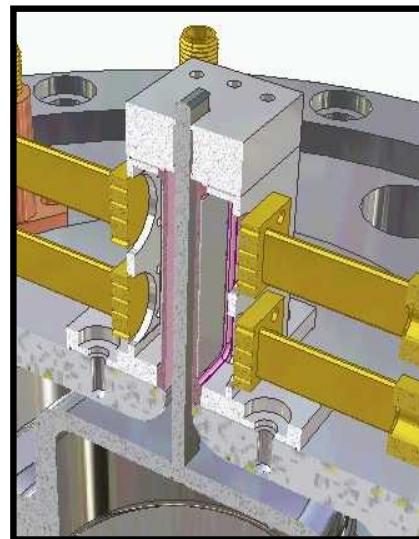
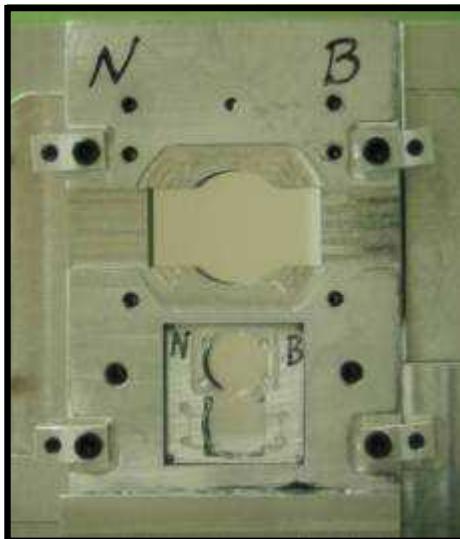


# Characterization of the release response of alpha-quartz in the multi-Mbar regime for use as an impedance match standard

2013 Joint APS-SCCM / AIRAPT Conference  
Seattle, Washington July 7-12, 2013

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



## Acknowledgements

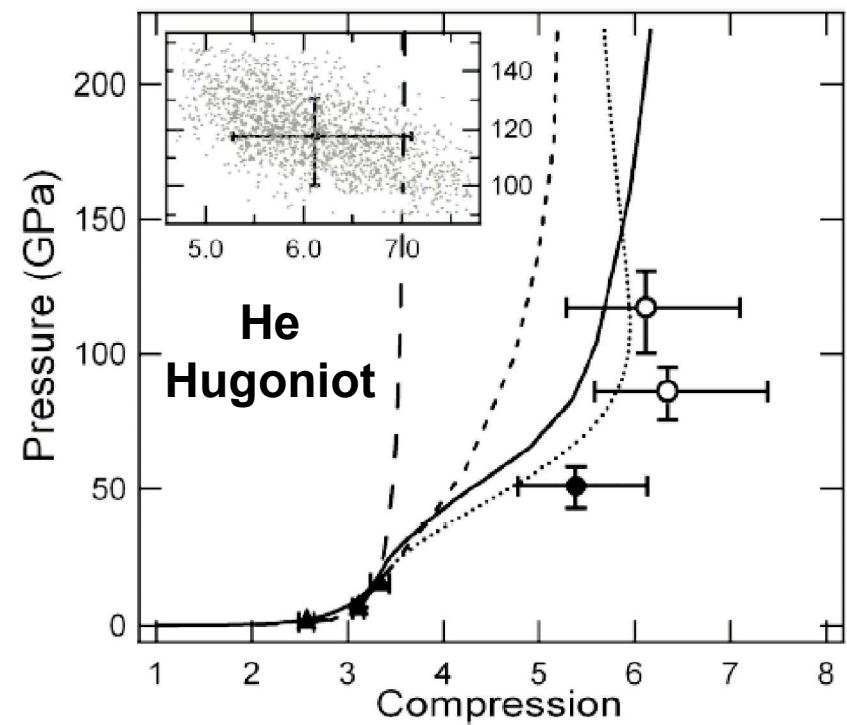
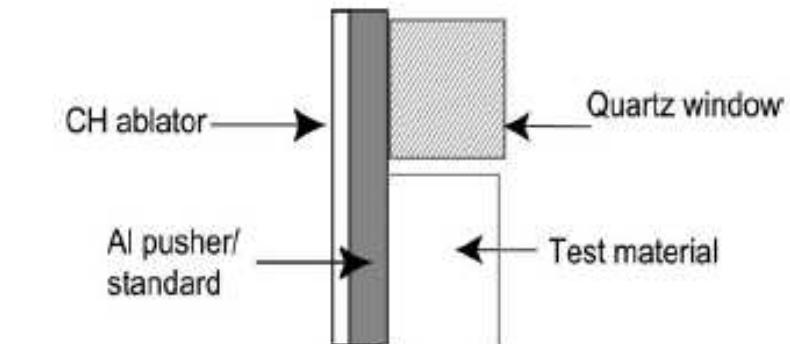
- **Mike Desjarlais**
  - Quantum Molecular Dynamics (QMD) calculations
- **Ray Lemke**
  - Flyer plate design and MHD simulations
- **Jean-Paul Davis, Devon Dalton, Ken Struve, Mark Savage, Keith LeChien, Brian Stoltzfus, Dave Hinshelwood**
  - Bertha model, pulse shaping
- **Charlie Meyer, Devon Dalton, Dustin Romero, Anthony Romero, entire Z crew...**
  - Experiment support



# Motivation for $\alpha$ -Quartz measurements

- Quartz melts at  $\sim 100$  GPa into a conducting fluid
  - Shock front becomes reflective
- Quartz is quickly becoming a high pressure shock wave standard
  - Helium, diamond, deuterium, water, xenon, krypton, carbon dioxide, ...
- For accurate results there is a need to understand the off-Hugoniot response of quartz
  - In particular the quartz release response is needed for use with lower impedance materials

