

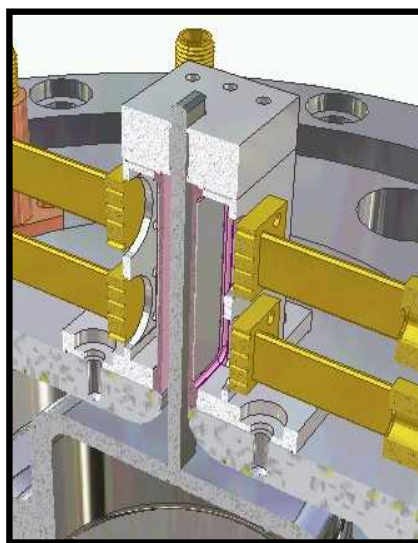
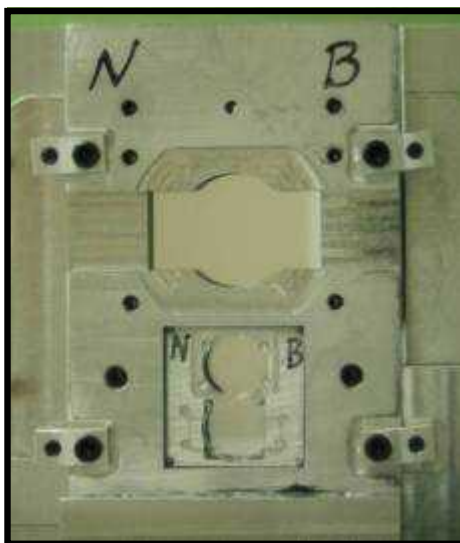


Characterization of the release response of alpha-quartz in the multi-Mbar regime for use as an impedance match standard

7th International Workshop on Warm Dense Matter (WDM)
Saint-Malo, France June 23-26, 2013

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Acknowledgements

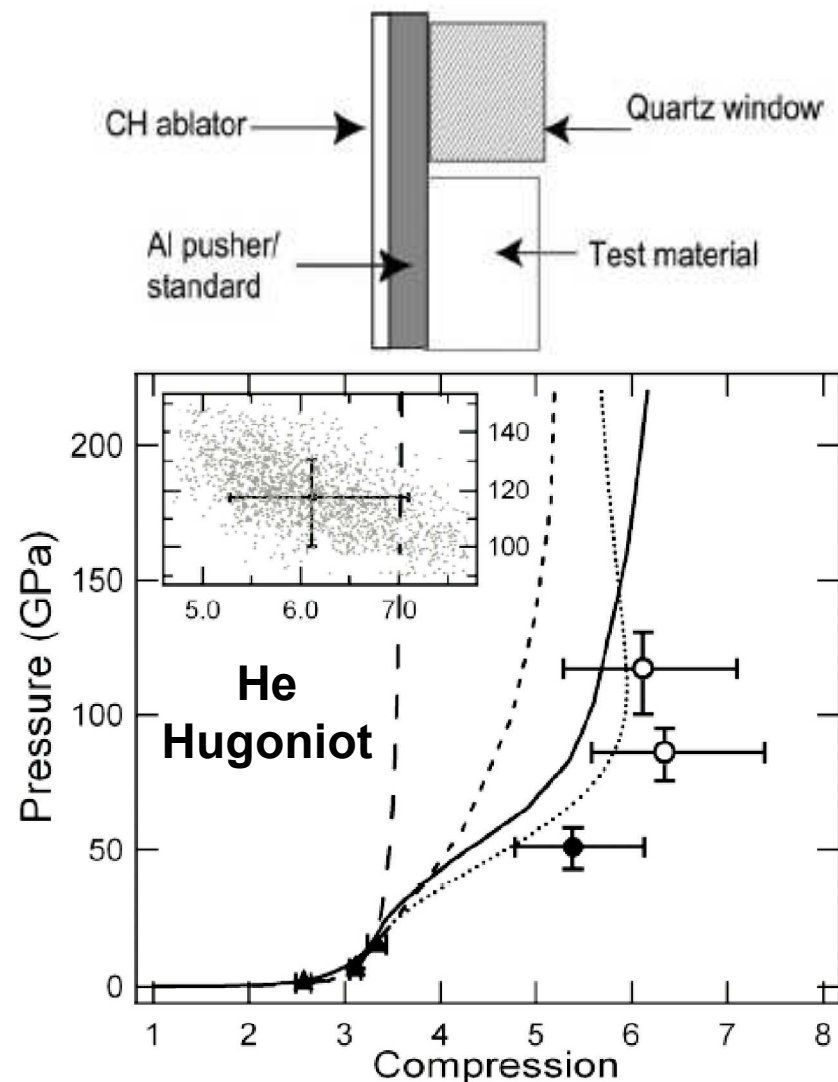
- **Mike Desjarlais**
 - Quantum Molecular Dynamics (QMD) calculations
- **Ray Lemke**
 - Flyer plate design and MHD simulations
- **Jean-Paul Davis, Devon Dalton, Ken Struve, Mark Savage, Keith LeChien, Brian Stoltzfus, Dave Hinshelwood**
 - Bertha model, pulse shaping
- **Charlie Meyer, Devon Dalton,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



Motivation for α -Quartz measurements

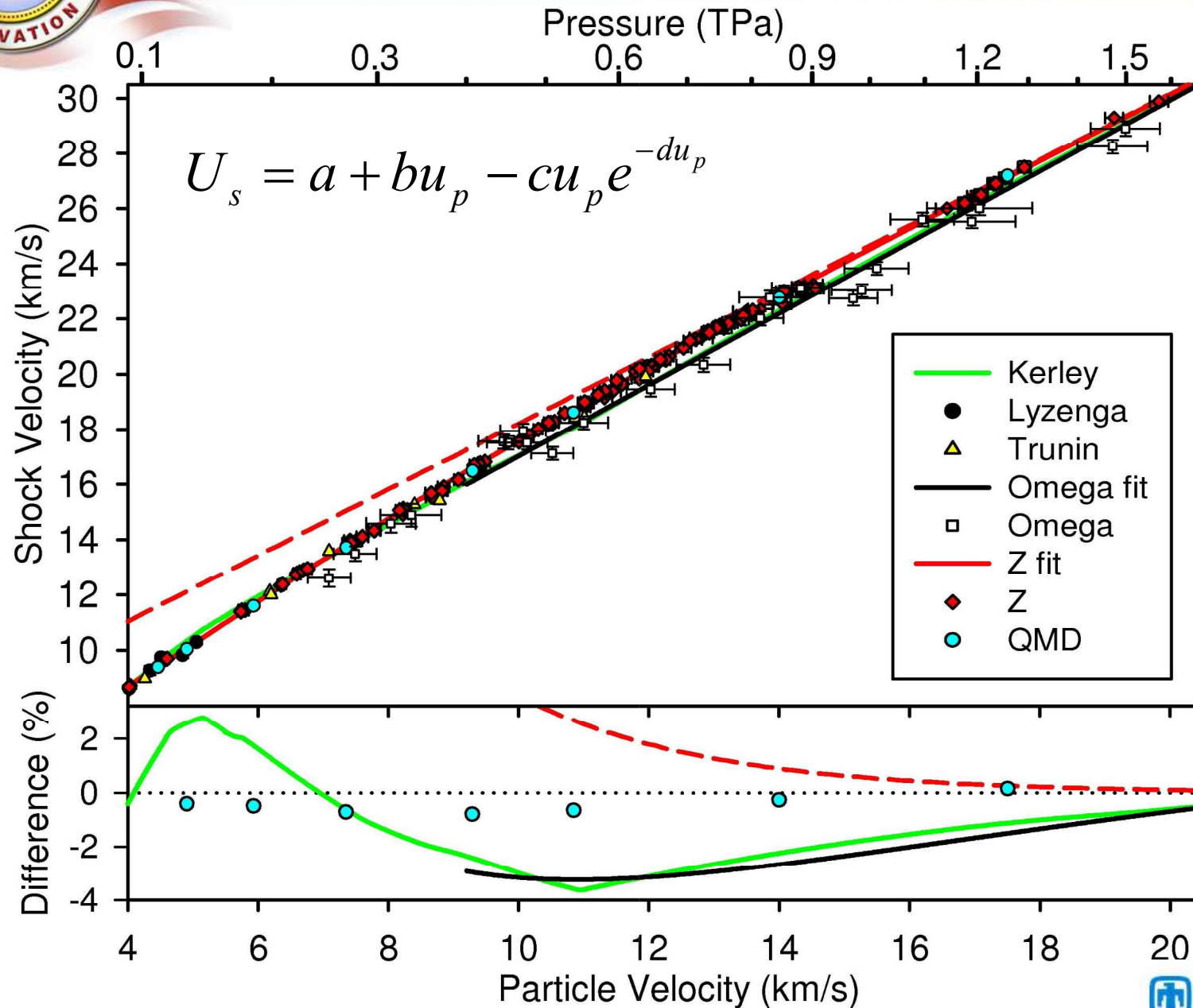
- Quartz melts at ~ 100 GPa into a conducting fluid
 - Shock front becomes reflective
- Quartz is quickly becoming a high pressure shock wave standard
 - Helium, diamond, deuterium, water, xenon, krypton, carbon dioxide, ...
- For accurate results there is a need to understand the off-Hugoniot response 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



