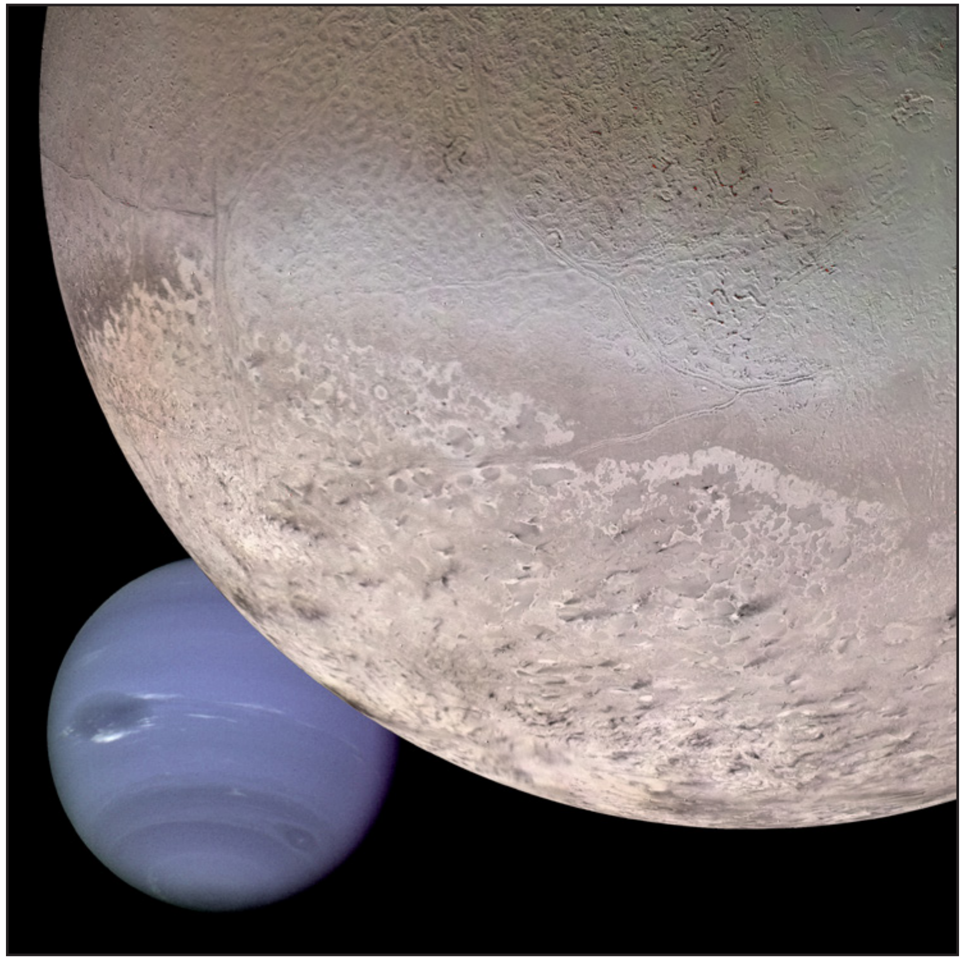
Equation-of-State Measurements of Precompressed CO_2



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Precompressed CO_2 was shocked to ~1 TPa and is less compressible than predicted by current models

- Ice giants (Uranus, Neptune) and their moons (Triton) contain CO_2, which may contribute to planetary dynamics
- CO_2 was precompressed in diamond-anvil cells to a liquid at ~1.16 GPa and shock compressed to 980 GPa
- Shock velocity and self-emission were measured to provide Hugoniot, reflectivity, and temperature data
- Shock-compressed CO_2 exhibits stiffer behavior than predicted by density functional theory (DFT)