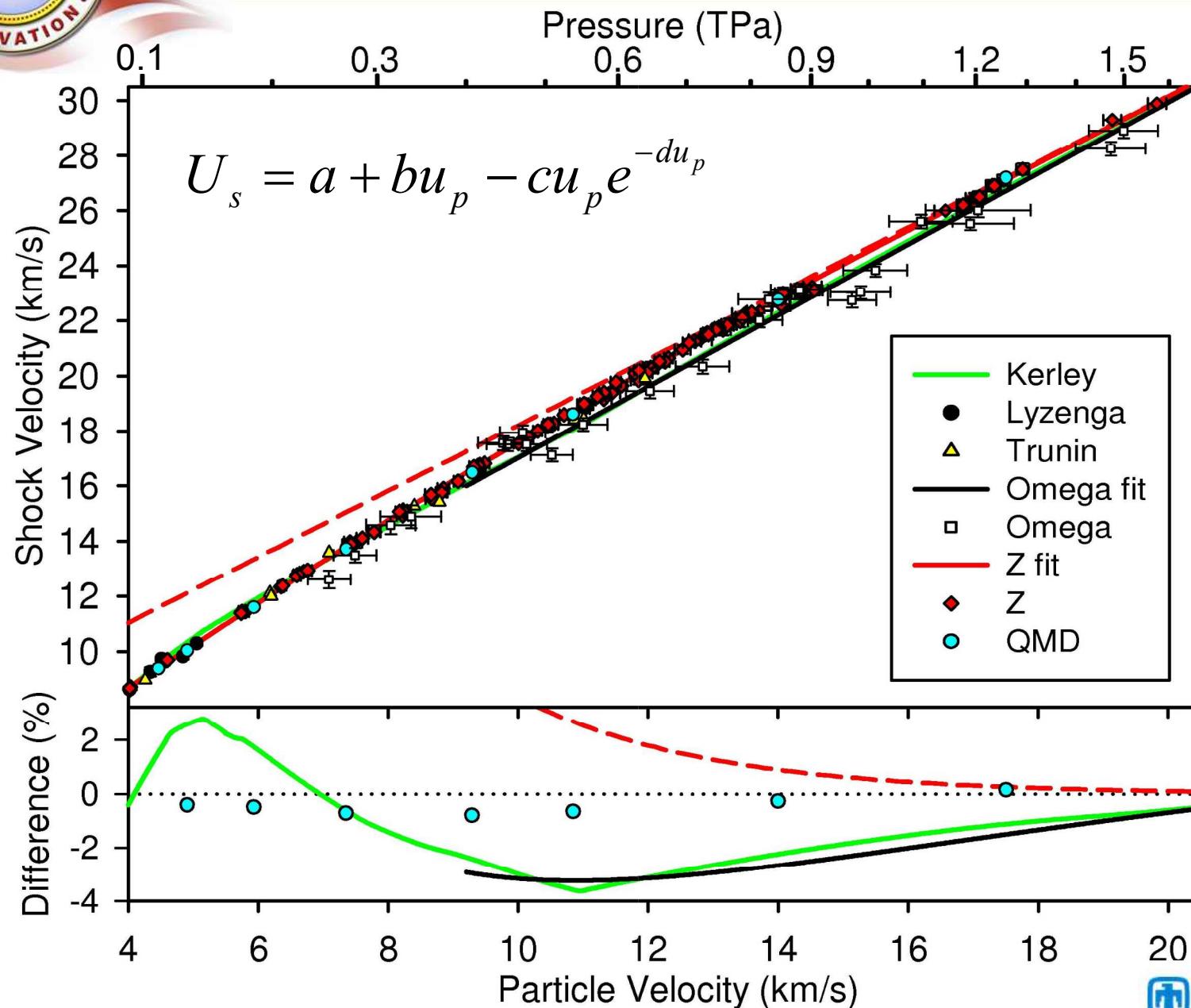
## APPENDIX: DEVELOPMENT OF QUARTZ AS AN IMPEDANCE-MATCH STANDARD



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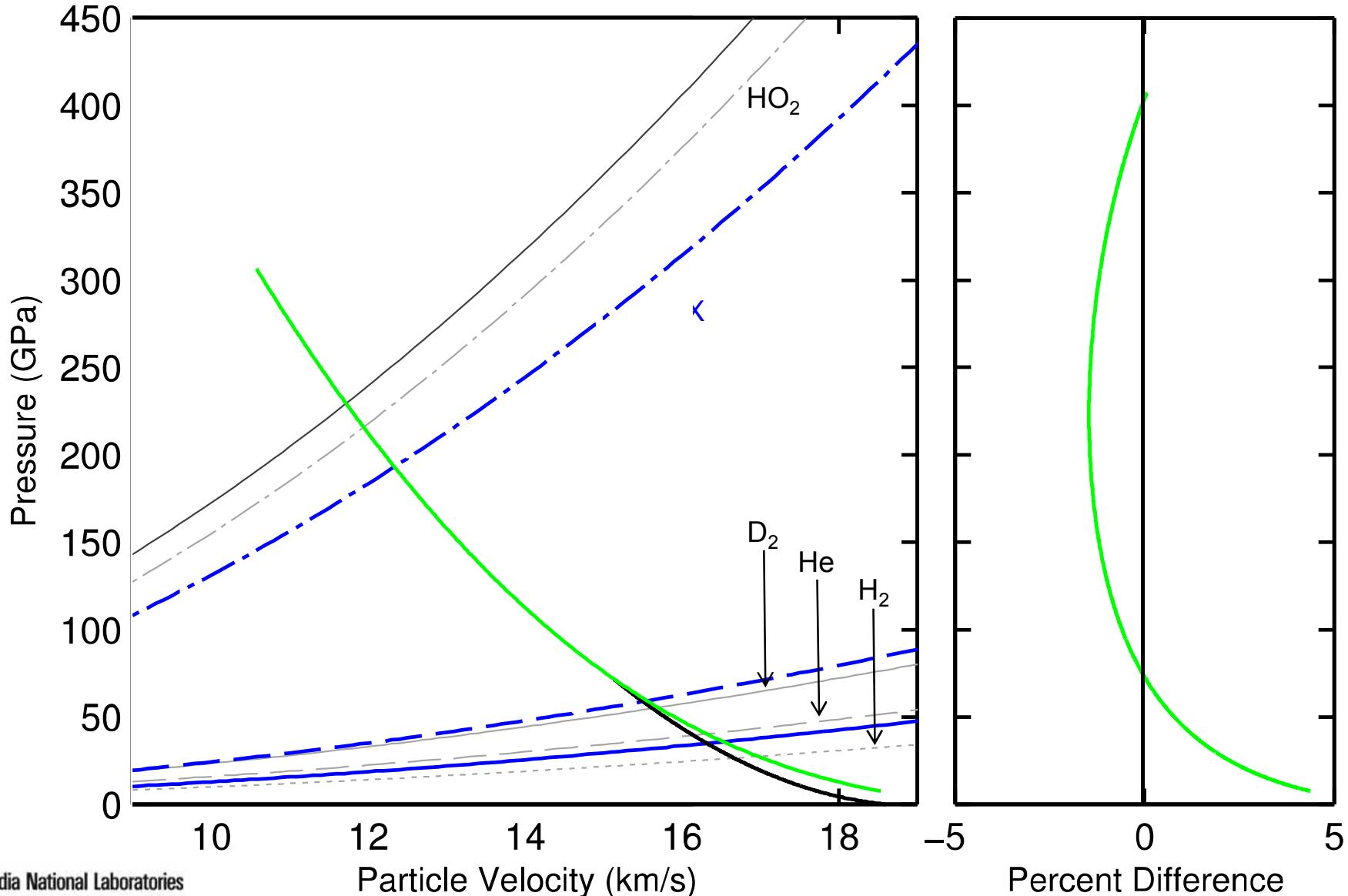
# $U_s$ - $u_p$ Hugoniot for $\alpha$ -Quartz

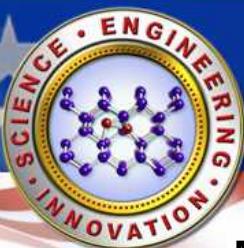


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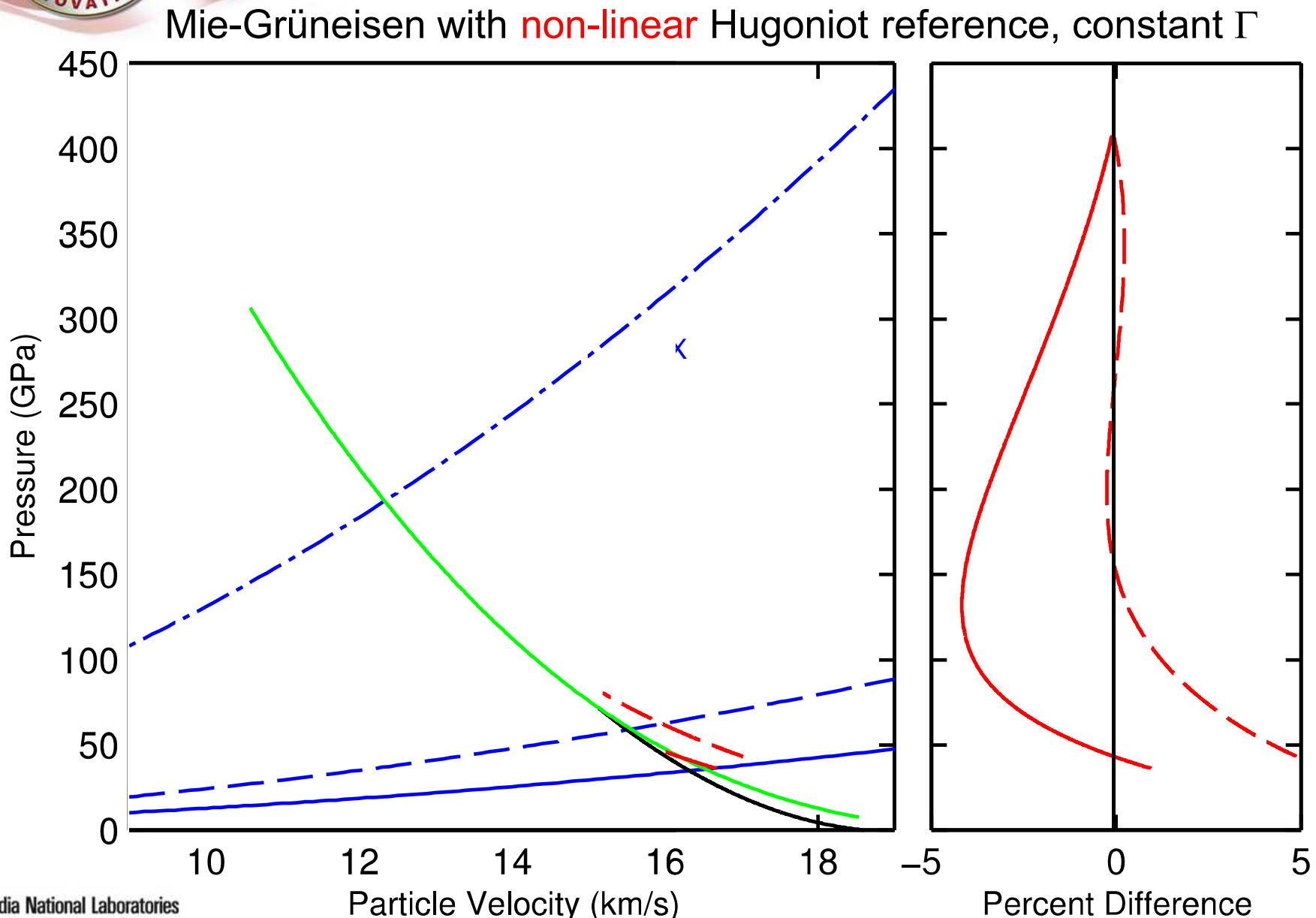