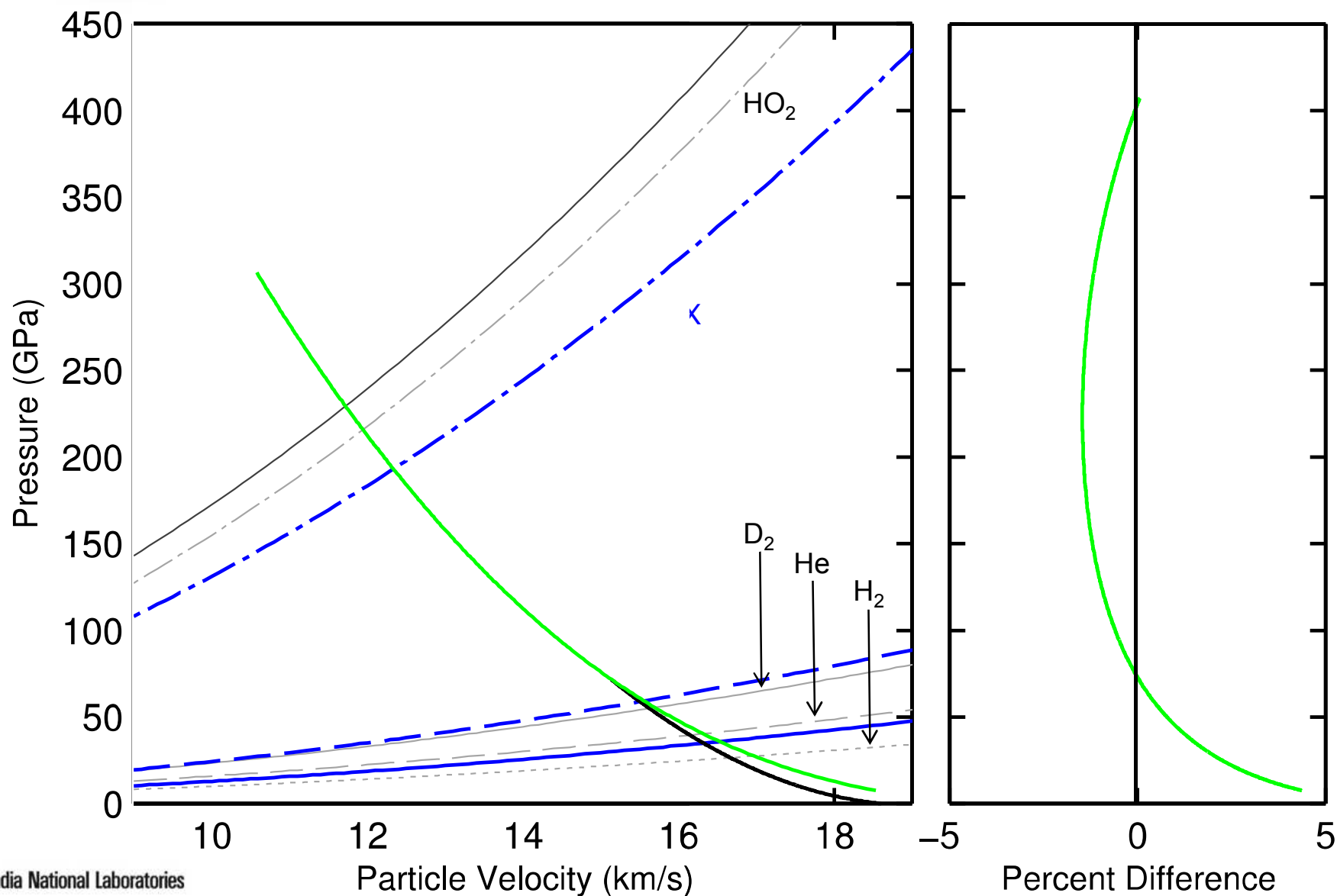


U_s-u_p Hugoniot for α -Quartz





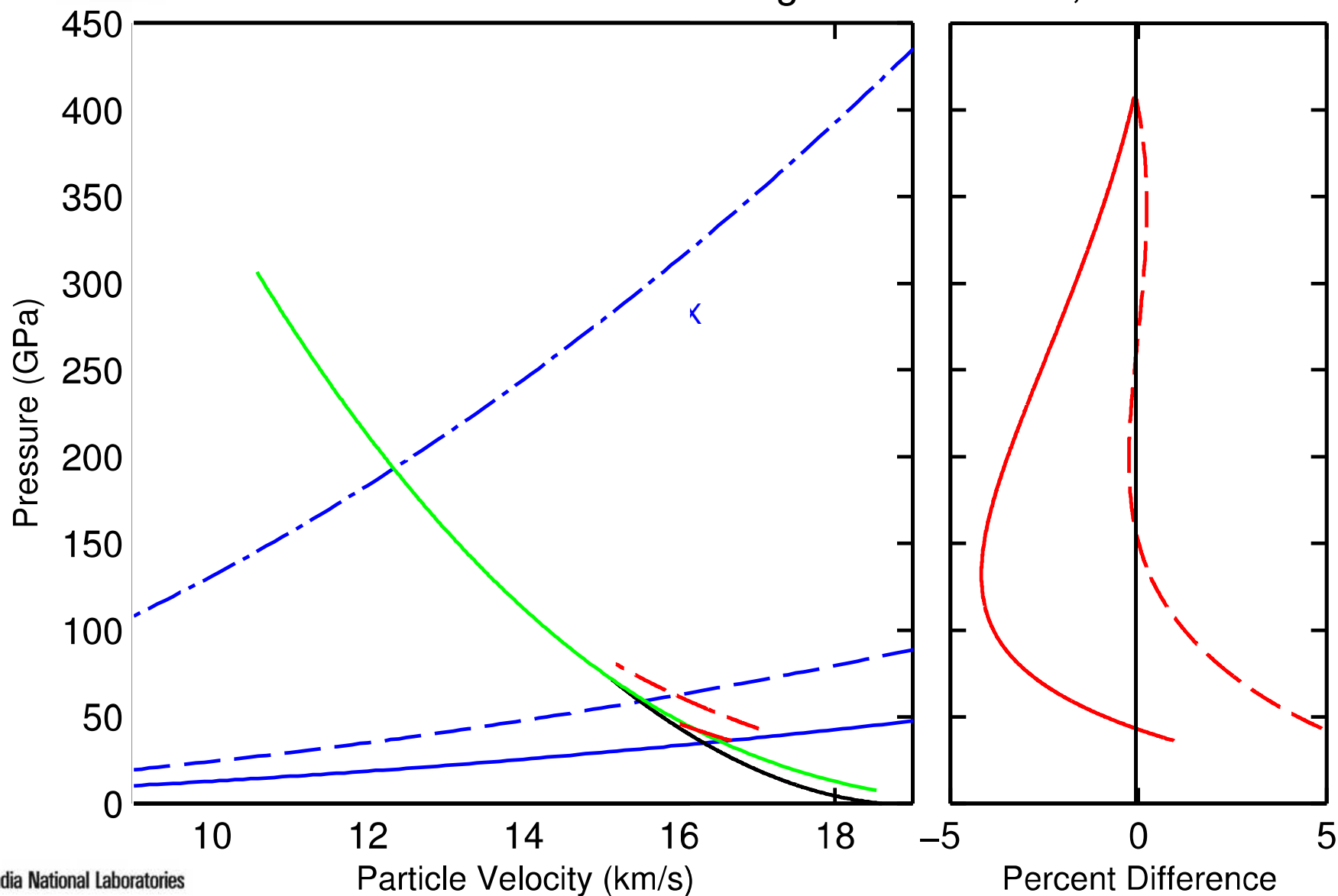
Corrections to Reflected Hugoniot not insignificant and change sign depending on sample impedance





Mie-Grüneisen, constant Γ with *non-linear* reference does not provide adequate description of release

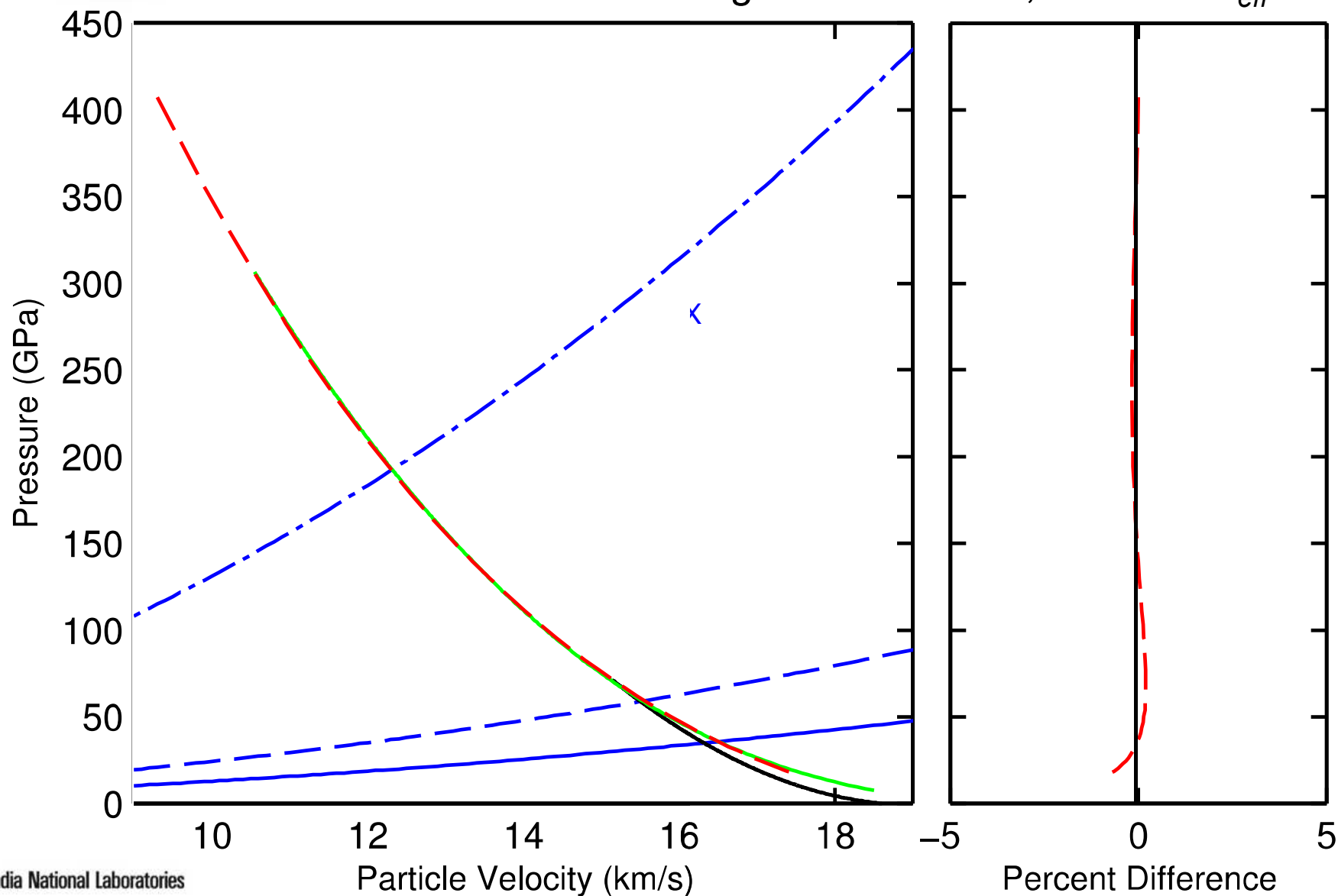
Mie-Grüneisen with **non-linear** Hugoniot reference, constant Γ





Mie-Grüneisen, constant Γ_{eff} with *linear* reference shows remarkable agreement with QMD release