Collaborators

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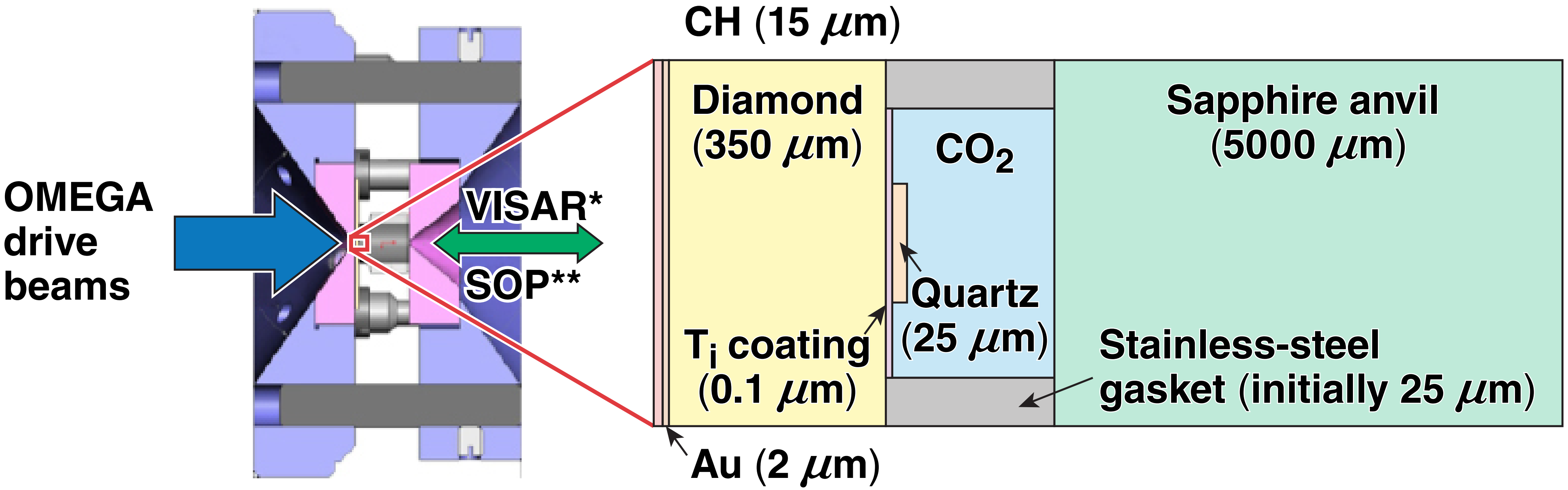
Diamond-anvil cells precompressed CO_2 that was shock compressed with the OMEGA laser



- CO_2 samples were precompressed to 1.2 GPa in diamond-anvil cells and driven with laser shocks to 980 GPa
- Impedance matching was performed to the quartz standard
- Shock velocity, emission, and reflectance were measured using VISAR and SOP

*VISAR: velocity interferometer system for any reflector
**SOP: streaked optical pyrometer

