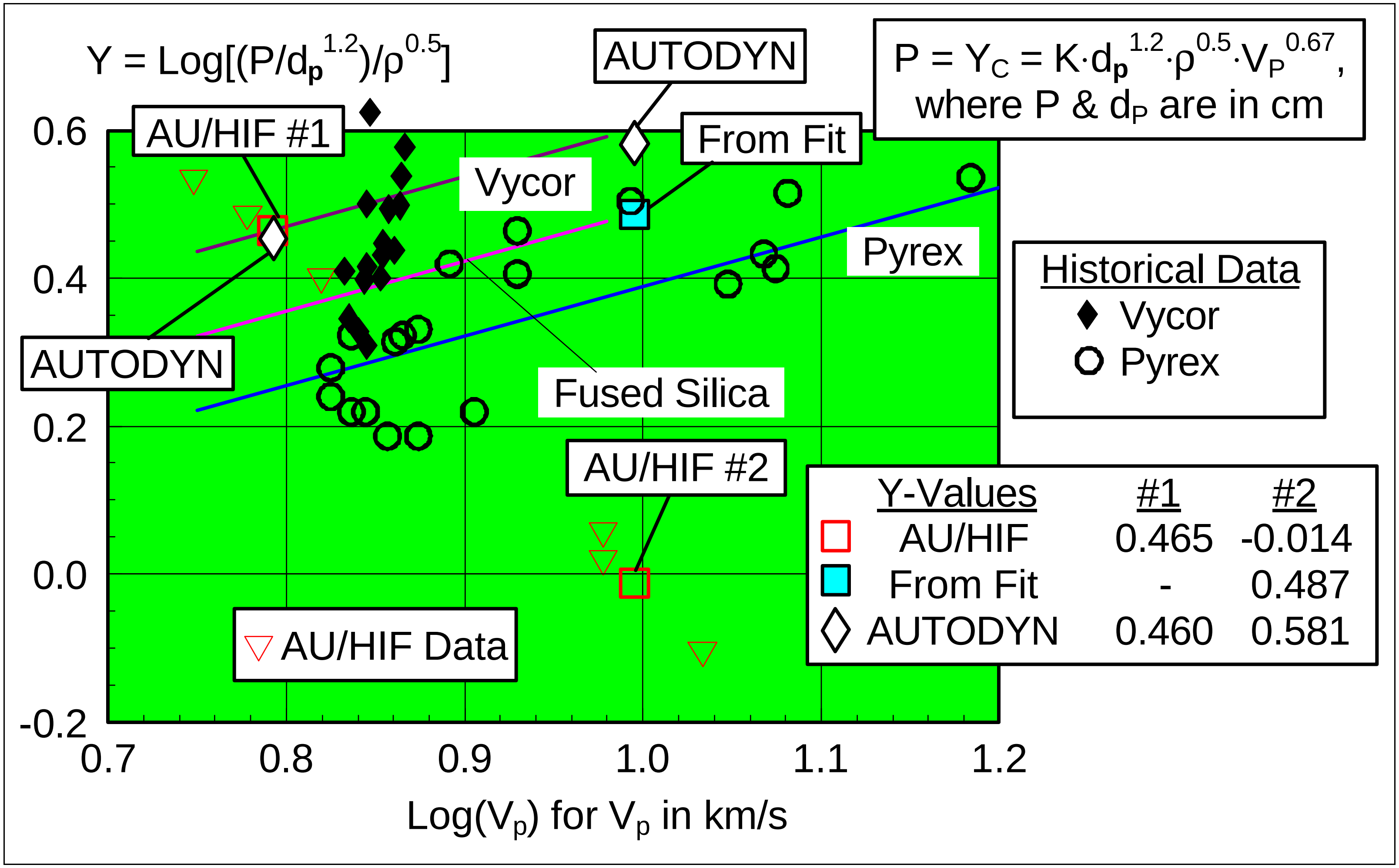
Energy	D_P (μ)	V_P (km/s)	KE (erg)
Low	62	6.2	$5.38 \cdot 10^4$
High	124	9.9	$1.098 \cdot 10^6$