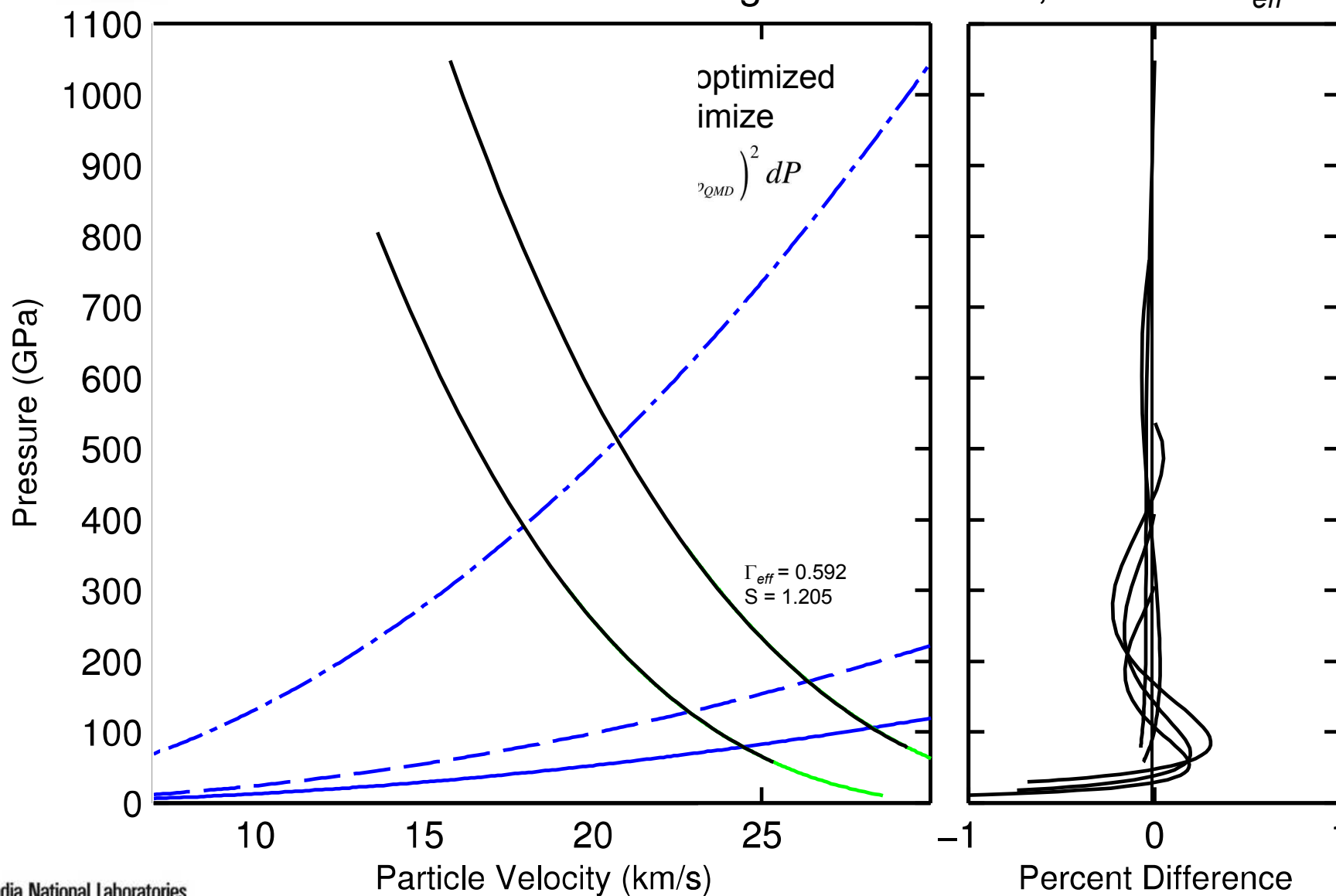
Mie-Grüneisen with **linear** Hugoniot reference, constant Γ_{eff}





Mie-Grüneisen, constant Γ_{eff} with *linear* reference agrees over large extent of the quartz Hugoniot

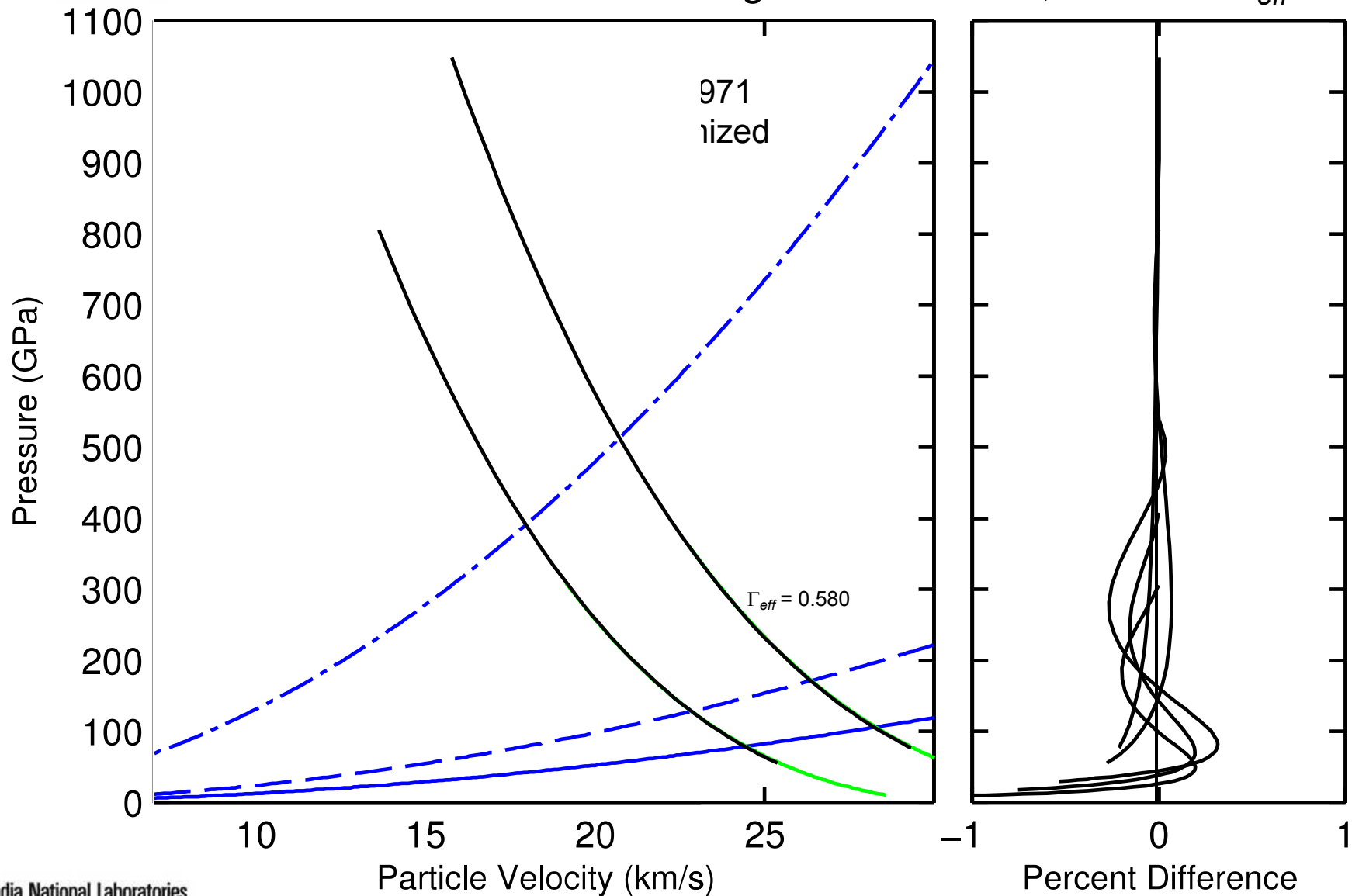
Mie-Grüneisen with **linear** Hugoniot reference, constant Γ_{eff}

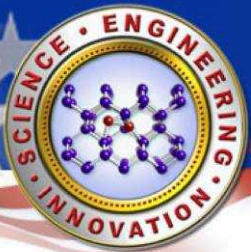




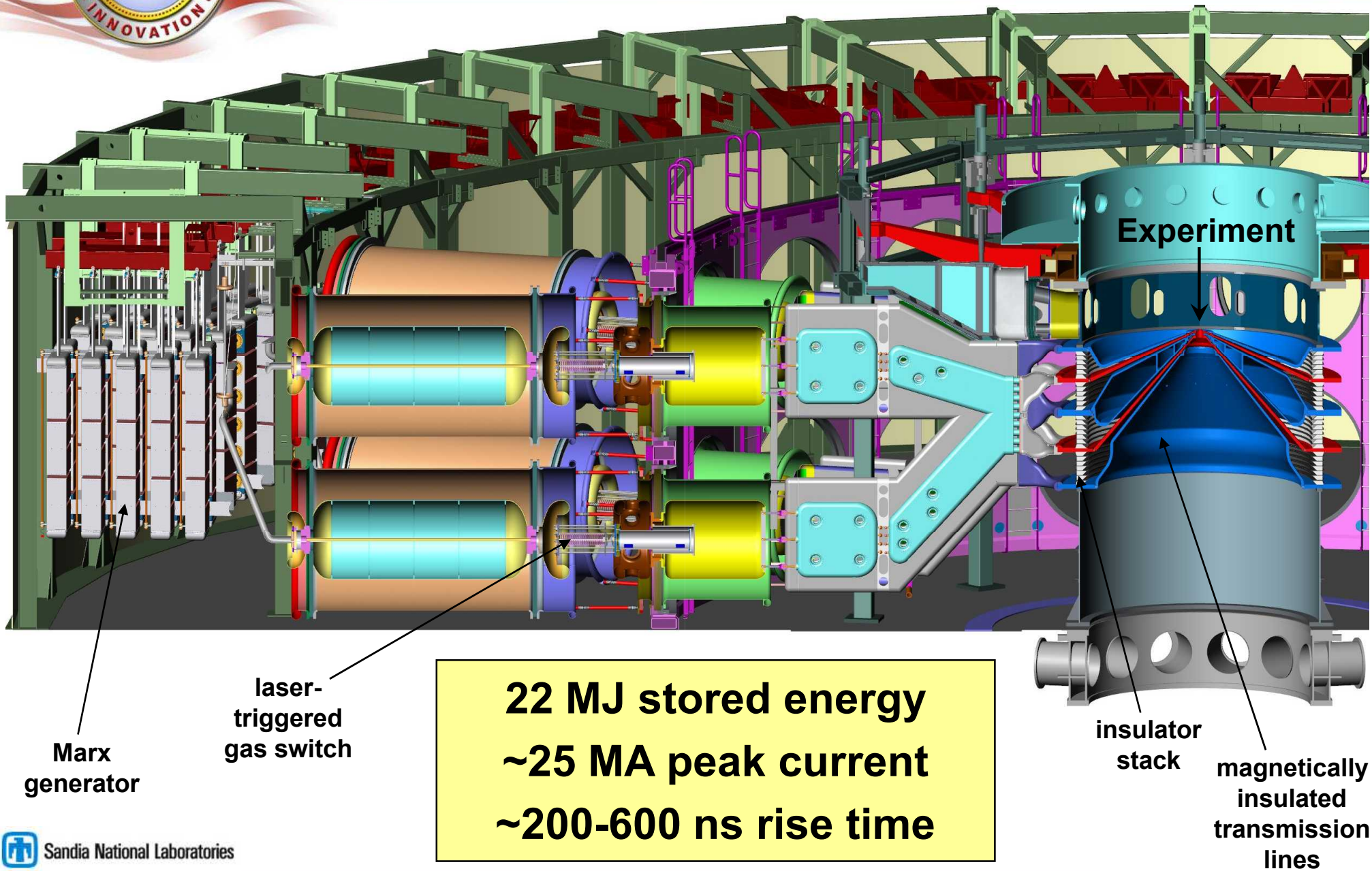
Mie-Grüneisen, constant Γ_{eff} with *linear* reference and fixed S negligibly degrades level of agreement