# Corrections to Reflected Hugoniot not insignificant and change sign depending on sample impedance



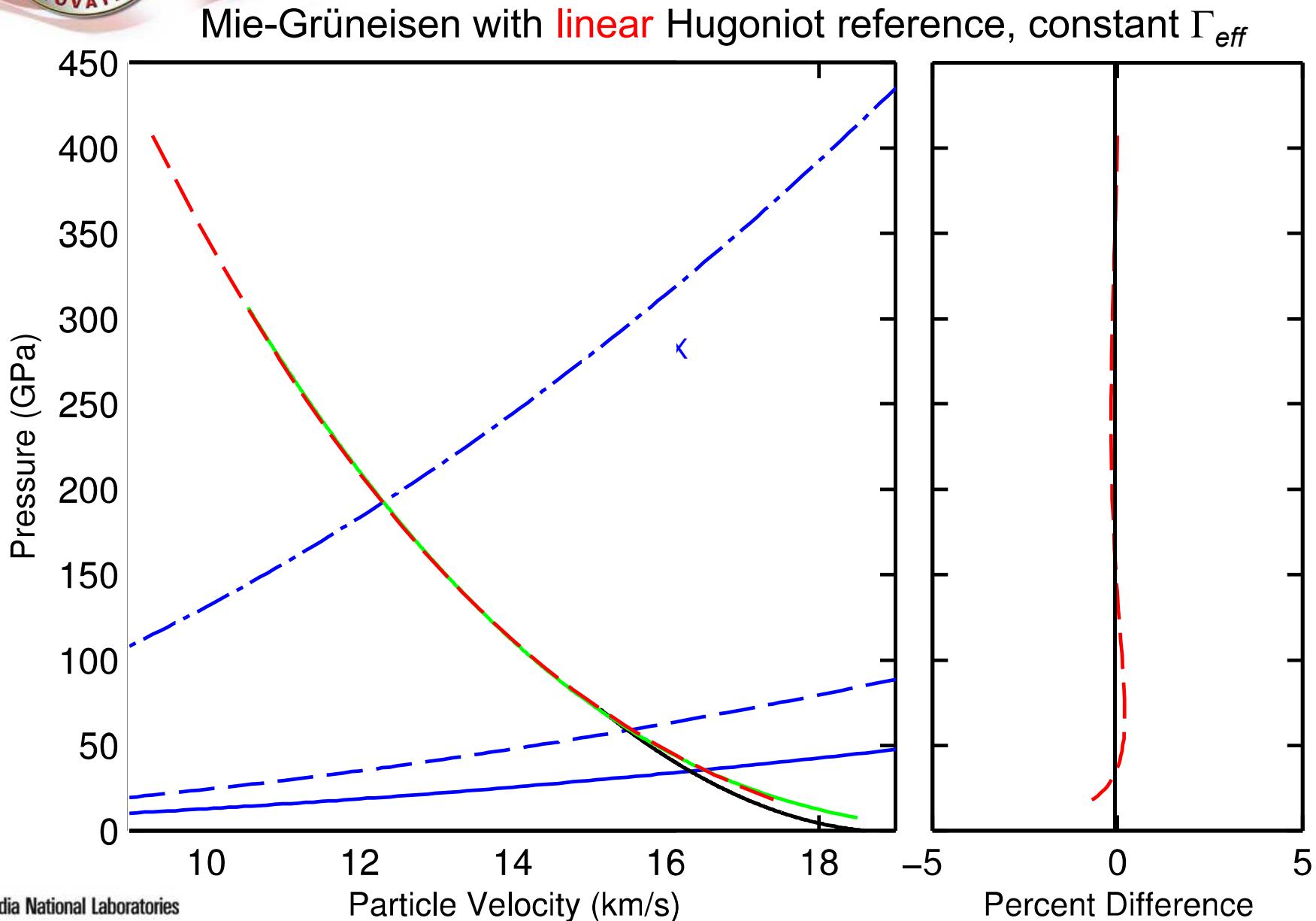


# Mie-Grüneisen, constant $\Gamma$ with *non-linear* reference does not provide adequate description of release



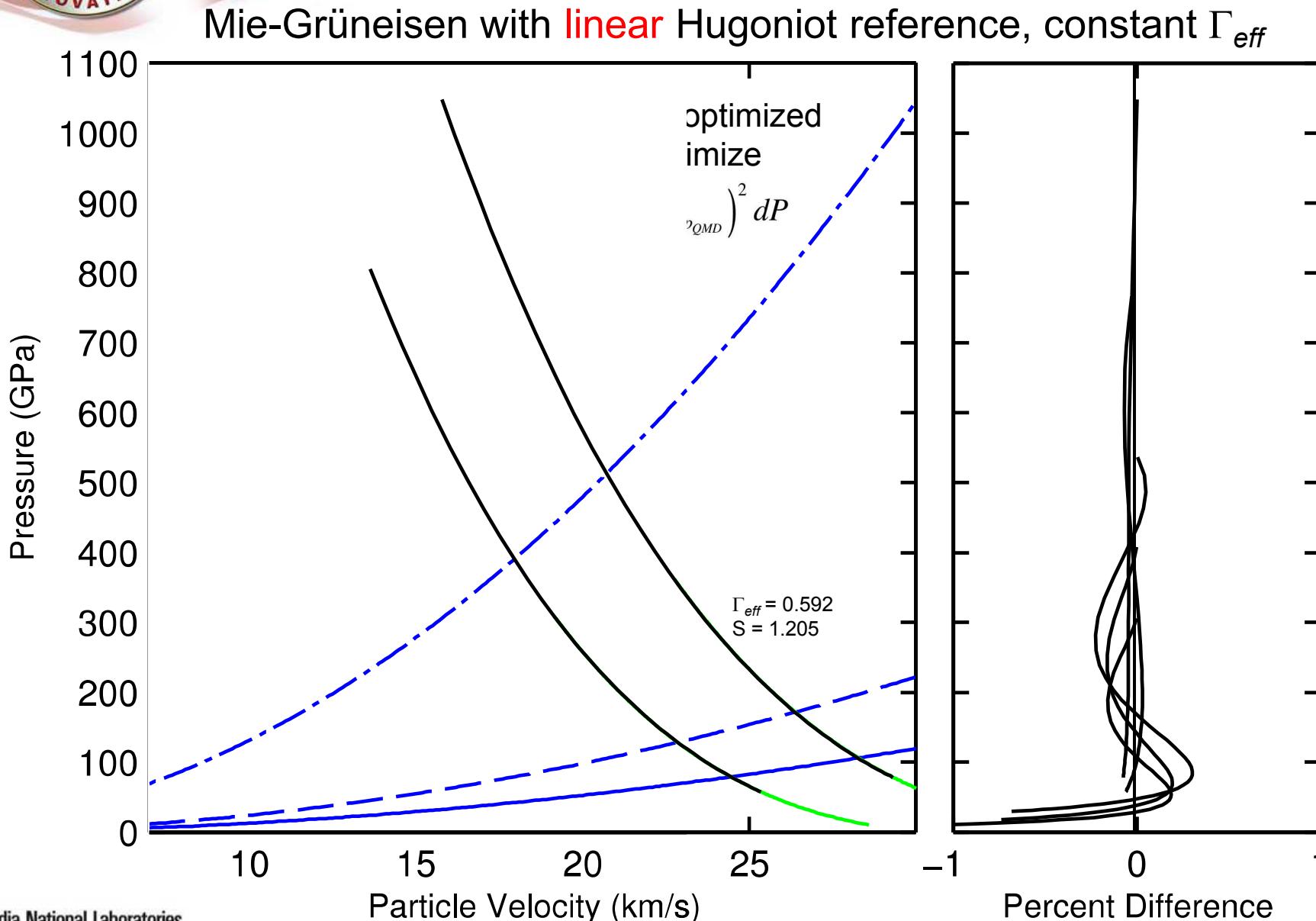


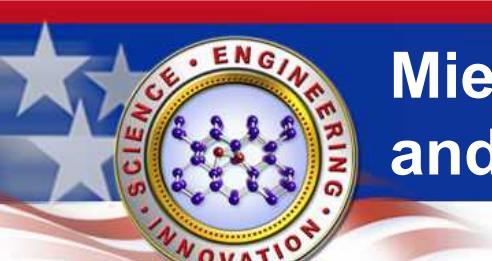
# Mie-Grüneisen, constant $\Gamma_{\text{eff}}$ with *linear* reference shows remarkable agreement with QMD release



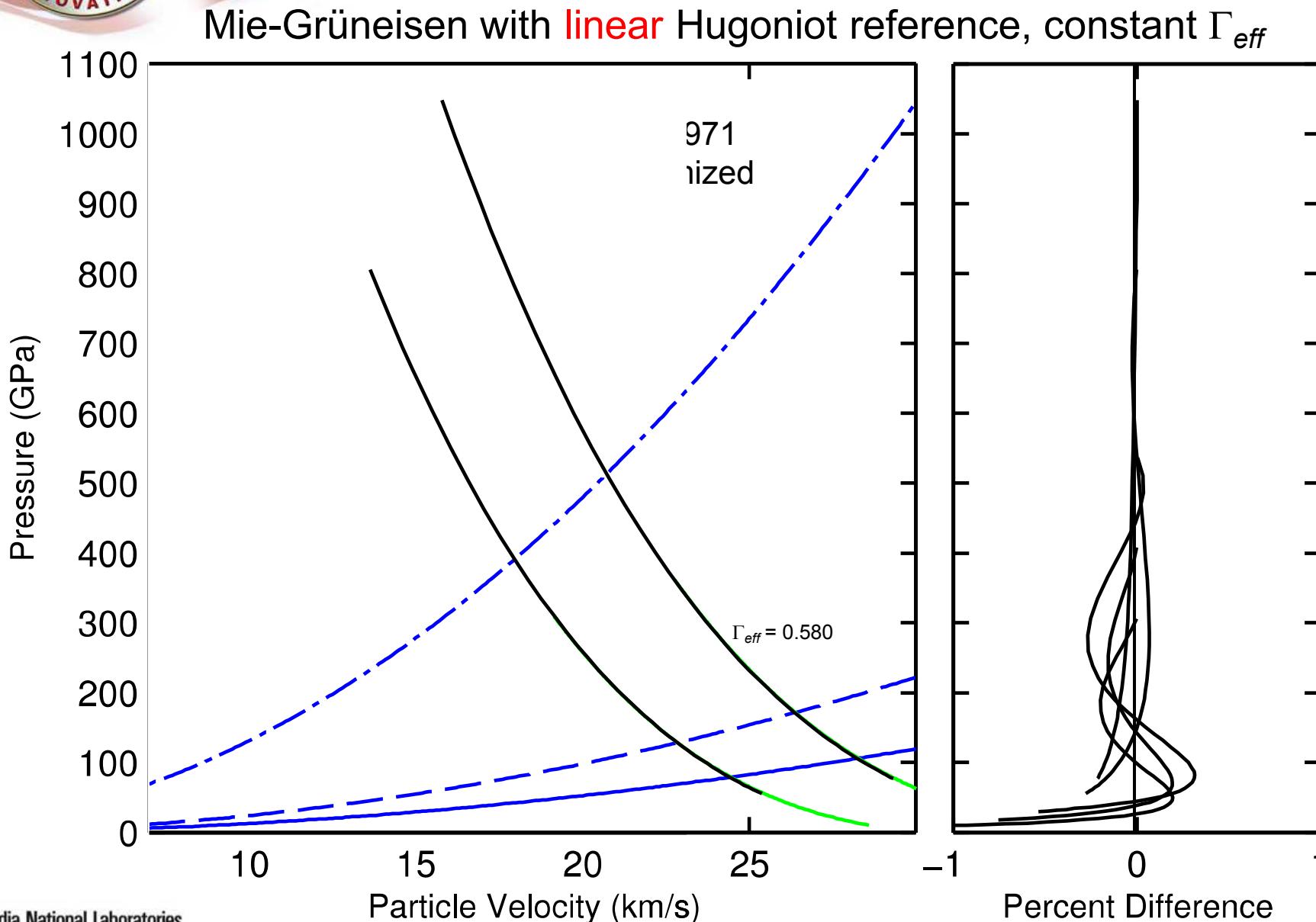


# Mie-Grüneisen, constant $\Gamma_{\text{eff}}$ with *linear* reference agrees over large extent of the quartz Hugoniot



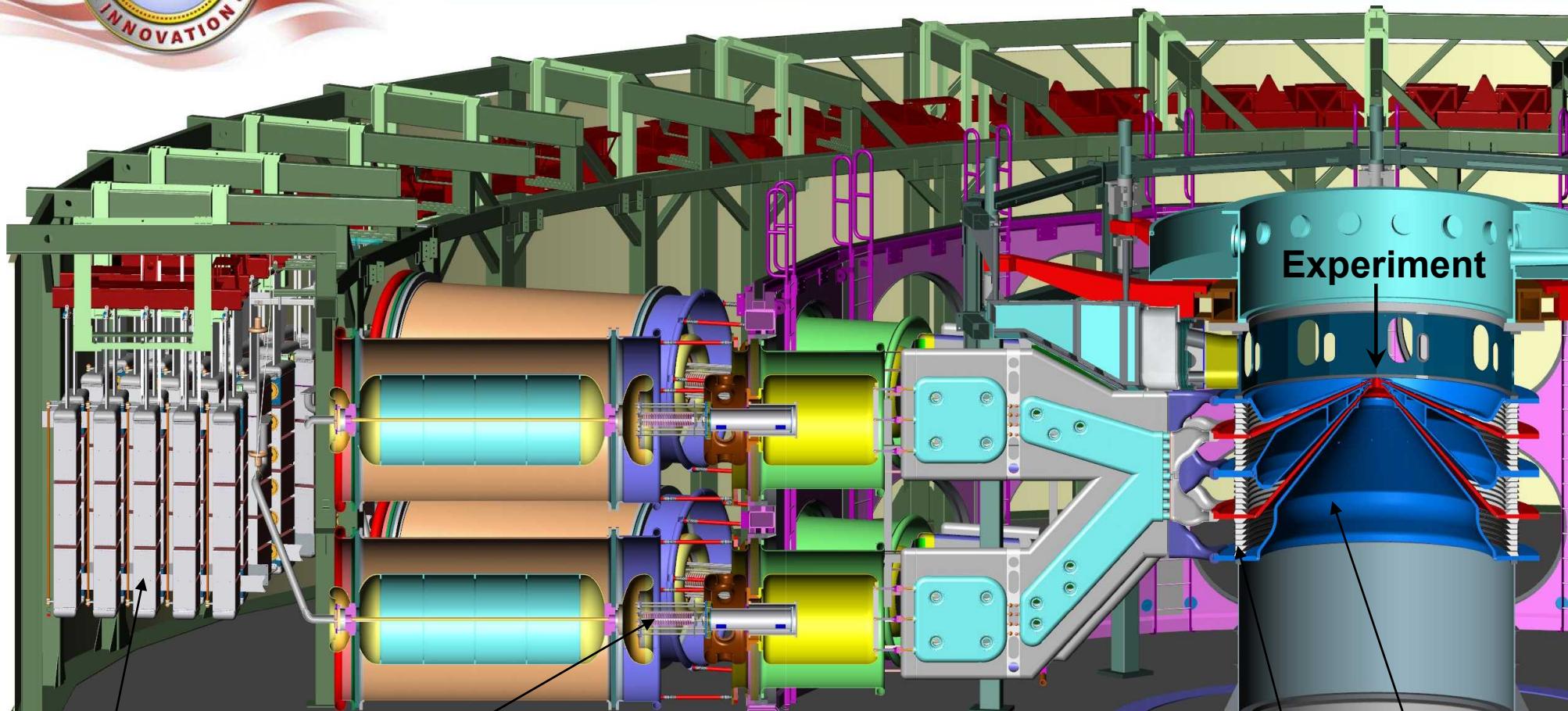


# Mie-Grüneisen, constant $\Gamma_{\text{eff}}$ with *linear* reference and fixed S negligibly degrades level of agreement