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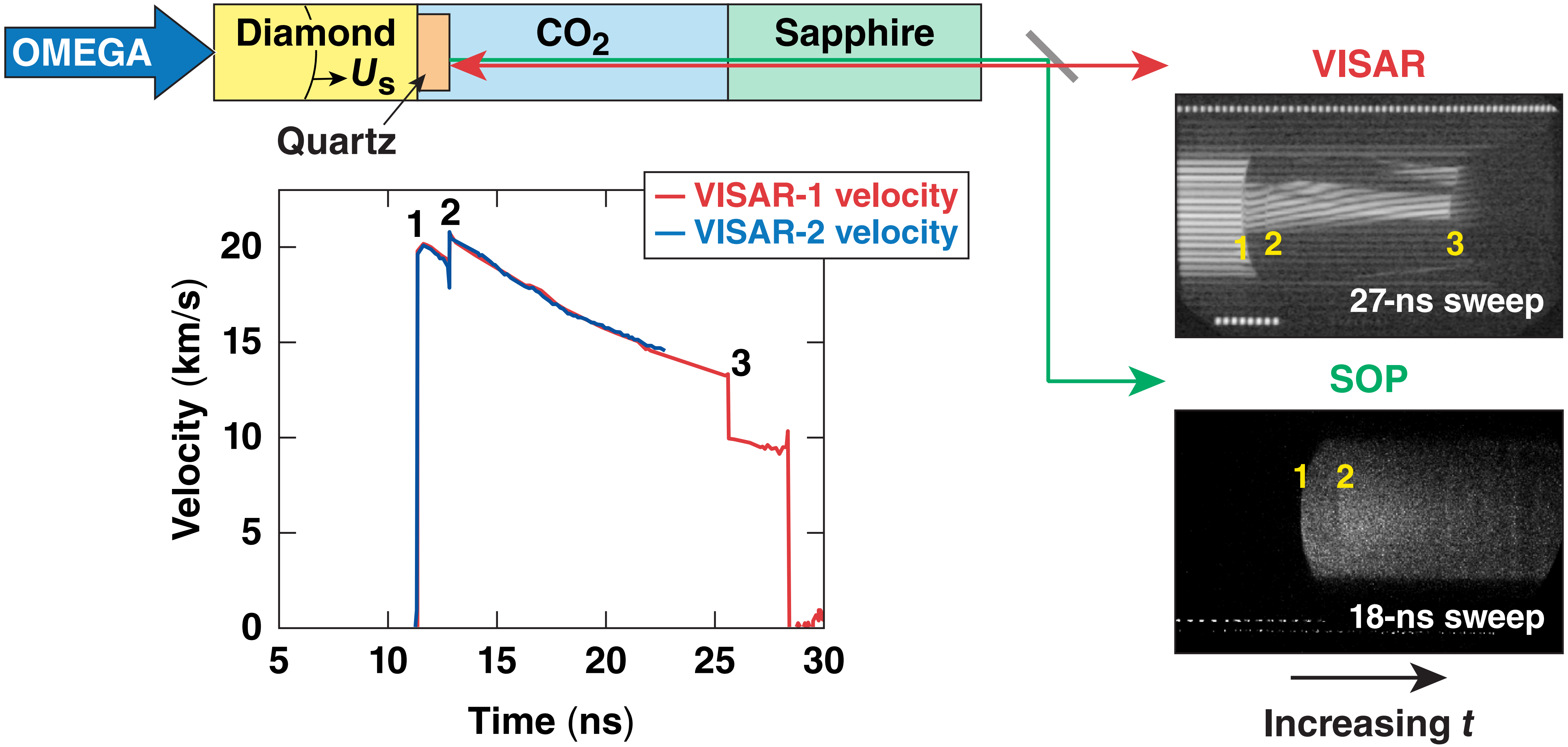
Simultaneous VISAR and pyrometer data provided a temporal profile of the shock velocity and temperature