Mie-Grüneisen with **linear** Hugoniot reference, constant Γ_{eff}

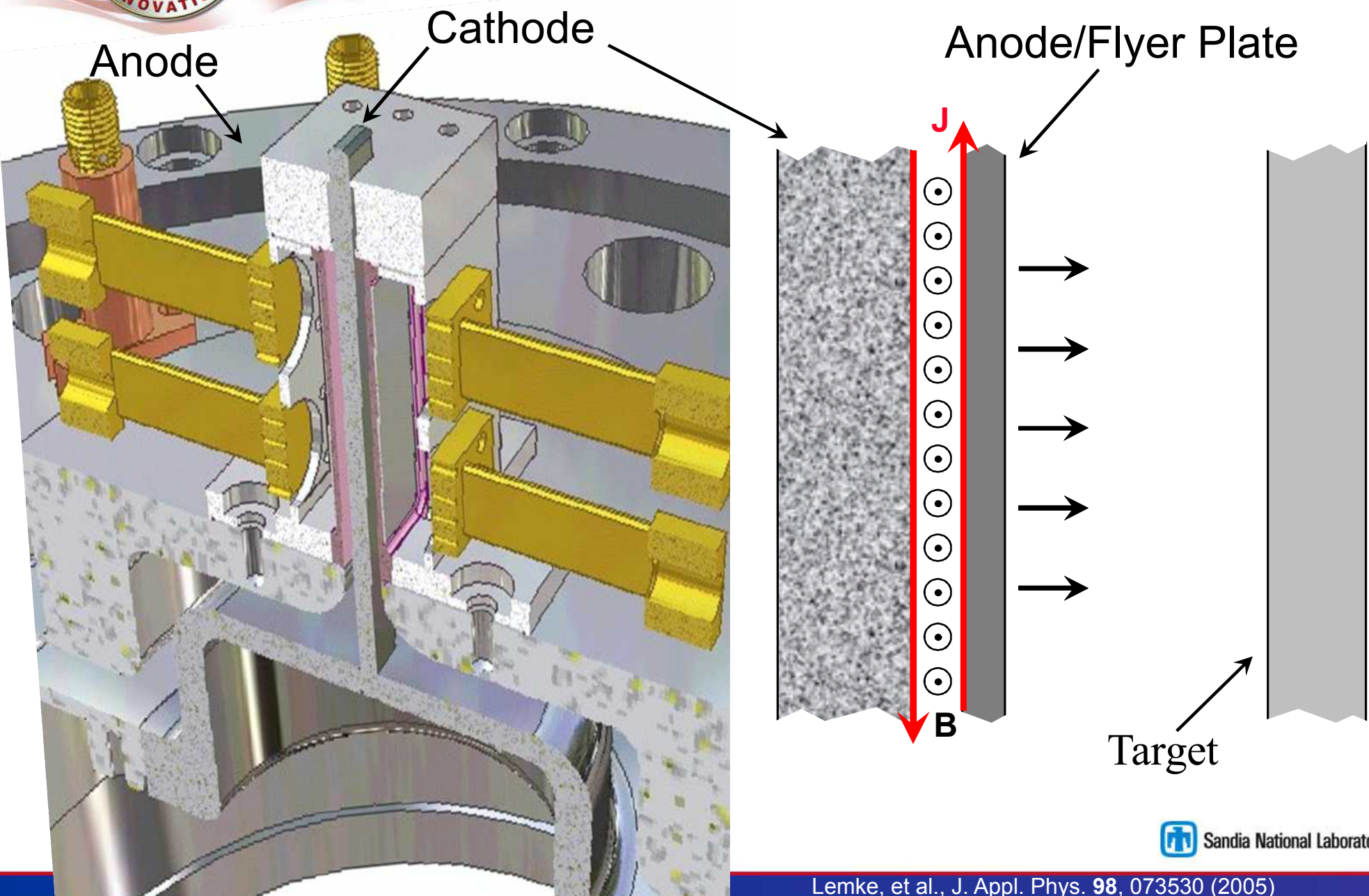




The Sandia Z Machine

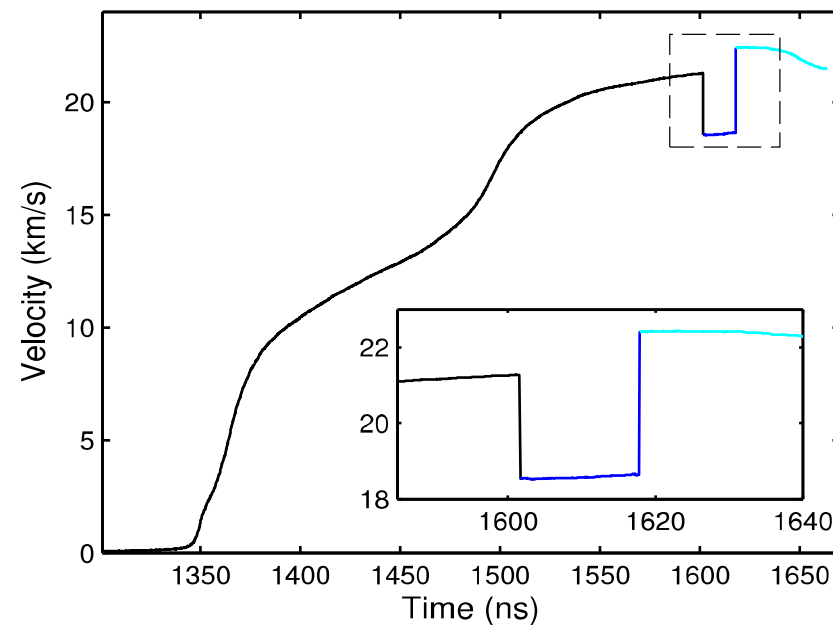
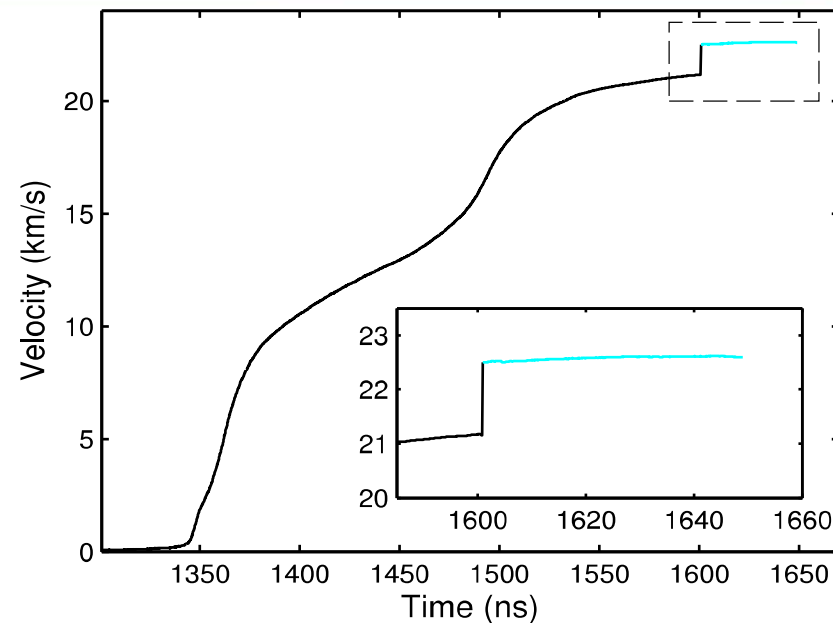
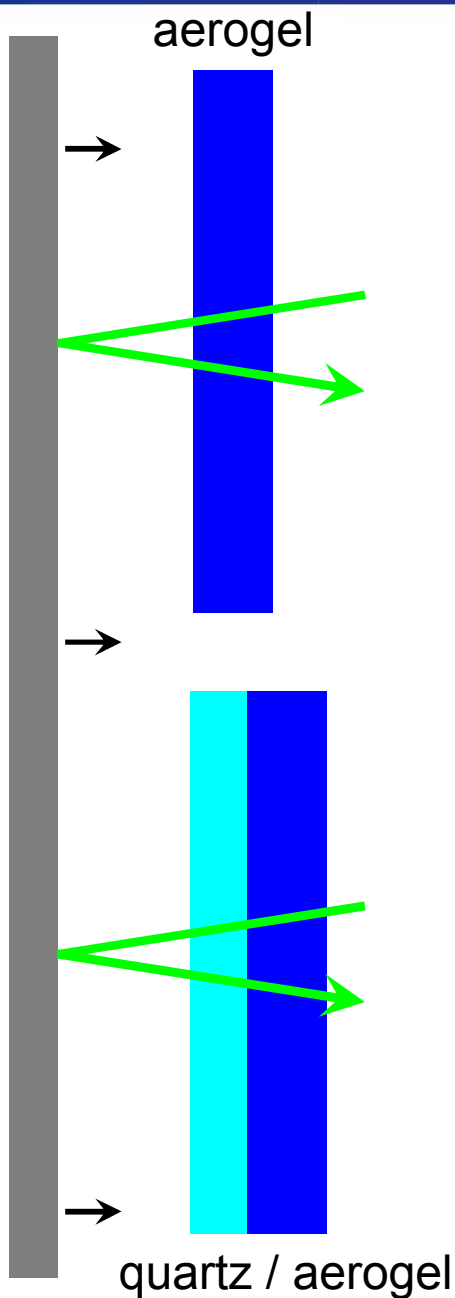
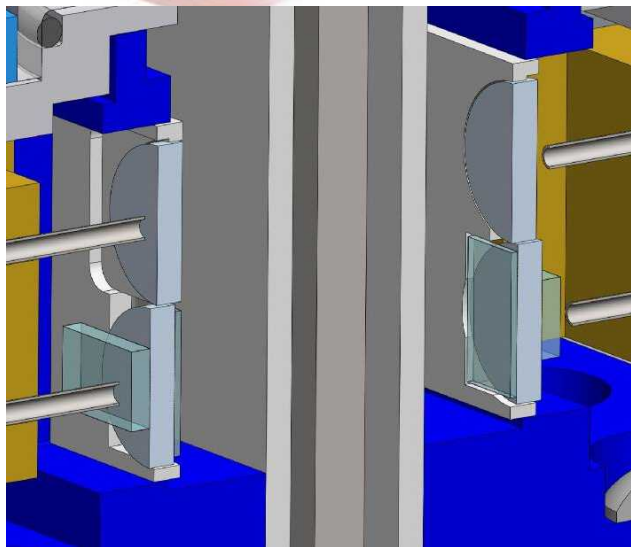