# The Sandia Z Machine



Marx generator

laser-triggered gas switch

**22 MJ stored energy**  
**~25 MA peak current**  
**~200-600 ns rise time**

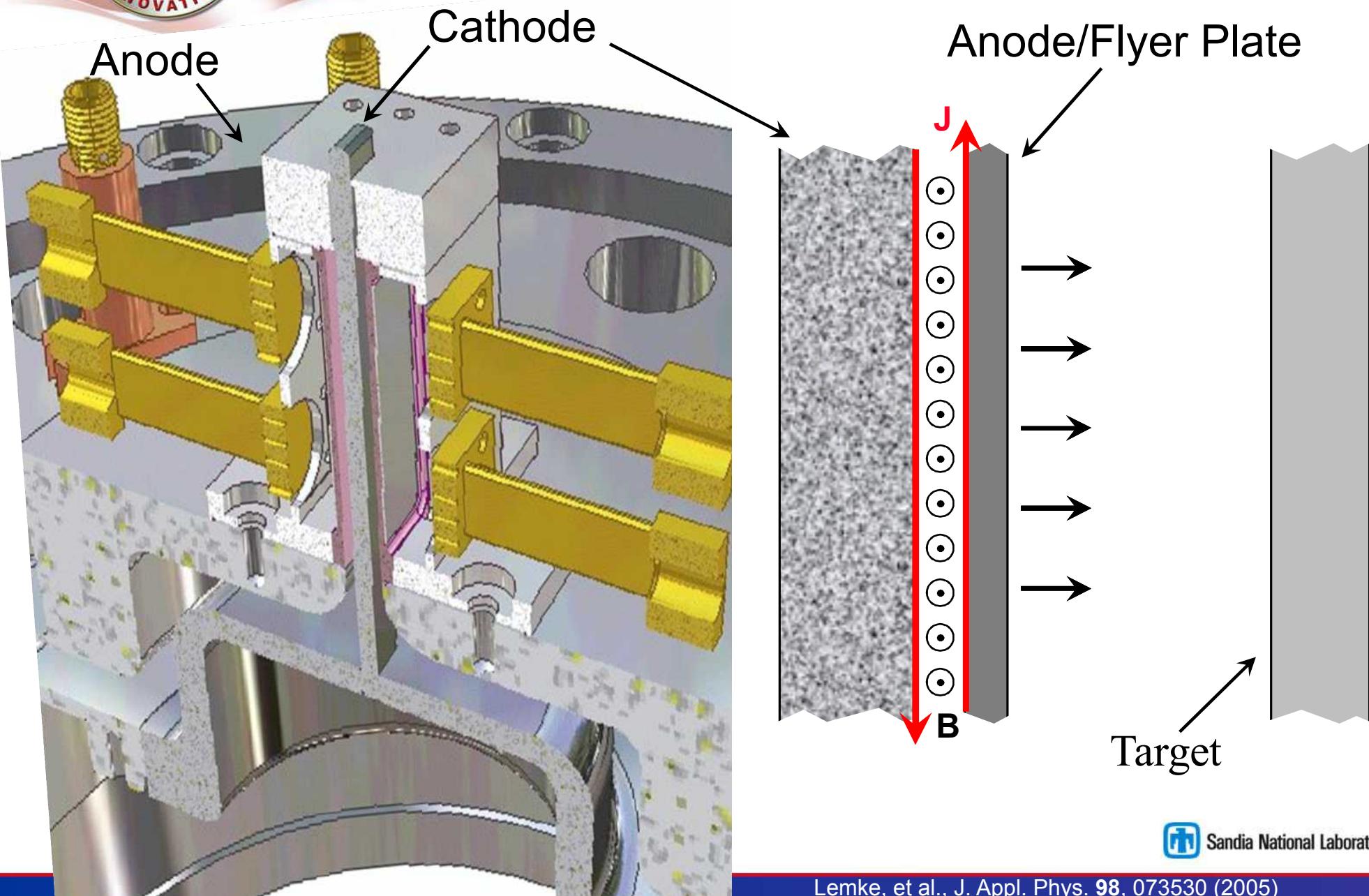
insulator stack

magnetically insulated transmission lines





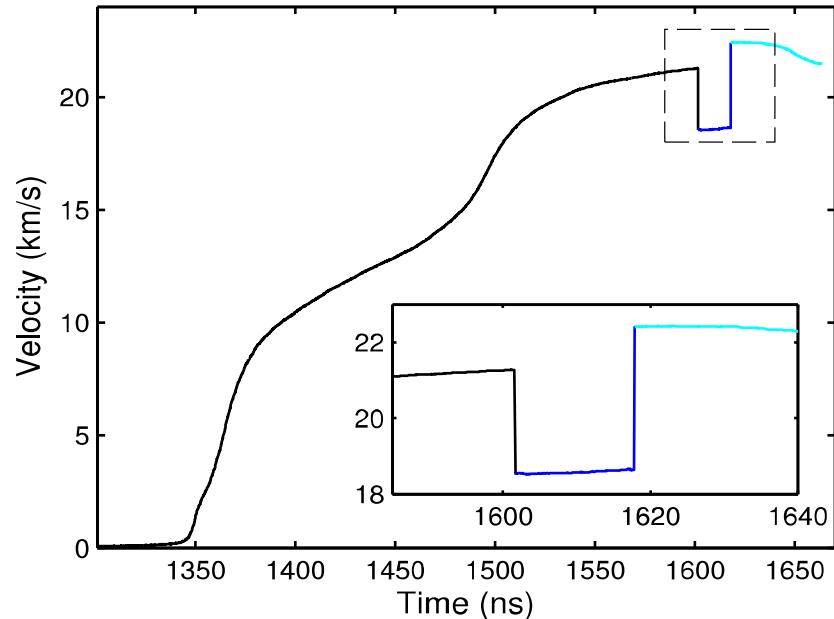
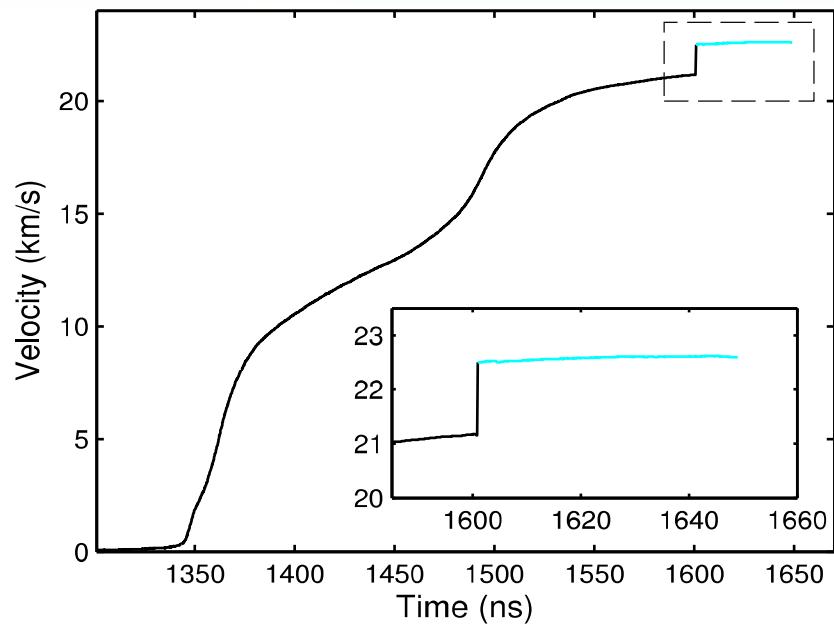
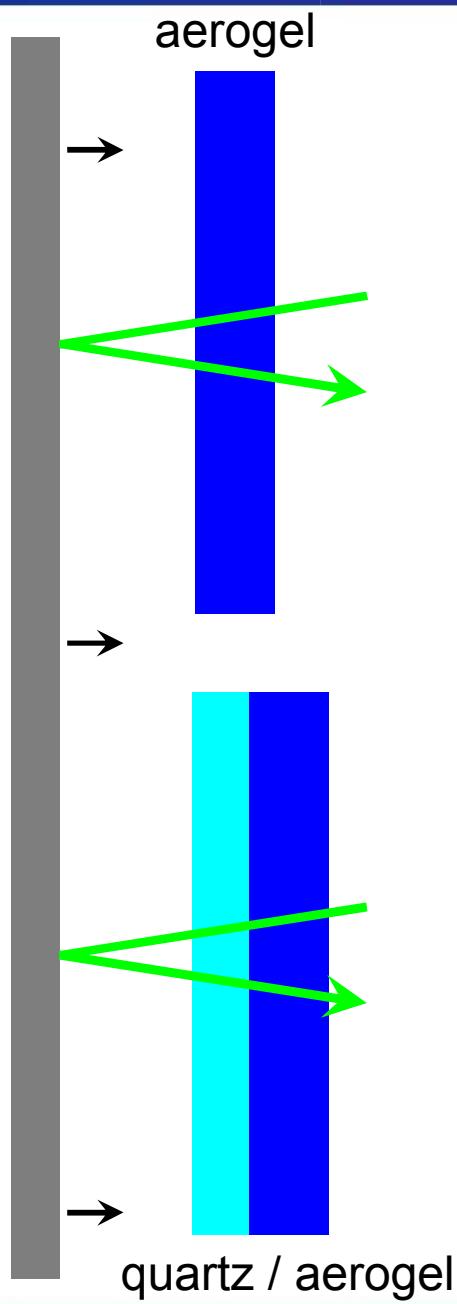
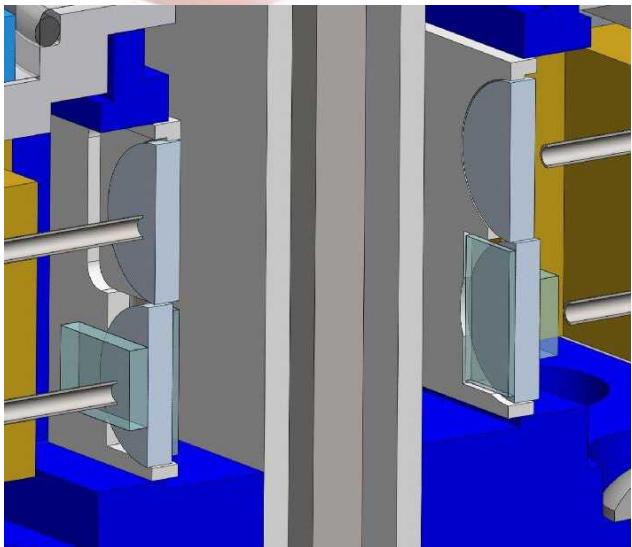
With proper pulse shape and design the anode can be launched as an effective high-velocity flyer plate