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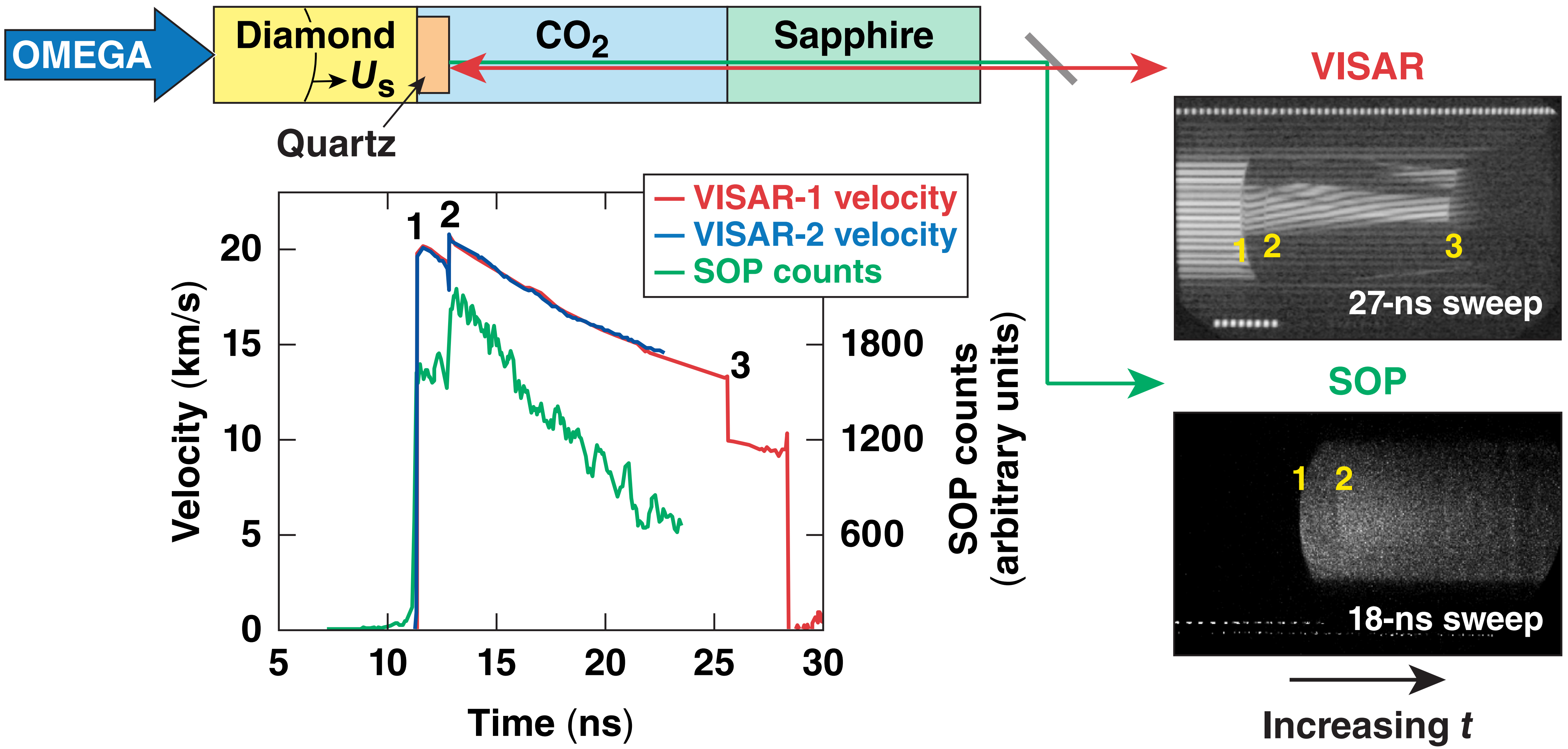
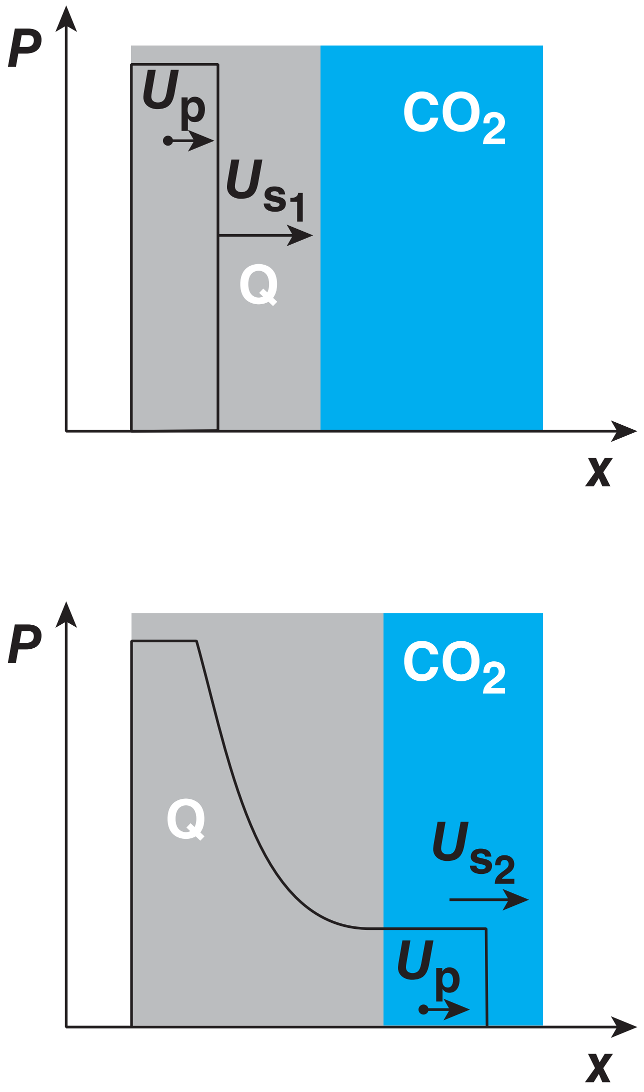