With proper pulse shape and design the anode can be launched as an effective high-velocity flyer plate



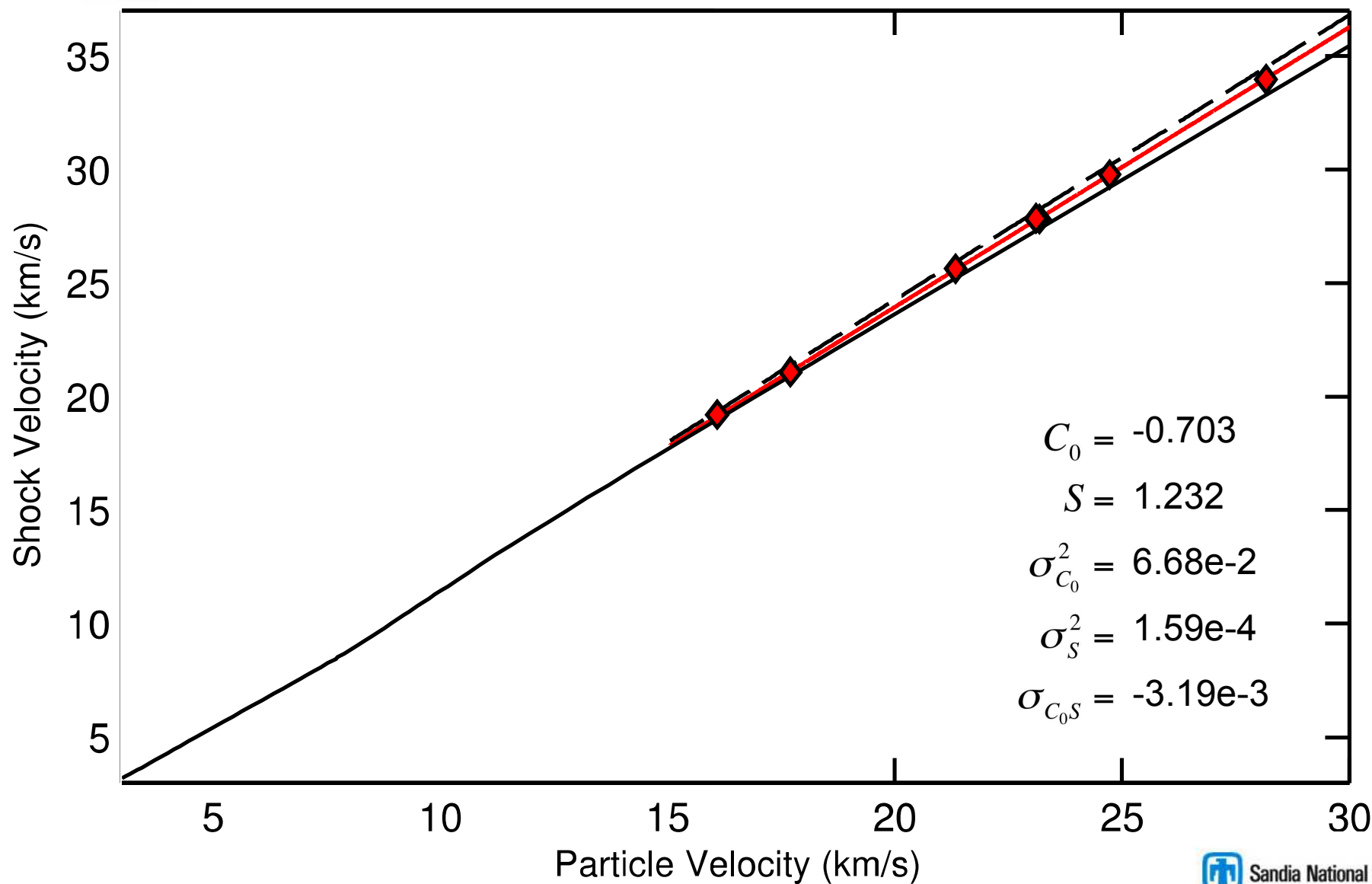


The same experiment provides Hugoniot and release measurements via velocity interferometry