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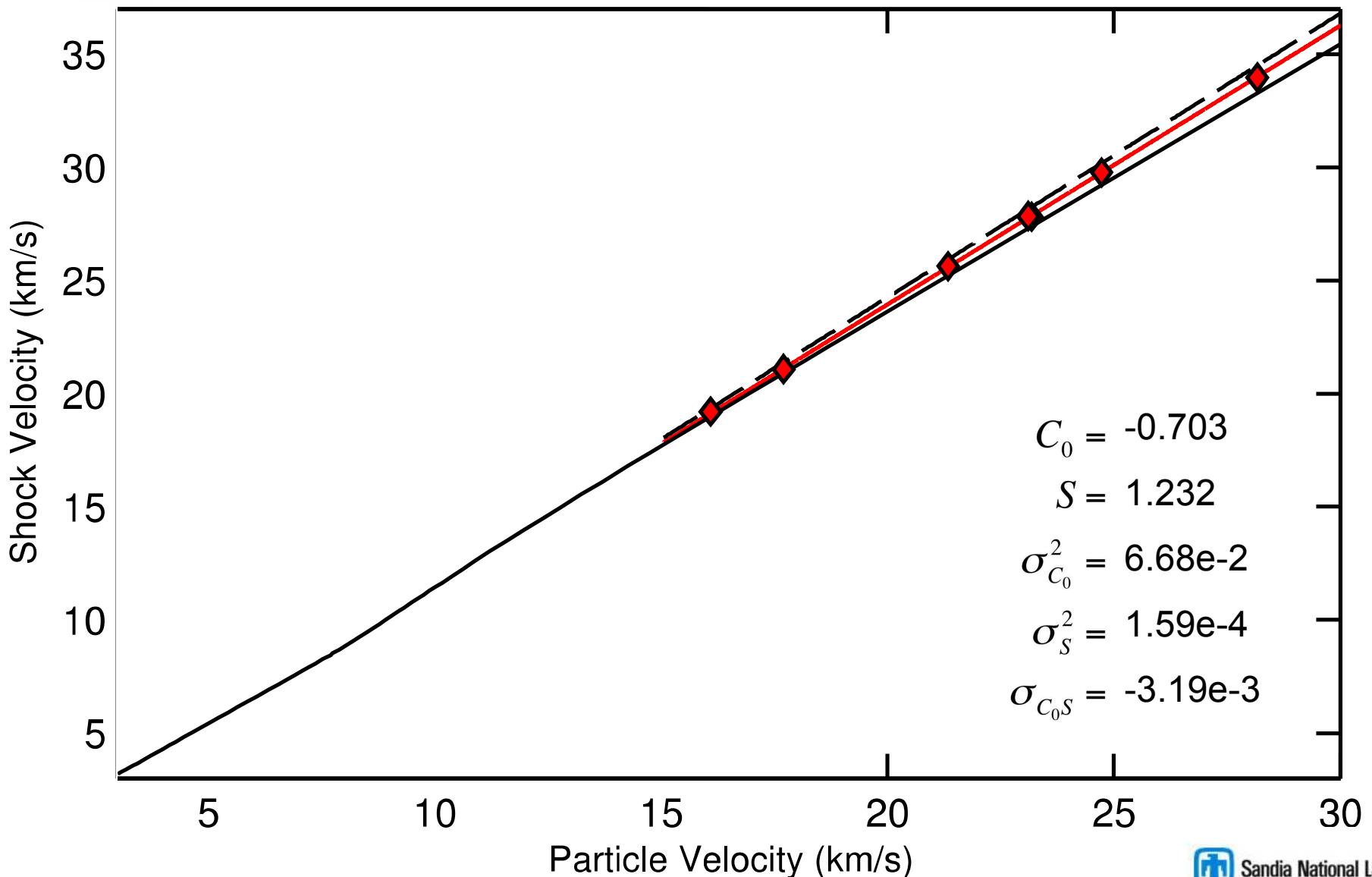