Glasses and Their Constituents

		Constituents				
Type	*r* *(gm/cm^3)*	SiO_2	TiO_2	B_2O_3	Na_2O	Al_2O_3
Quartz	2.65	~100	-	-	-	-
Fused Silica (Corning 7940)	2.20	99.9	-	-	-	-
Ultra-Low Expansion (ULE, Corning 7971)	2.21	92.5	7.5	-	-	-
Borosilicate (Pyrex, Corning 7740)	2.23	81	-	13	4	2
Vycor	2.2	94	-	5	1	-
Soda-Lime (Float)*	2.53	74	-	-	11	2

*Other constituents: 9% CaO, 3% MgO, & 1% K_2O

Penetration (Crater Depth)

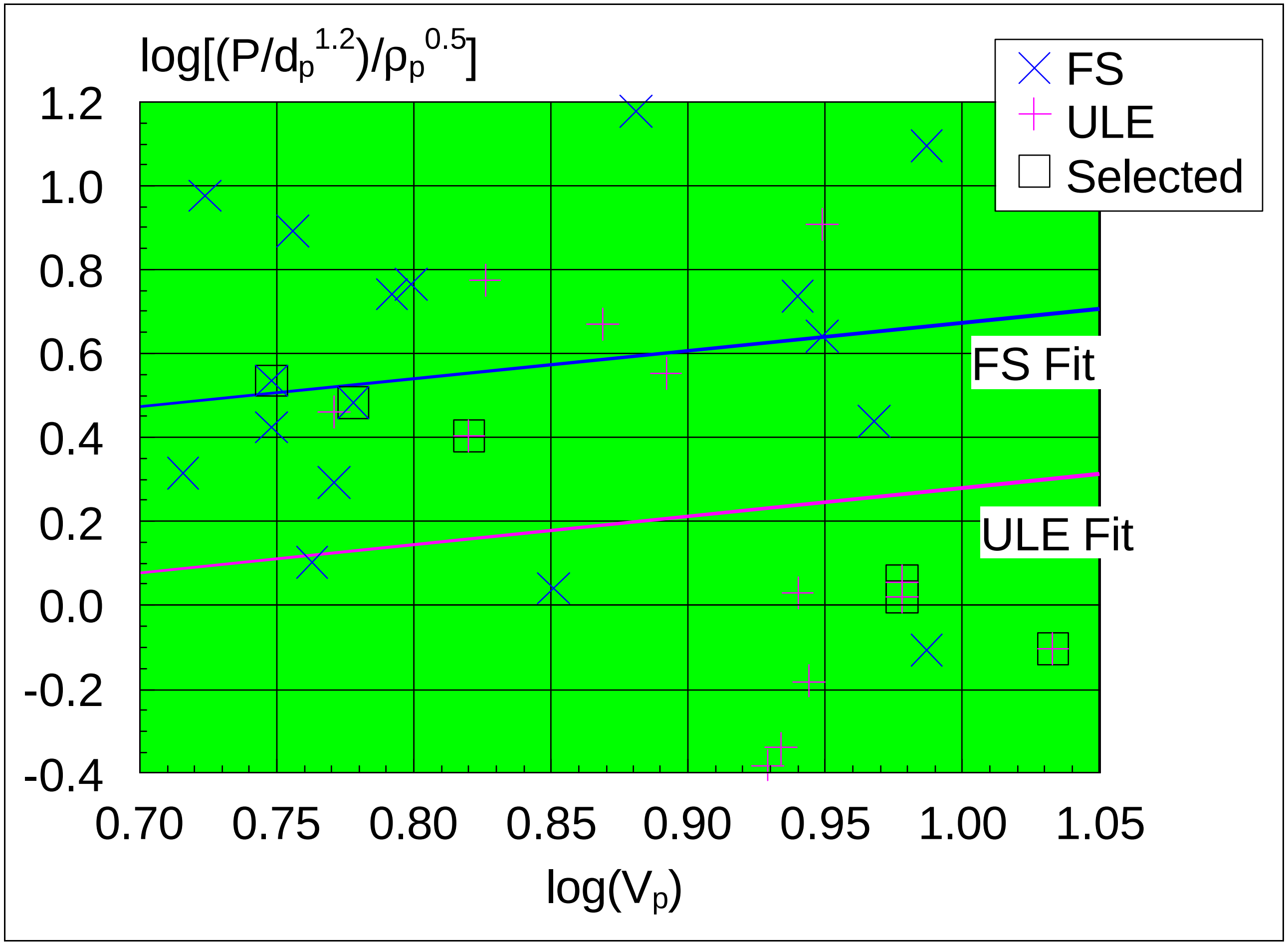


$$P = Y_C = K \cdot d_p^{1.2} \cdot \rho^{0.5} \cdot V_P^{0.67},$$

where P & d_P are in cm

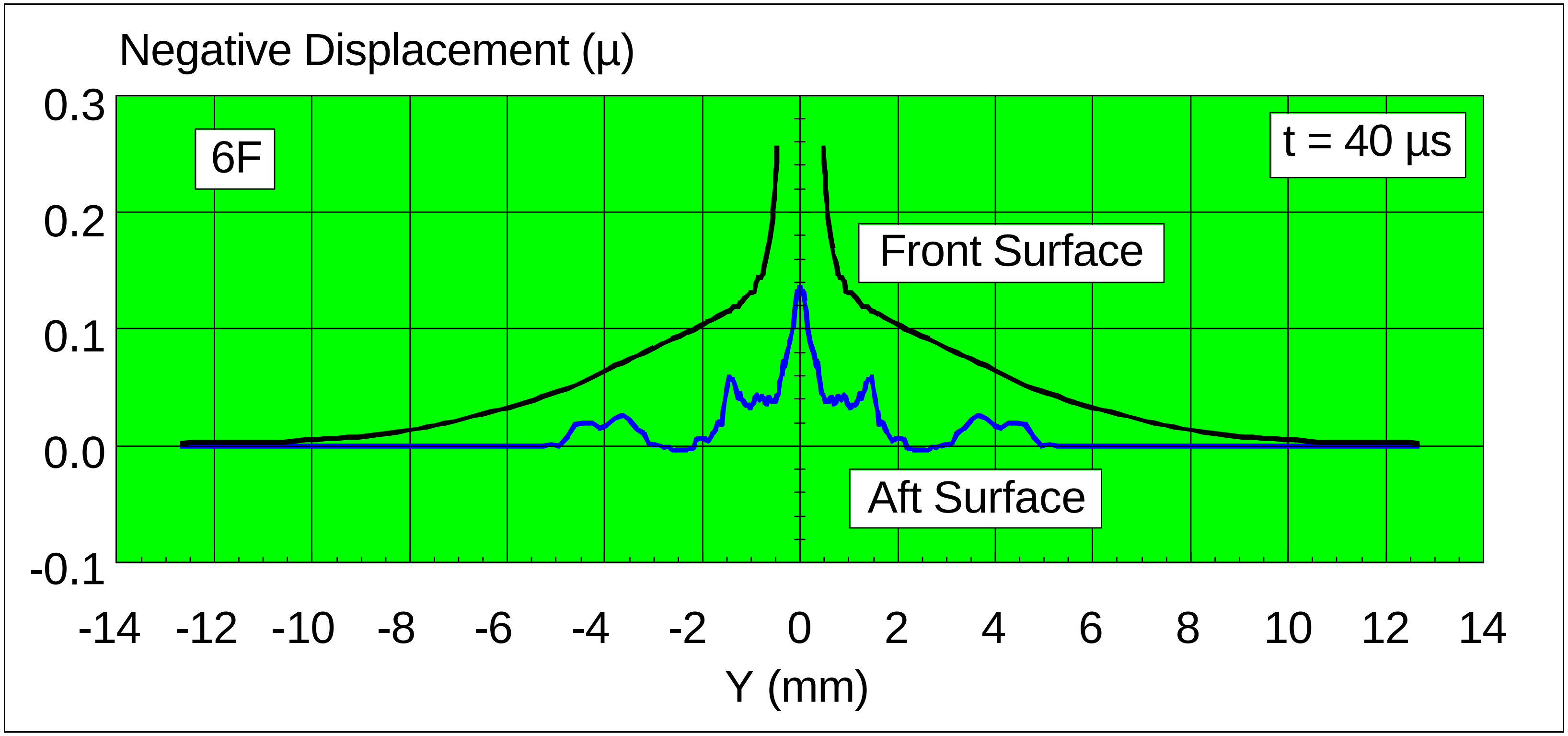
Y-Values	#1	#2
🟥 AU/HIF	0.465	-0.014
🟦 From Fit	-	0.487
◇ AUTODYN	0.460	0.581