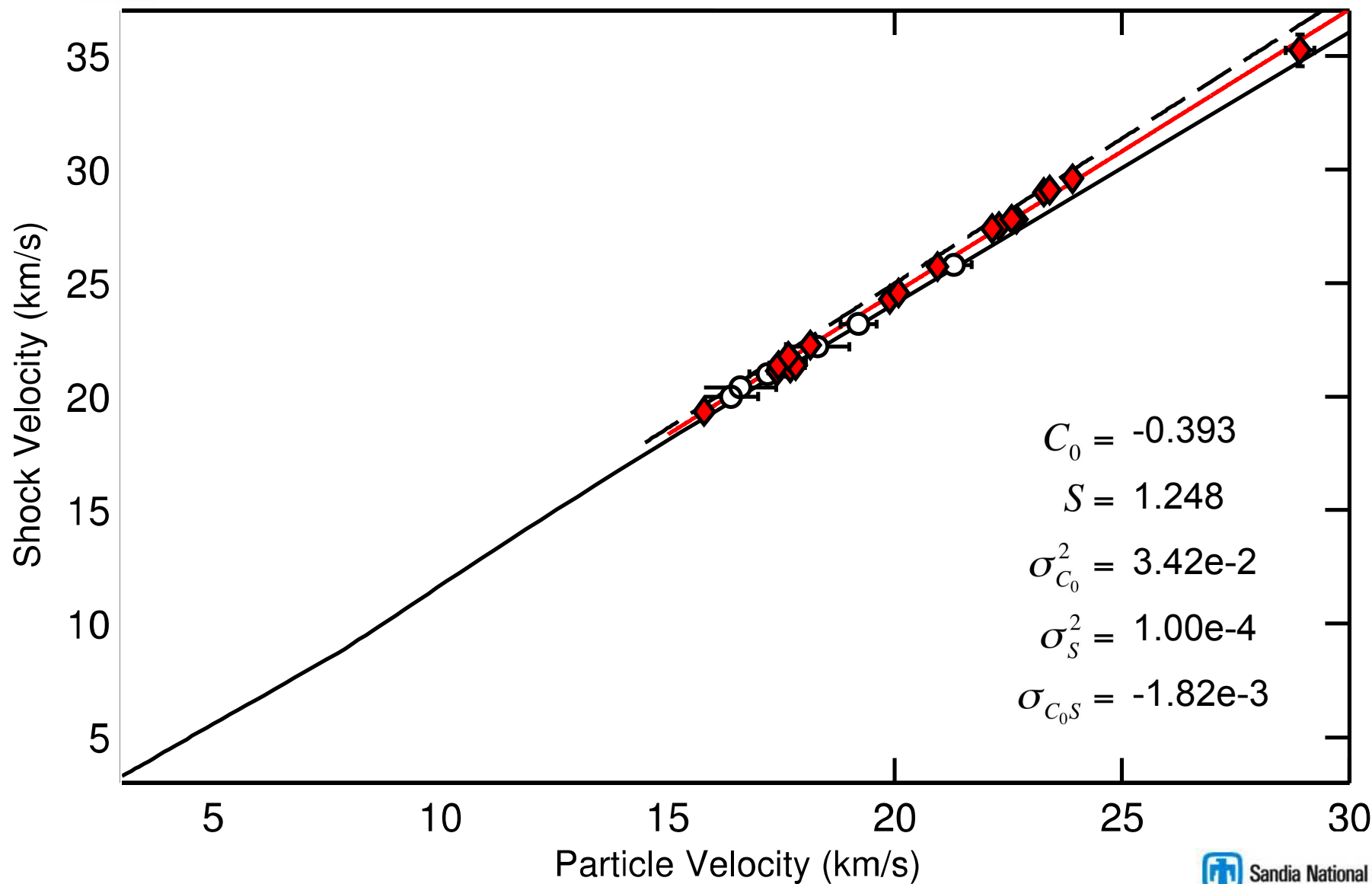


~110 mg/cc silica aerogel U_s - u_p Hugoniot



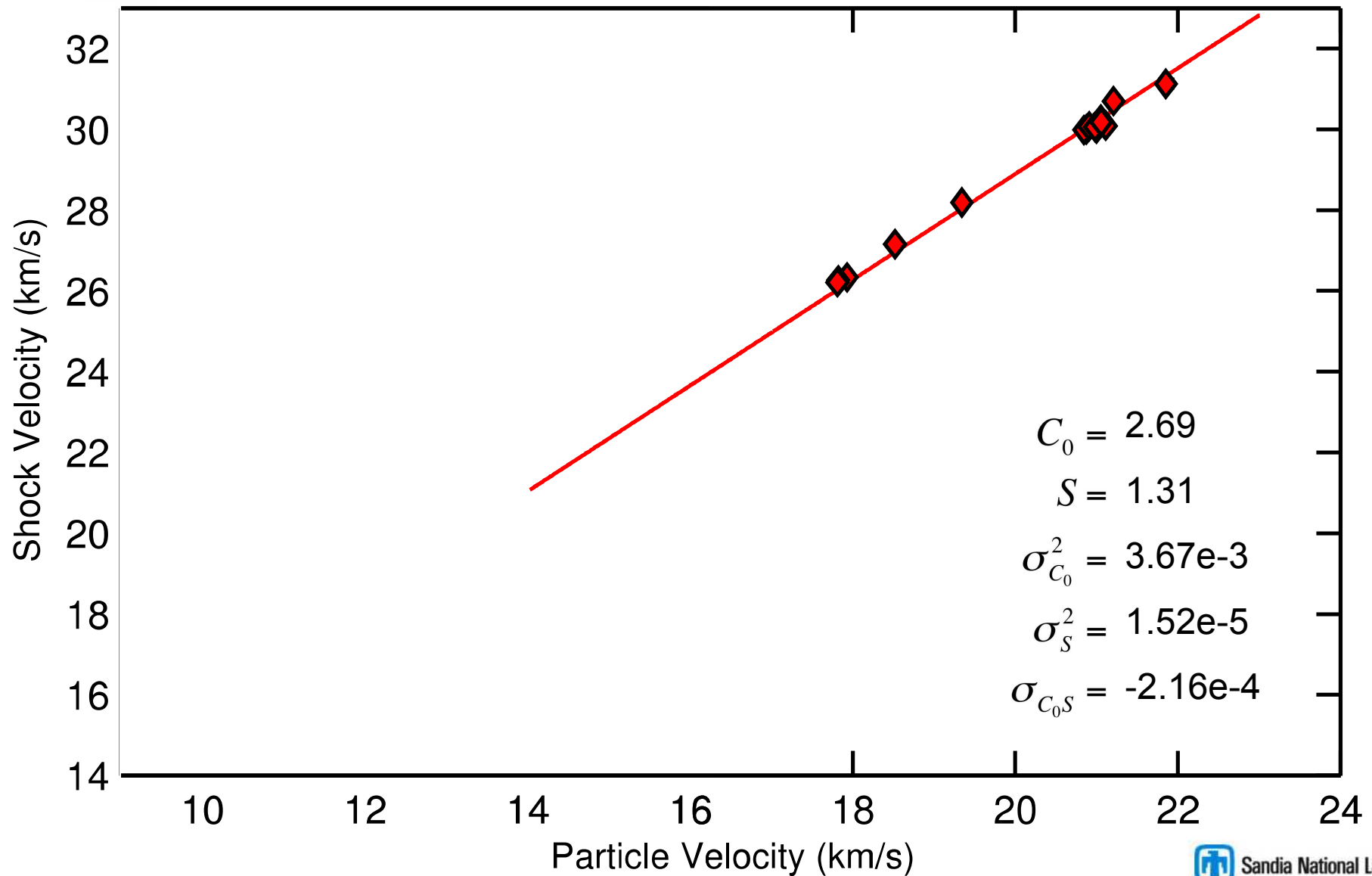


~200 mg/cc silica aerogel U_s - u_p Hugoniot



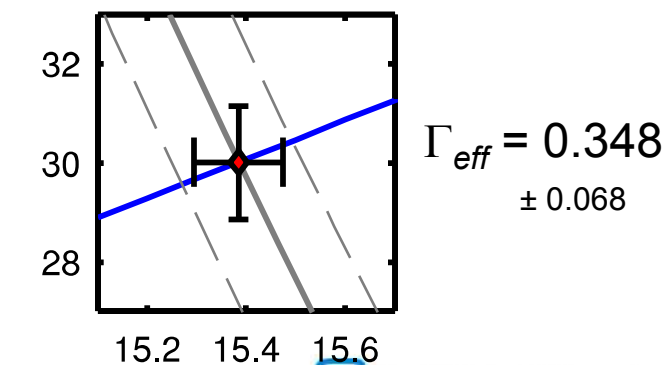
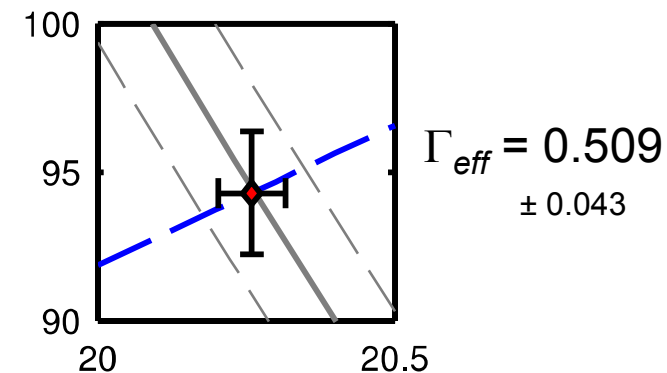
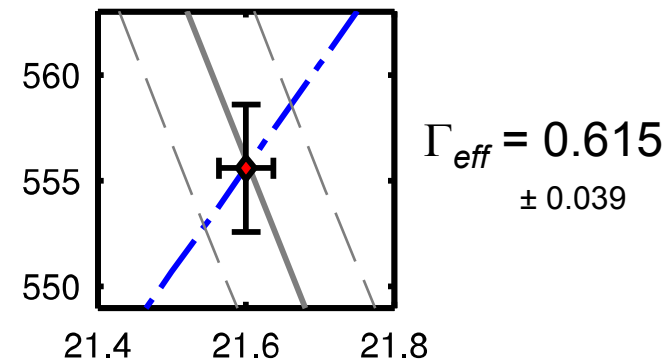
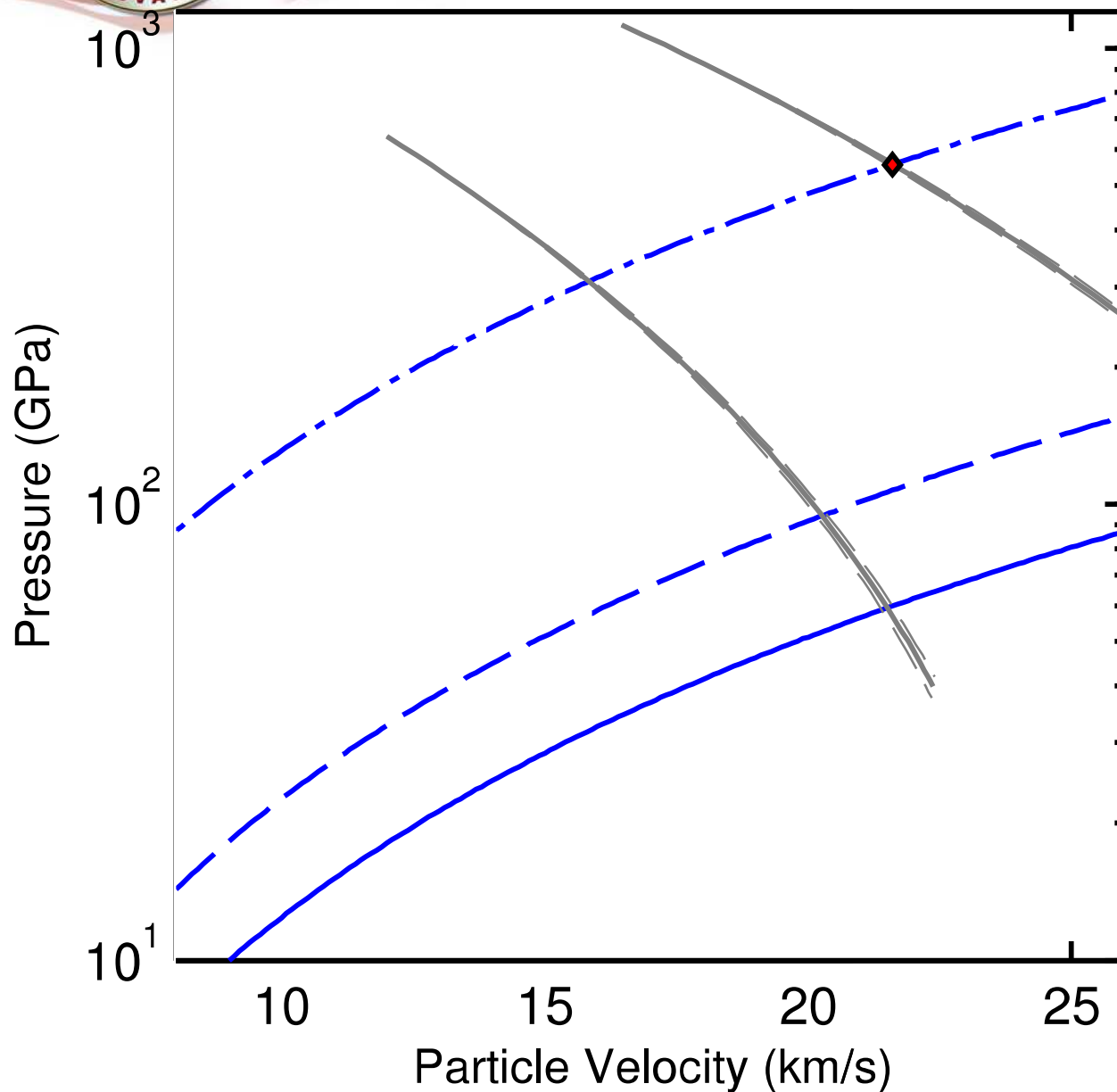


TPX U_s - u_p Hugoniot



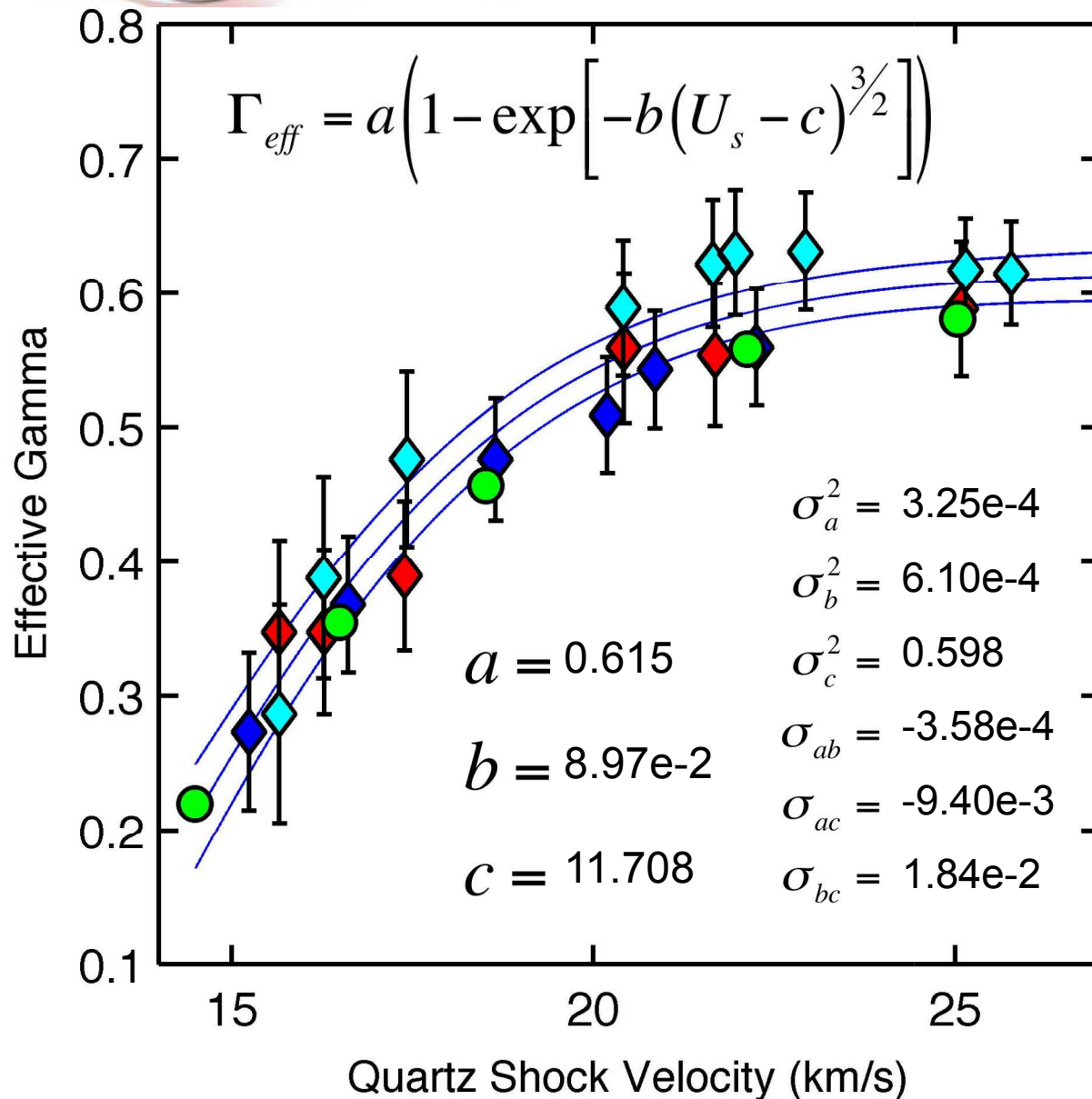


Γ_{eff} determined for each release measurement,
uncertainties evaluated via Monte Carlo method