# The same experiment provides Hugoniot and release measurements via velocity interferometry



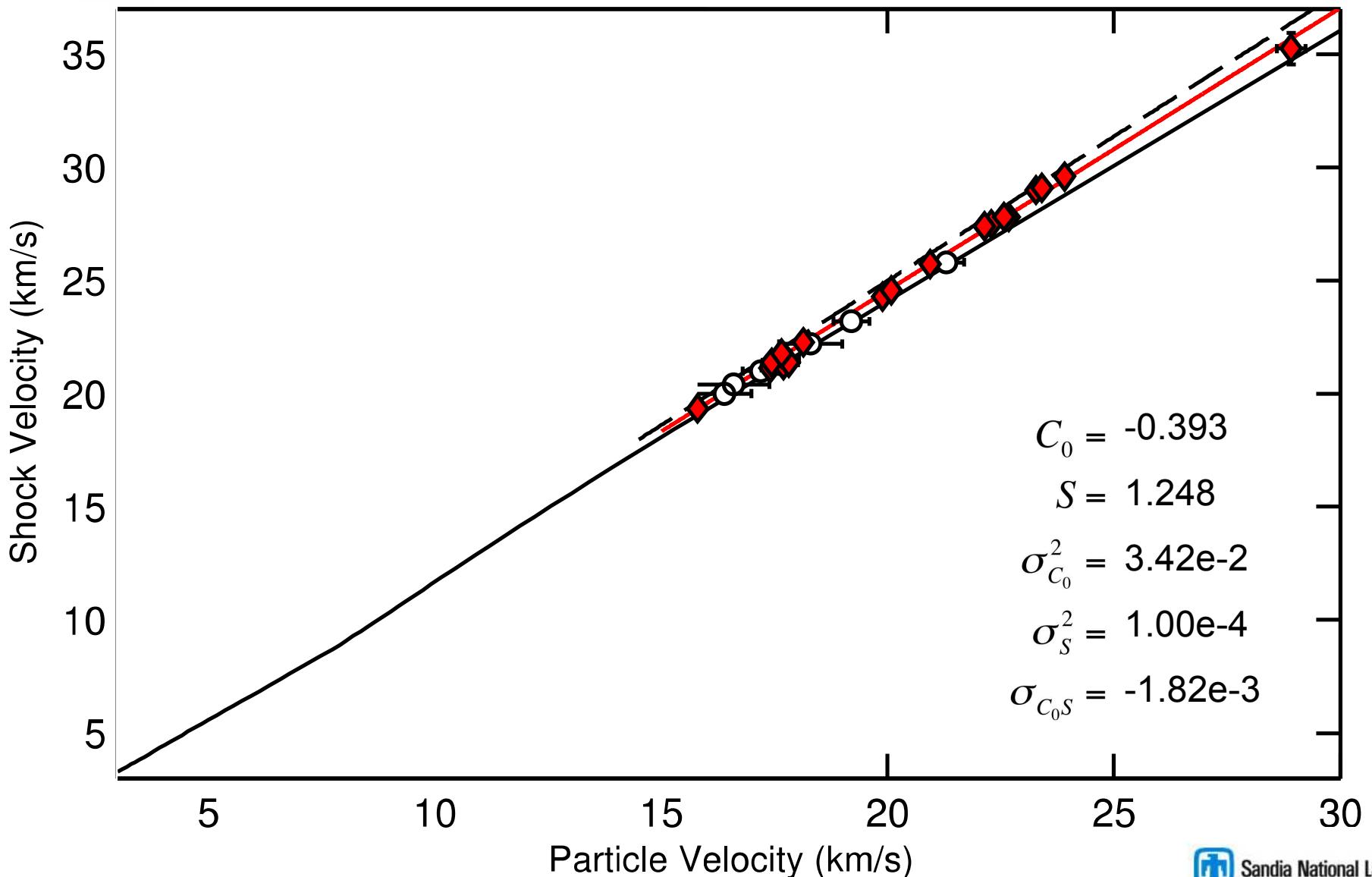


# ~110 mg/cc silica aerogel $U_s$ - $u_p$ Hugoniot



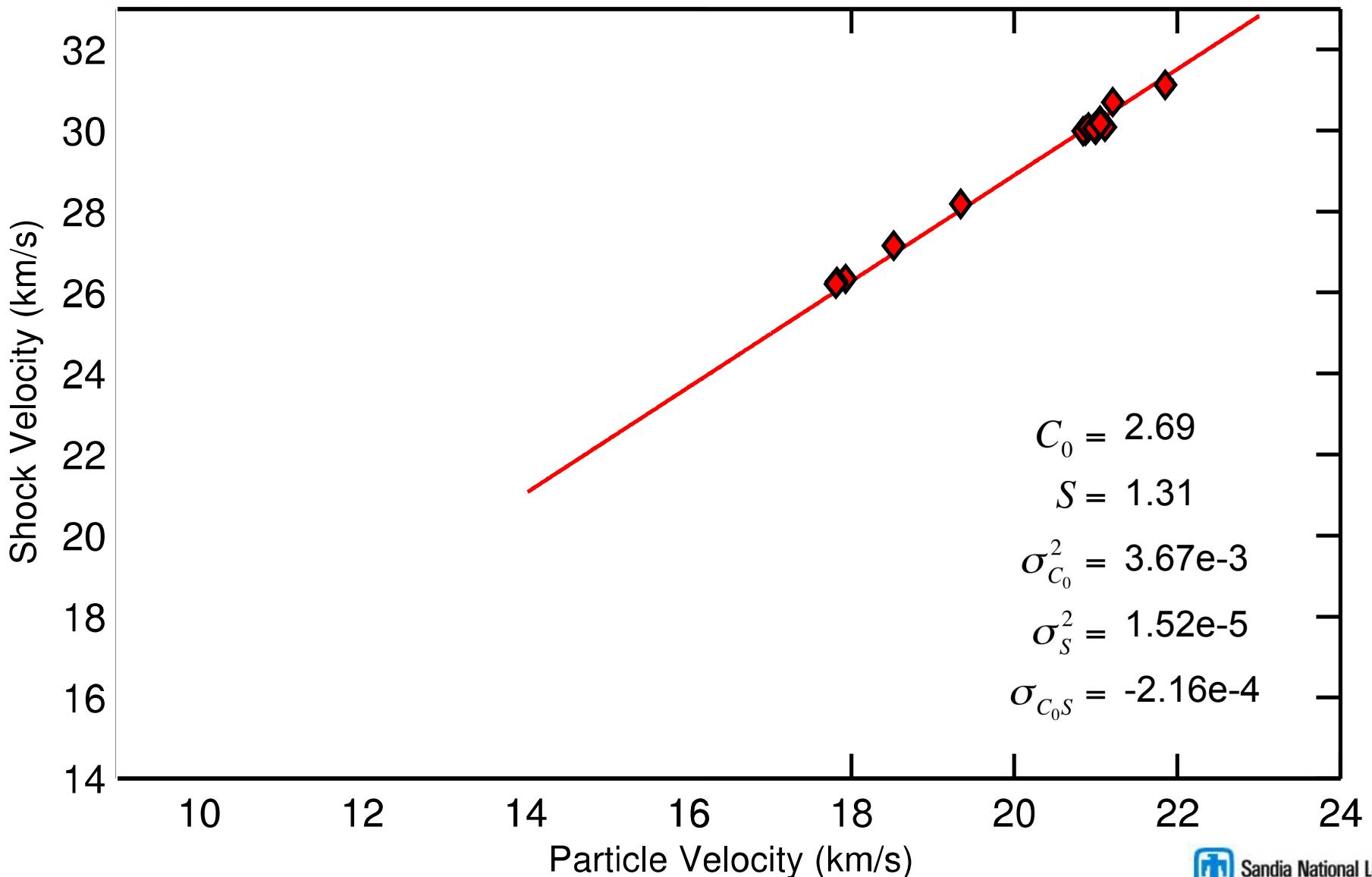


# ~200 mg/cc silica aerogel $U_s$ - $u_p$ Hugoniot





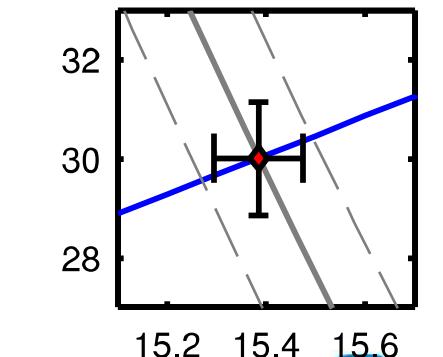
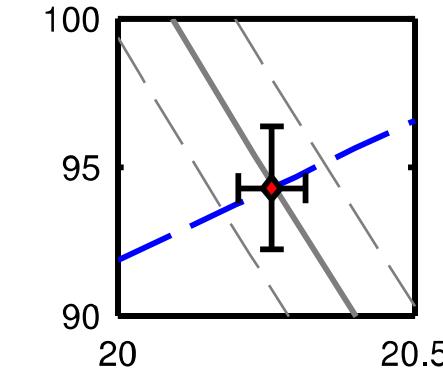
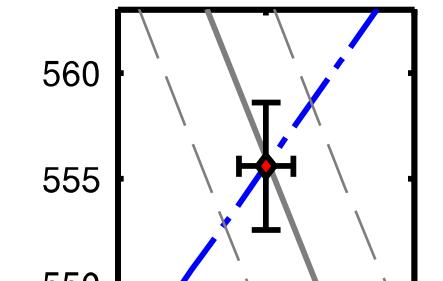
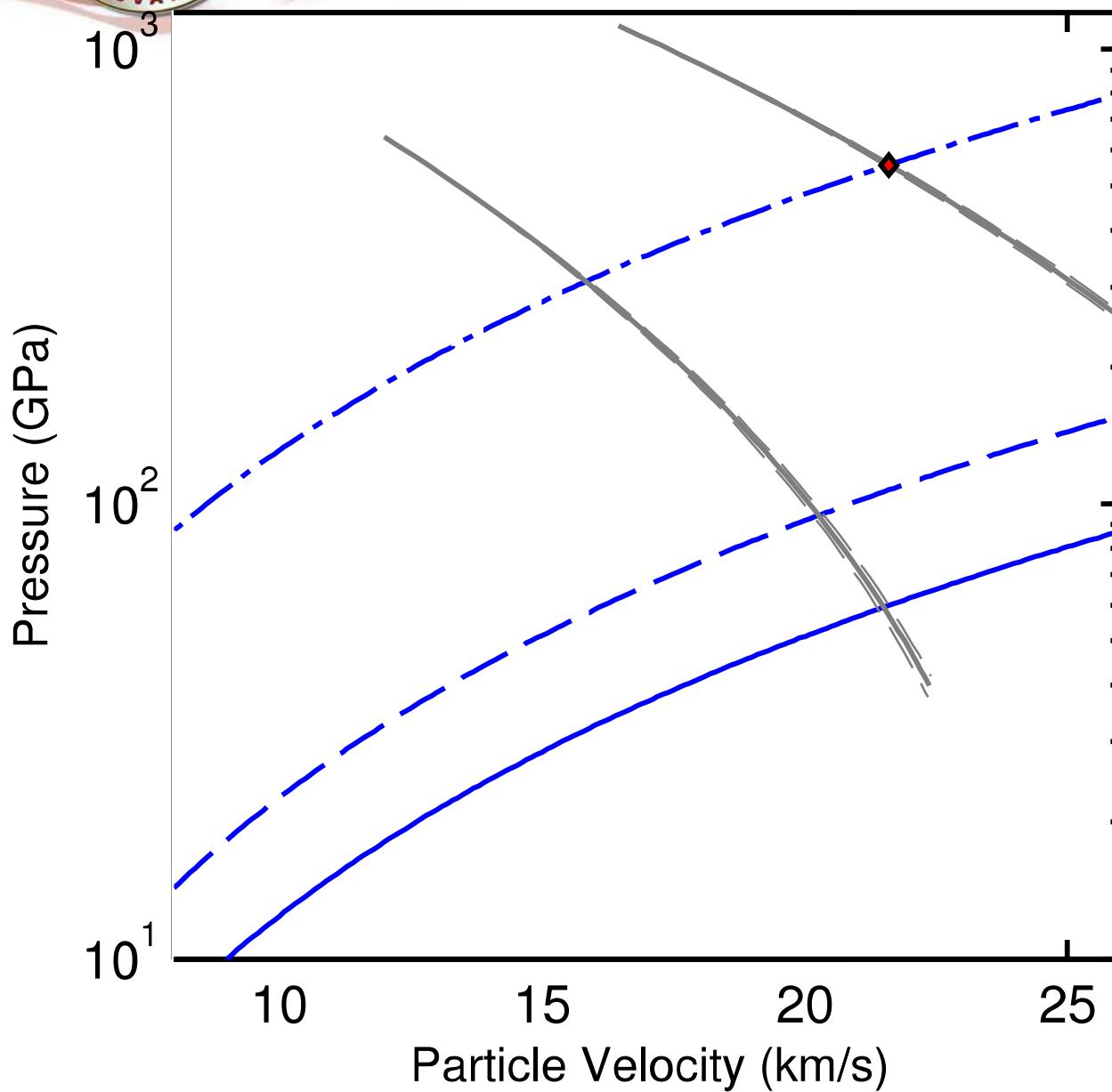
# TPX $U_s$ - $u_p$ Hugoniot



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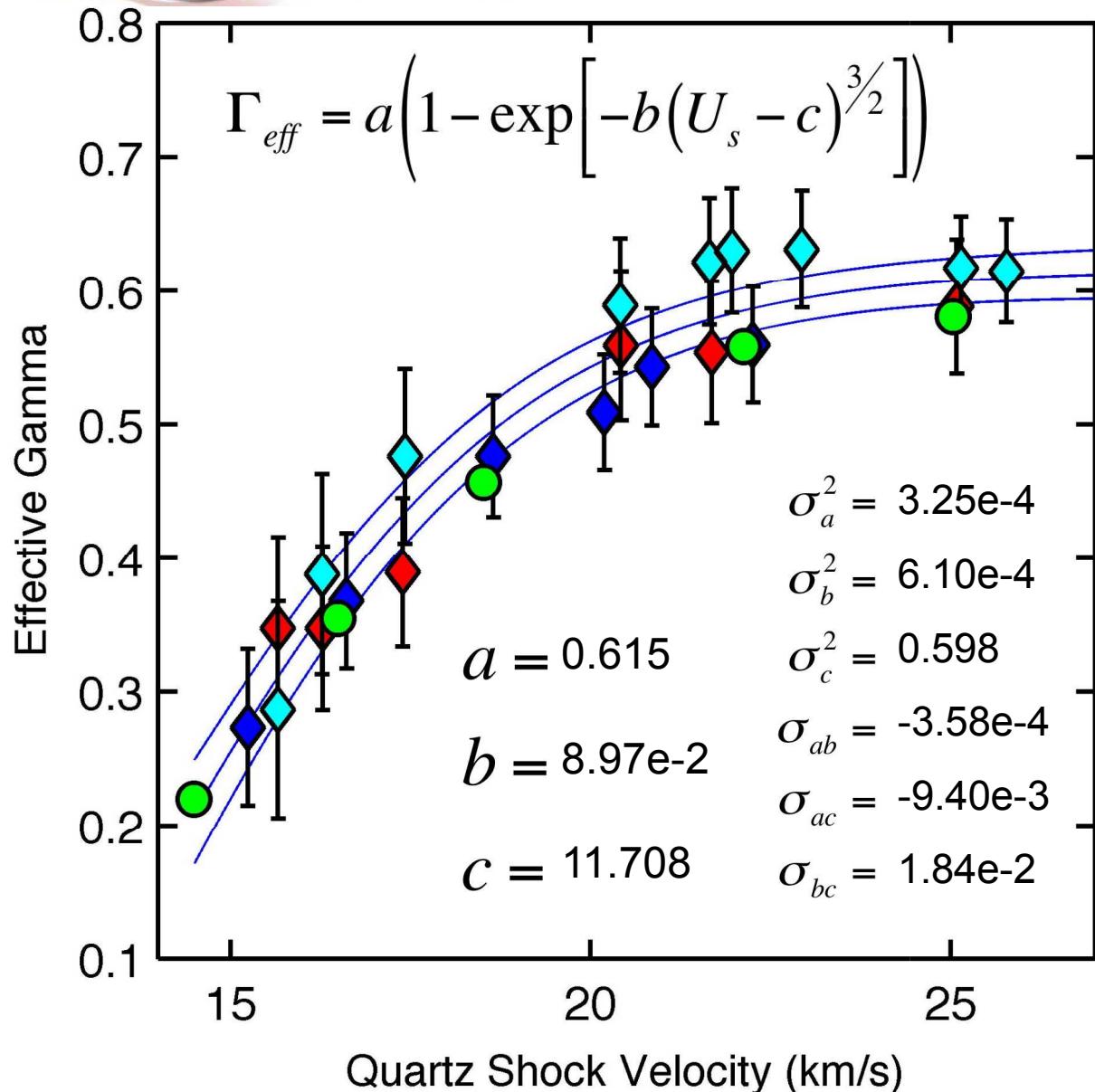