Penetration Data for Glass from AU/HIF



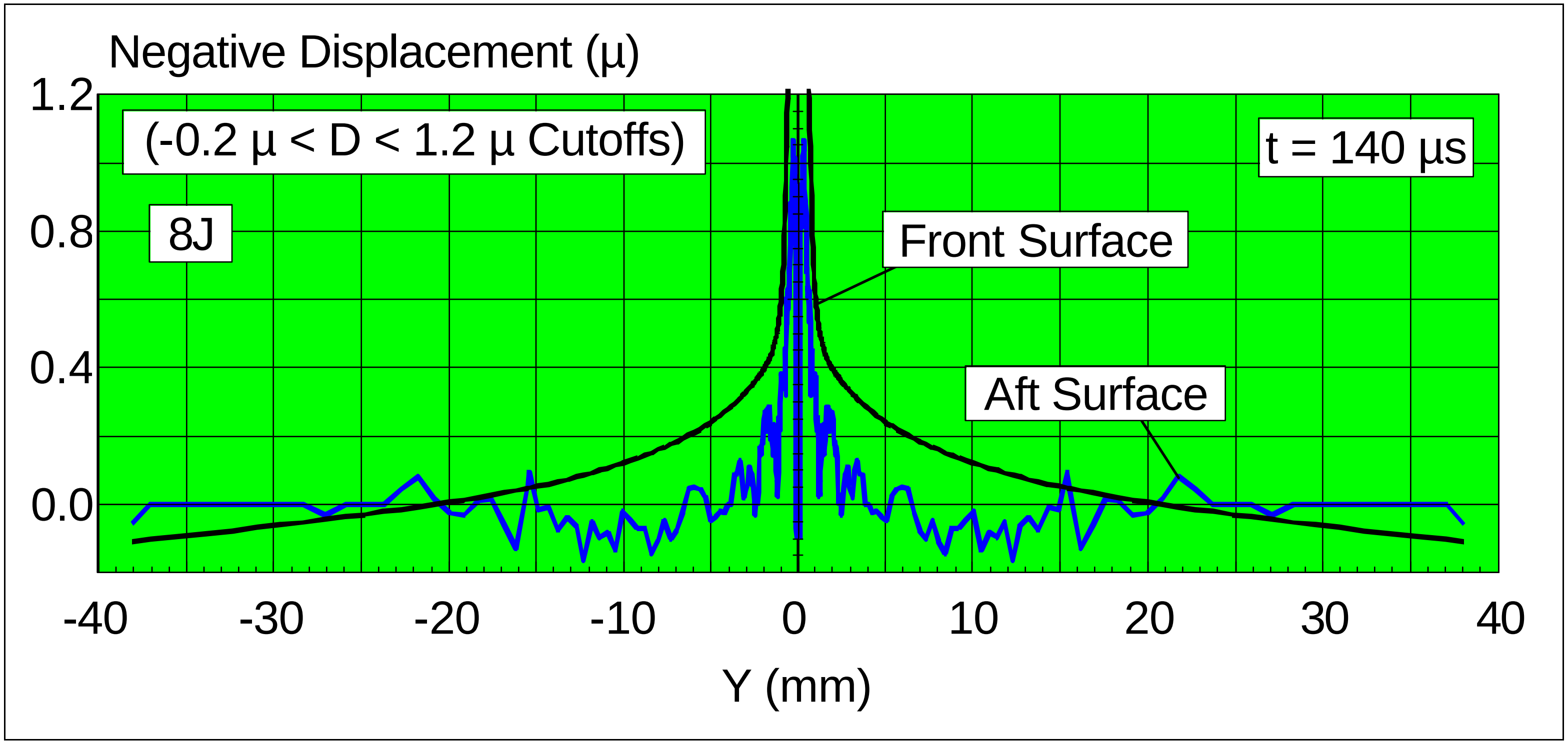
The FS data lies higher than the ULE data. The scatter is large.

Surface Displacements
Low Energy Impact/One-Inch Disk



The impact affected the glass to a diameter of 20 mm.

Surface Displacements
High Energy Impact/Three-Inch Disk



The impact affected the entire disk (note scales).

Conclusions

- Historical glass impact data should guide interpretation of analysis and test results
- AUTODYN matched cratering and spall data and predicted late-time surface shapes
- The fused silica penetration data lay above the ULE data
- The scatter in the AU/HIF data was large

Recommendations

- Obtain more data on glass impact at AU/HIF
- For future work:
  - Consider an energy-dependent EOS (e.g., Sesame)
  - Examine the effect of temperature on cratering and spall