Γ_{eff} exhibits similar trend for all release standards and shows very good agreement with QMD trend

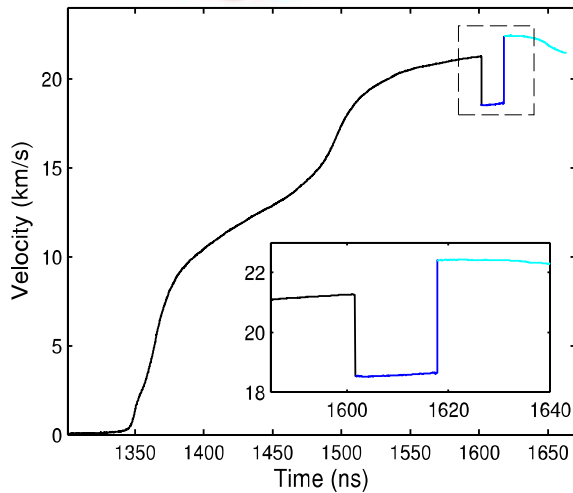


The similar trend in Γ_{eff} for all three release standards suggests that the Mie-Grüneisen, constant Γ_{eff} model with linear $U_s - u_p$ Hugoniot reference adequately describes the release path to quite low pressure states

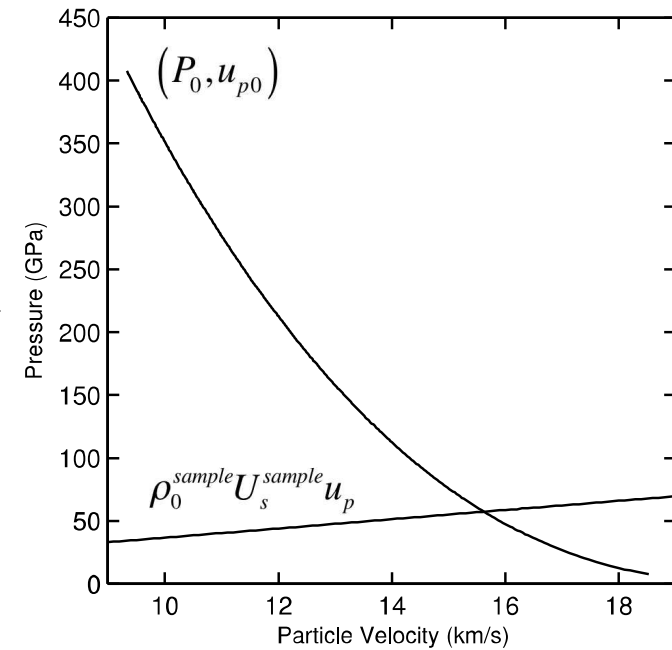
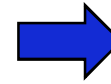
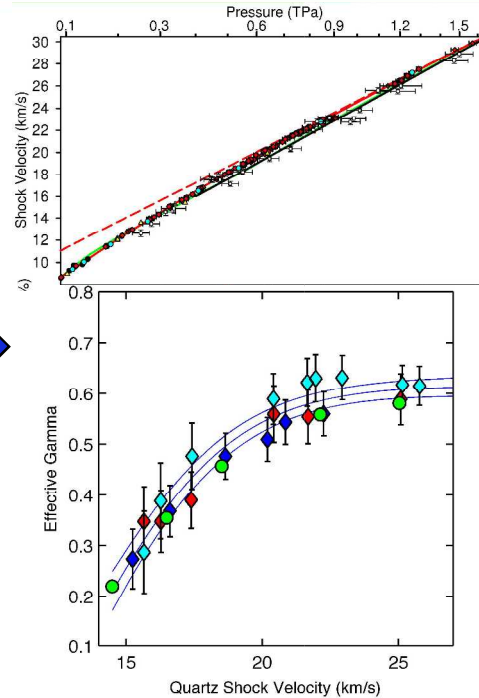
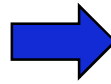
These results corroborate the QMD release calculations, albeit with a slightly higher Γ_{eff} for a given quartz shock velocity



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



measure U_s^{quartz} and U_s^{sample}



U_s^{quartz} determines:

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

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

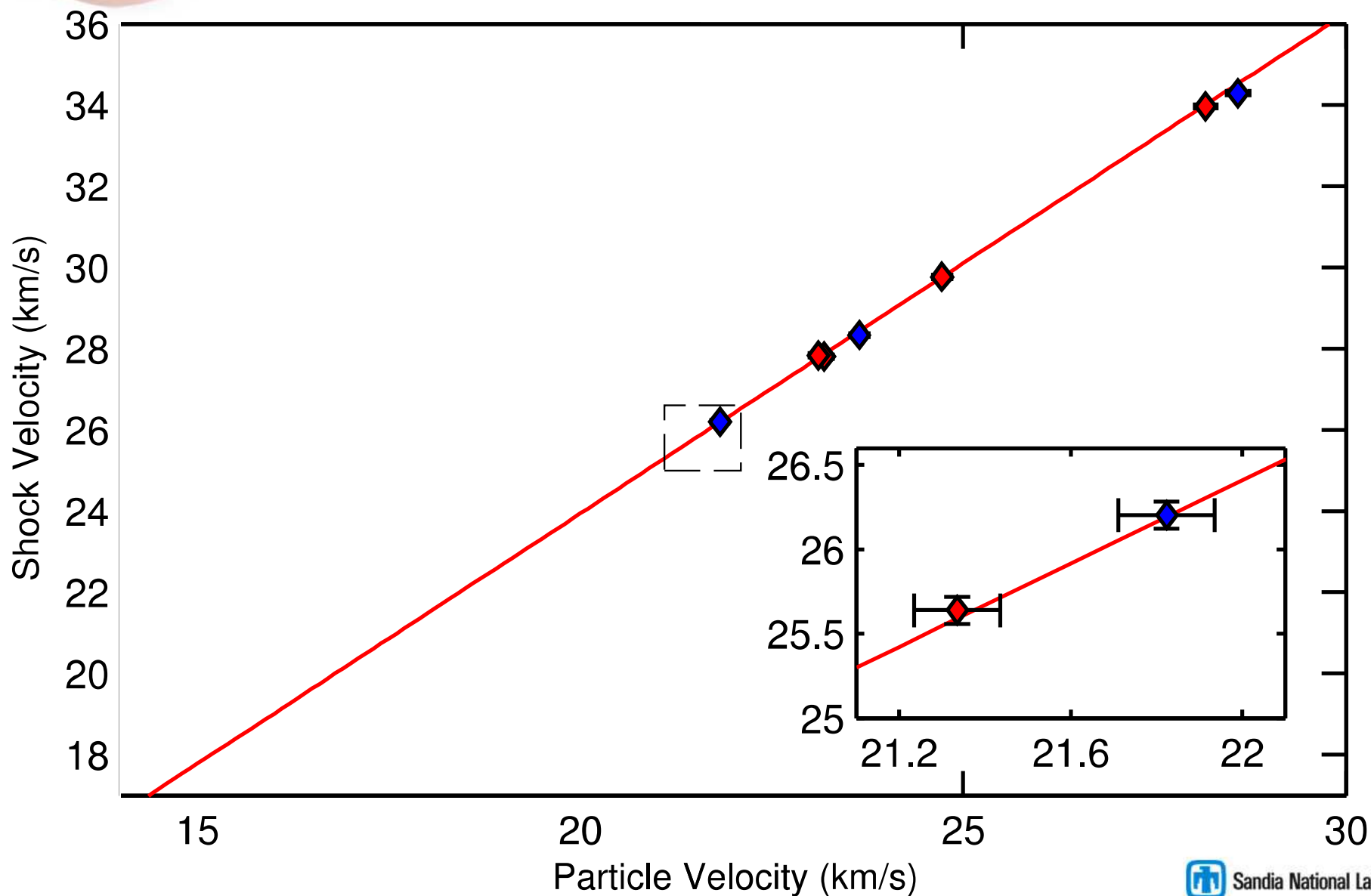
Solve the set of coupled ODEs:

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

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

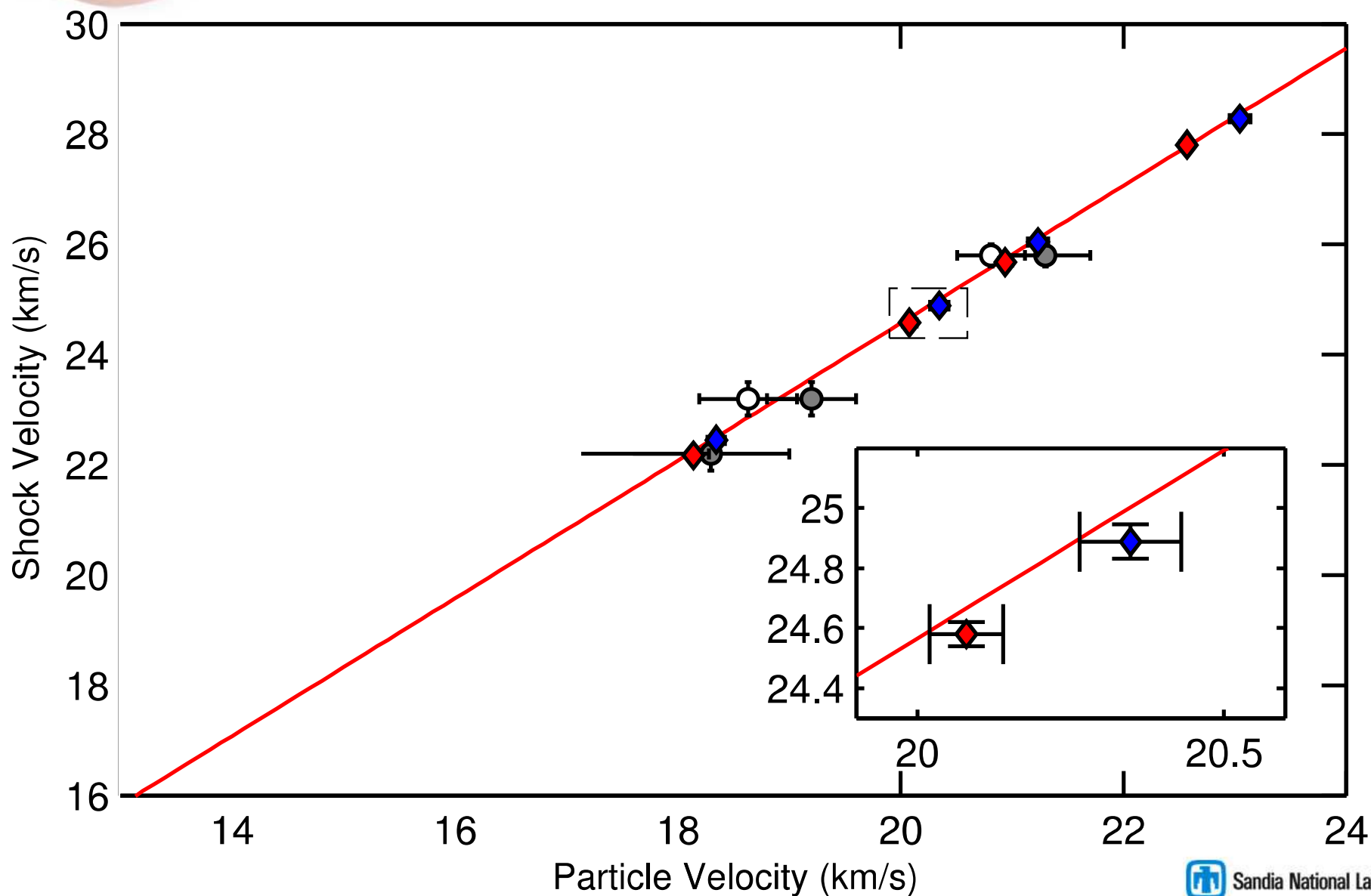


~110 mg/cc silica aerogel U_s - u_p Hugoniot



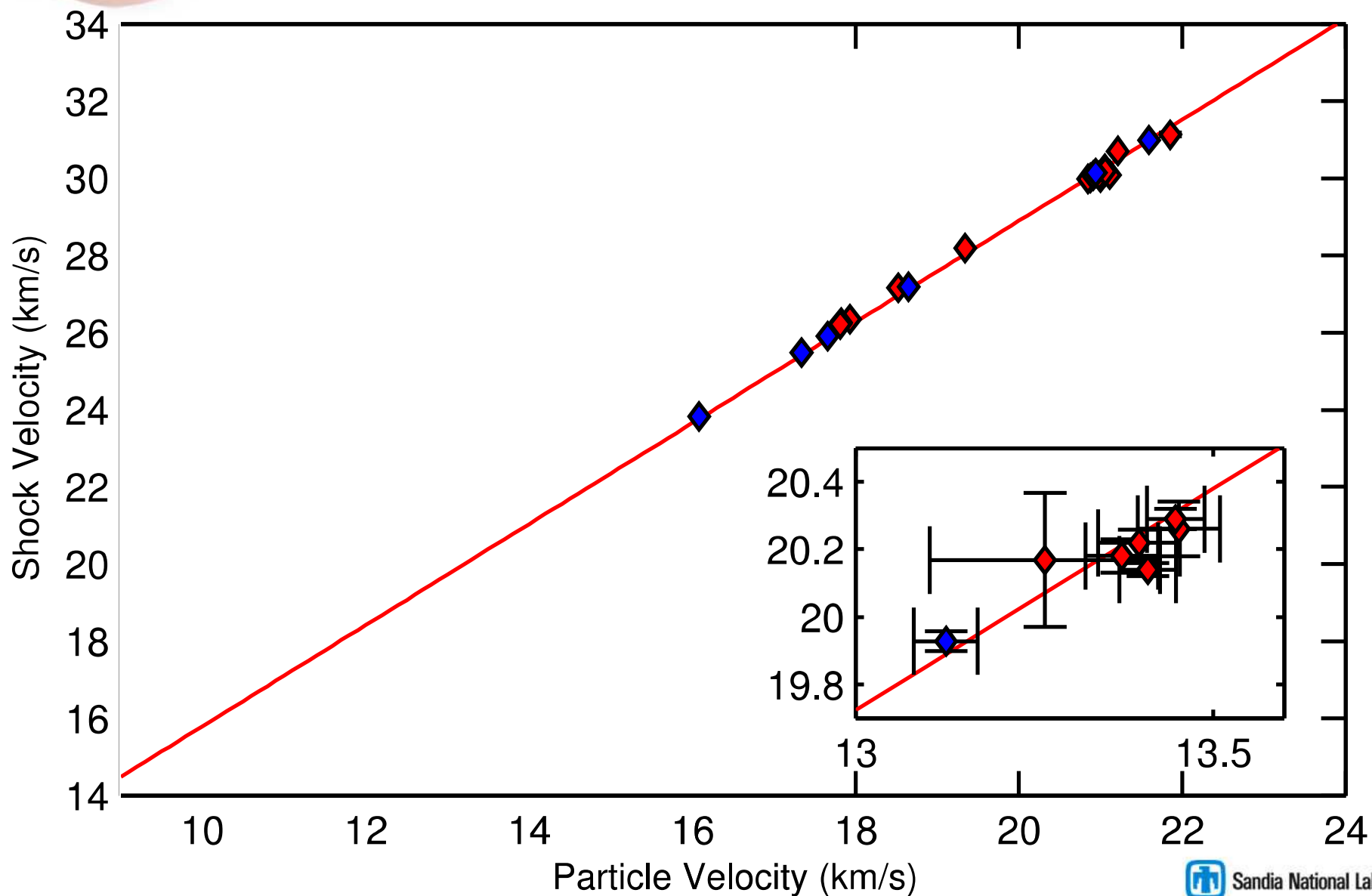


~200 mg/cc silica aerogel U_s - u_p Hugoniot





TPX U_s - u_p Hugoniot



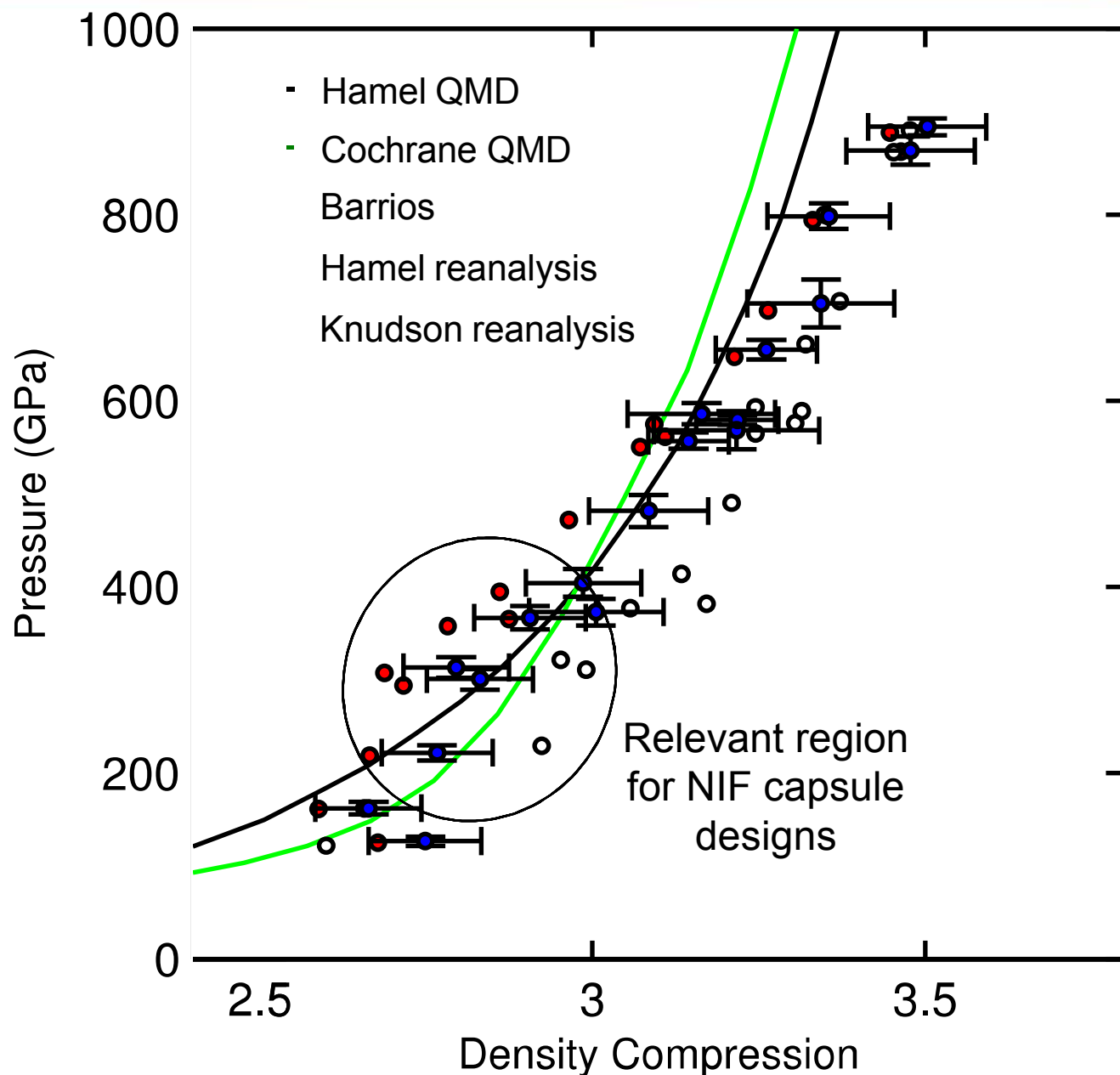


Recent GDP experiments nicely illustrate the effects of the quartz Hugoniot and release standard

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 Γ_{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 Γ_{eff} , and linear U_s-u_p Hugoniot reference
 - » S for the reference Hugoniot fixed at $S=1.1971$
 - » $\Gamma_{eff}(U_s)$ 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 $\Gamma_{eff}(U_s)$
 - » Agreement between inferred Γ_{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