# $\Gamma_{\text{eff}}$ determined for each release measurement, uncertainties evaluated via Monte Carlo method





# $\Gamma_{eff}$ exhibits similar trend for all release standards and shows very good agreement with QMD trend



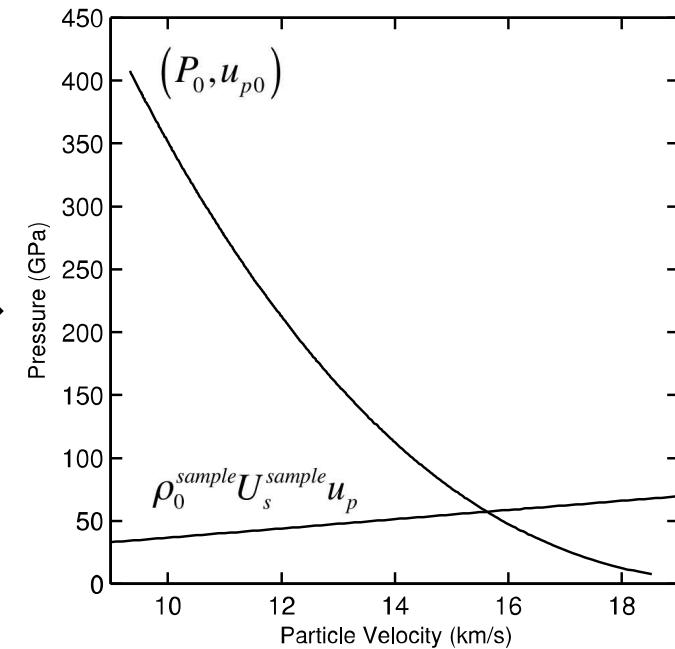
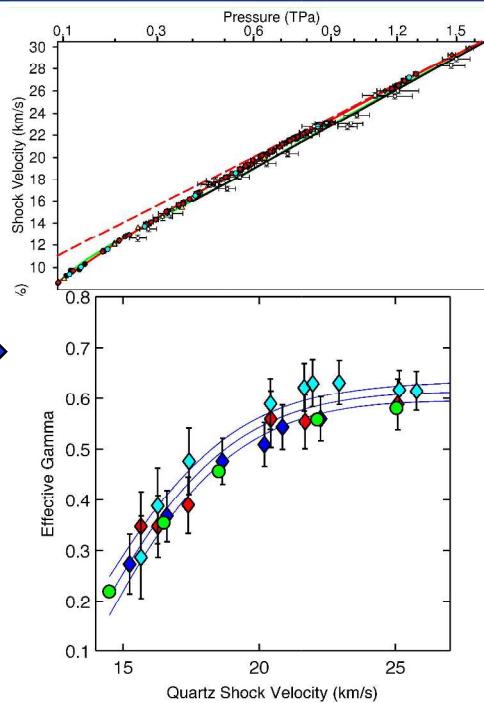
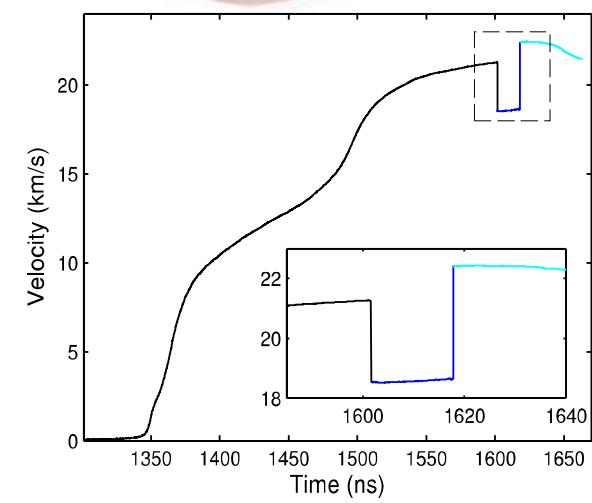
The similar trend in  $\Gamma_{eff}$  for all three release standards suggests that the Mie-Grüneisen, constant  $\Gamma_{eff}$  model with linear  $U_s - u_p$  Hugoniot reference adequately describes the release path to quite low pressure states

These results corroborate the QMD release calculations, albeit with a slightly higher  $\Gamma_{eff}$  for a given quartz shock velocity





# Simple analytical model for impedance matching with quartz into lower impedance material



$U_s^{quartz}$  determines:

$$(P_0, u_{p0}), \quad C_0 = \frac{P_0}{\rho_0 u_{p0}} - S u_{p0}$$

$$\Gamma_{eff} = a \left( 1 - \exp \left[ -b (U_s - c)^{3/2} \right] \right)$$

Solve the set of coupled ODEs:

$$P = P_H + \frac{\Gamma_{eff}}{V} (E - E_H), \quad dE = -P dV$$

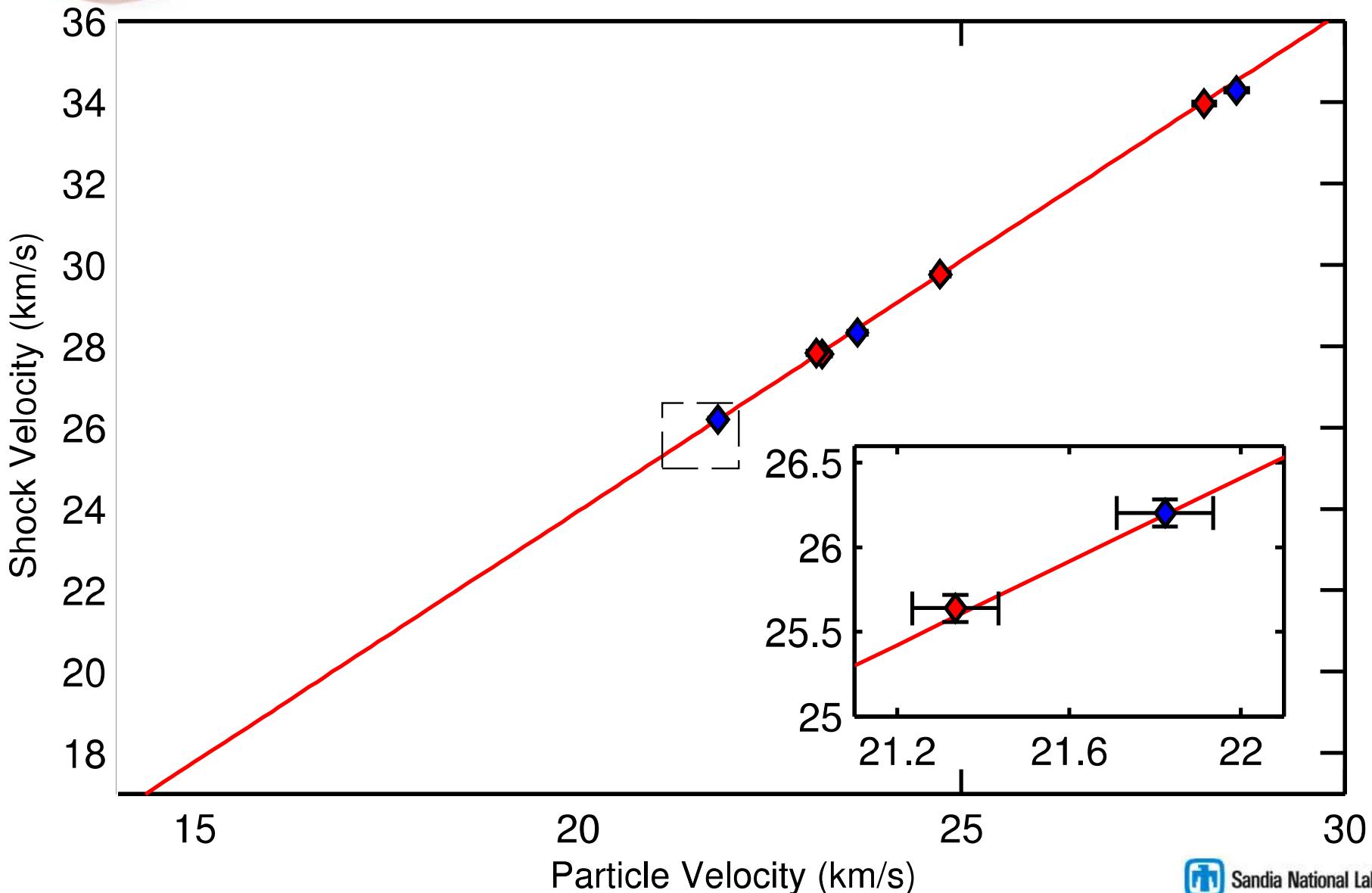
$$C_s^2 = -V^2 \left. \frac{\partial P}{\partial V} \right|_s, \quad u_p = u_{p0} + \int_{P_0}^P \frac{V dP}{C_s}$$



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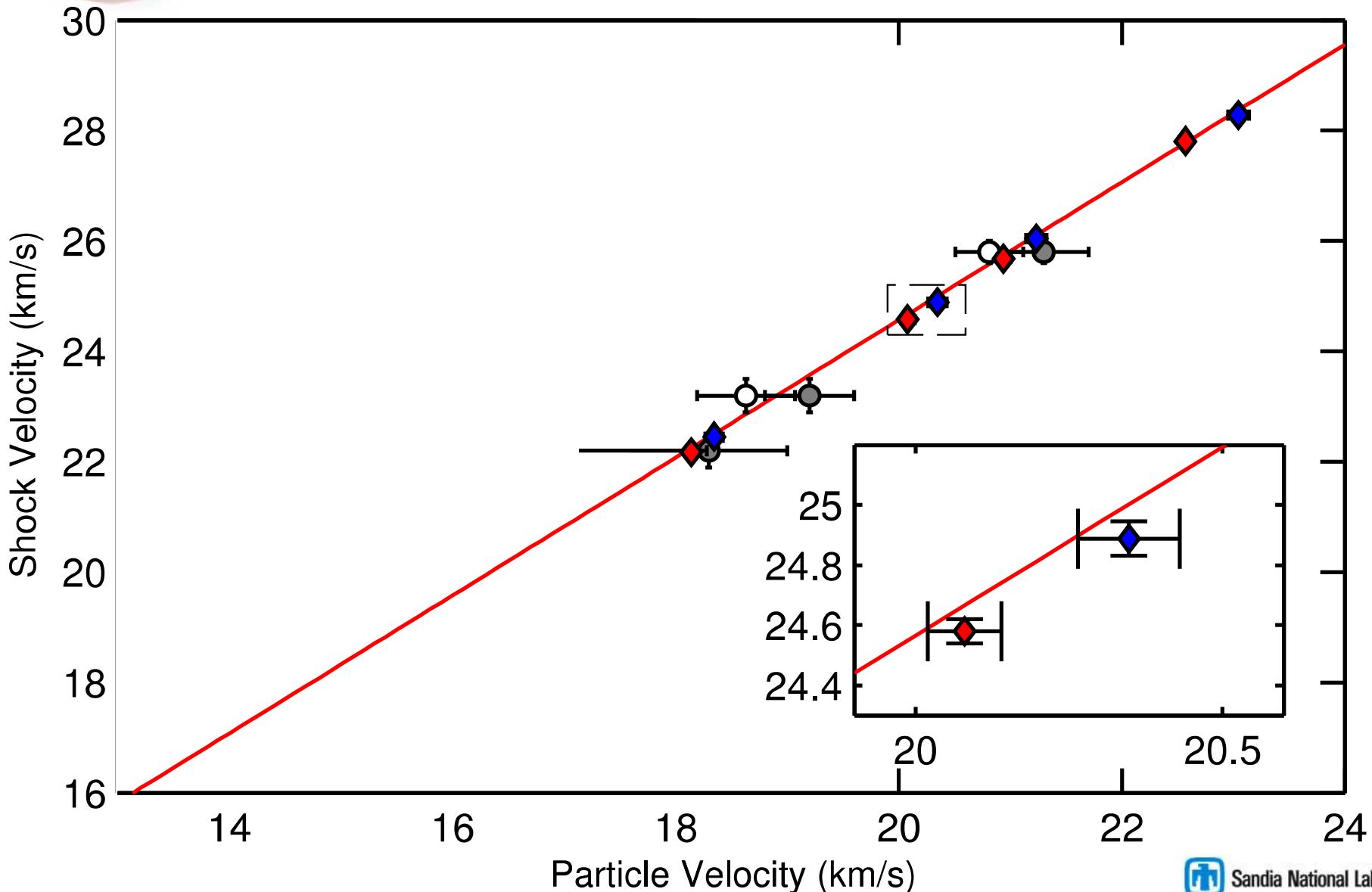


# ~110 mg/cc silica aerogel $U_s$ - $u_p$ Hugoniot



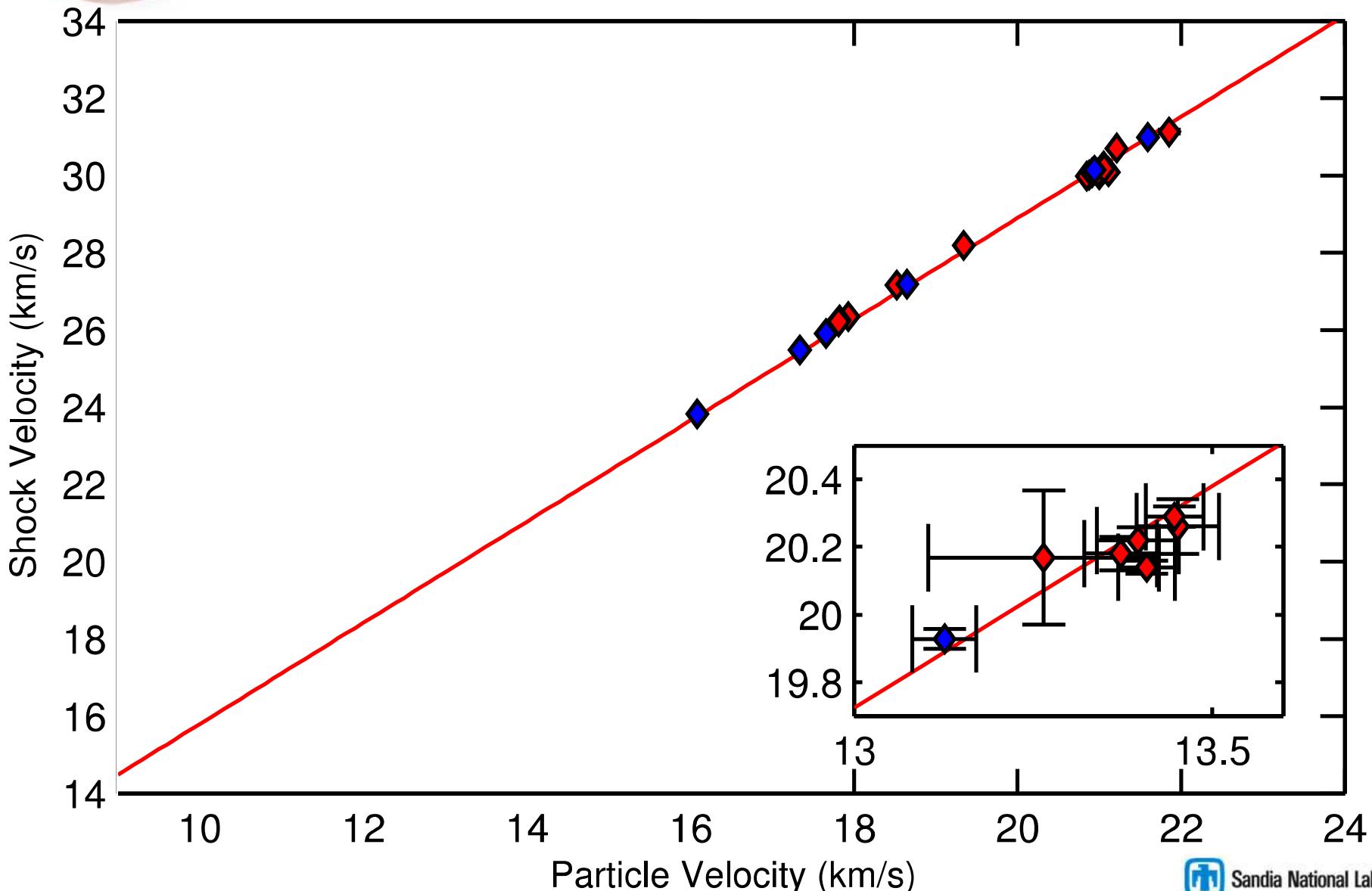


# ~200 mg/cc silica aerogel $U_s$ - $u_p$ Hugoniot





# TPX $U_s$ - $u_p$ Hugoniot



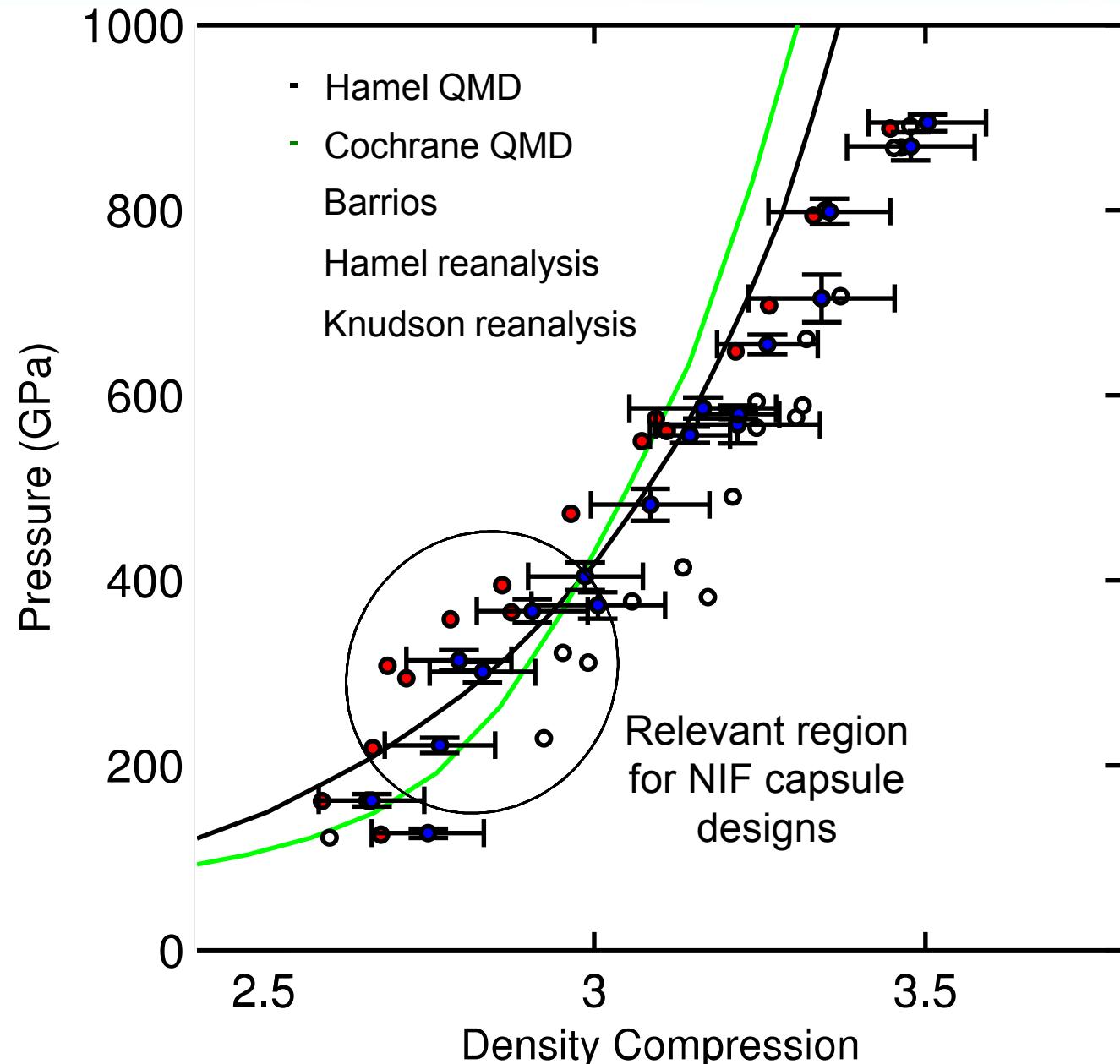


# Recent GDP experiments nicely illustrate the effects of the quartz Hugoniot and release standard

Original Omega experiments of Barrios used Hugoniot from laser driven experiments and Mie-Grüneisen, constant  $\Gamma=0.64$  with, and non-linear reference for impedance matching

Hamel performed a reanalysis using Z quartz Hugoniot but the same release model

Reanalysis with Z quartz Hugoniot and Mie-Grüneisen, constant  $\Gamma_{\text{eff}}$ , and linear reference lies between the two other analyses with reduced uncertainty





# Conclusions

- Quartz release behavior was explored through QMD calculations from 300–1100 GPa states along the Principal Hugoniot
  - » These calculations provided a framework for a simple release model
- A simple, analytical model was developed for impedance matching when using quartz as a standard with lower impedance materials
  - » Mie-Grüneisen, constant  $\Gamma_{\text{eff}}$ , and linear  $U_s$ - $u_p$  Hugoniot reference
  - »  $S$  for the reference Hugoniot fixed at  $S=1.1971$
  - »  $\Gamma_{\text{eff}}(U_s)$  determined through experiments using low density silica aerogel and TPX samples
- Quartz release experiments were performed using aerogel and TPX which exhibit a large range in shock impedance
  - » These results were analyzed to determine  $\Gamma_{\text{eff}}(U_s)$
  - » Agreement between inferred  $\Gamma_{\text{eff}}$  for the various samples suggests the simple model adequately describes the release response
- Model allows for simple reanalysis of previously reported data sets using quartz as a standard provided that the observables were included