The impedance-matching method relies on the shock and release behaviors of a known standard



Rankine–Hugoniot equations

$$\frac{\rho}{\rho_0} = \frac{U_s}{(U_s - U_p)}$$

$$P - P_0 = \rho_0 U_s U_p$$

$$E - E_0 = \frac{1}{2}(P + P_0)\left(\frac{1}{\rho_0} - \frac{1}{\rho}\right)$$

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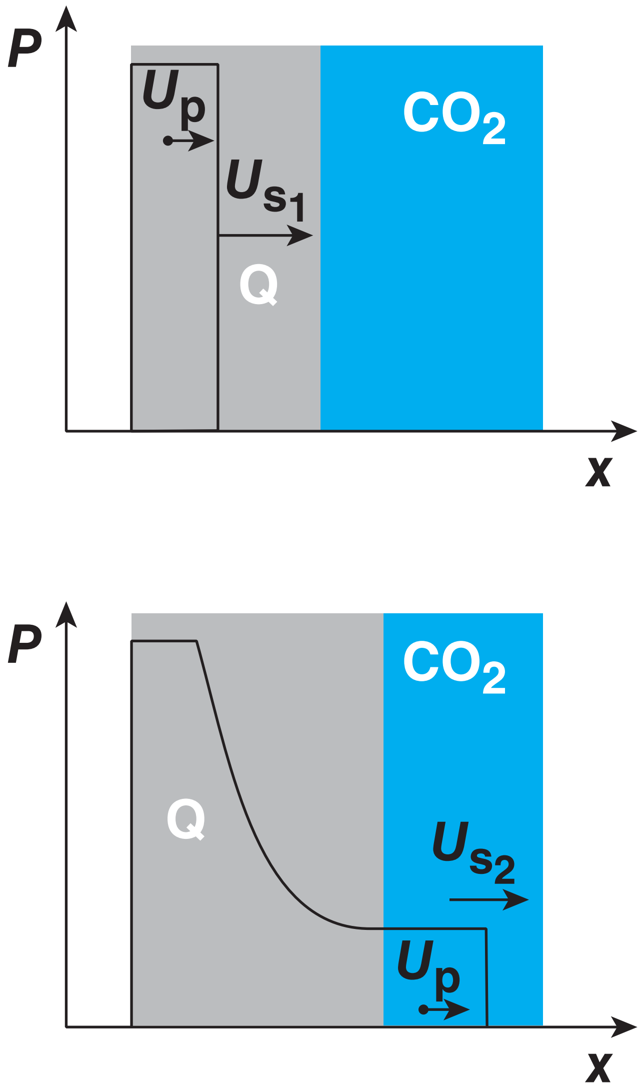

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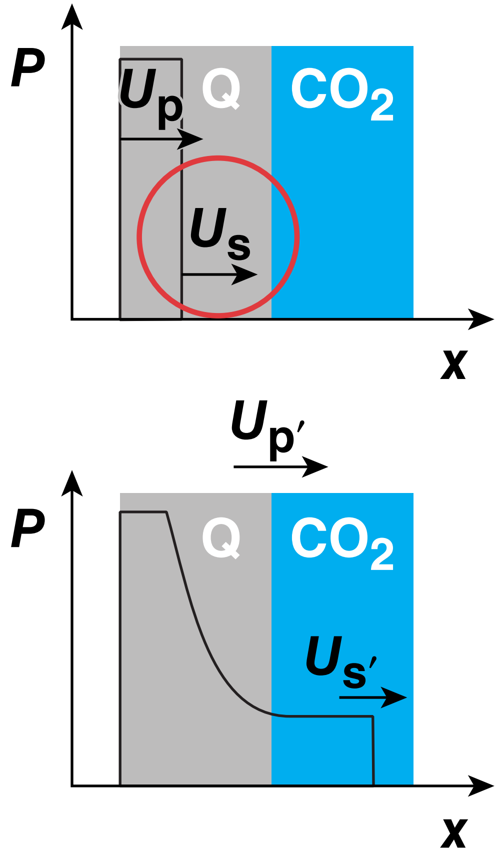
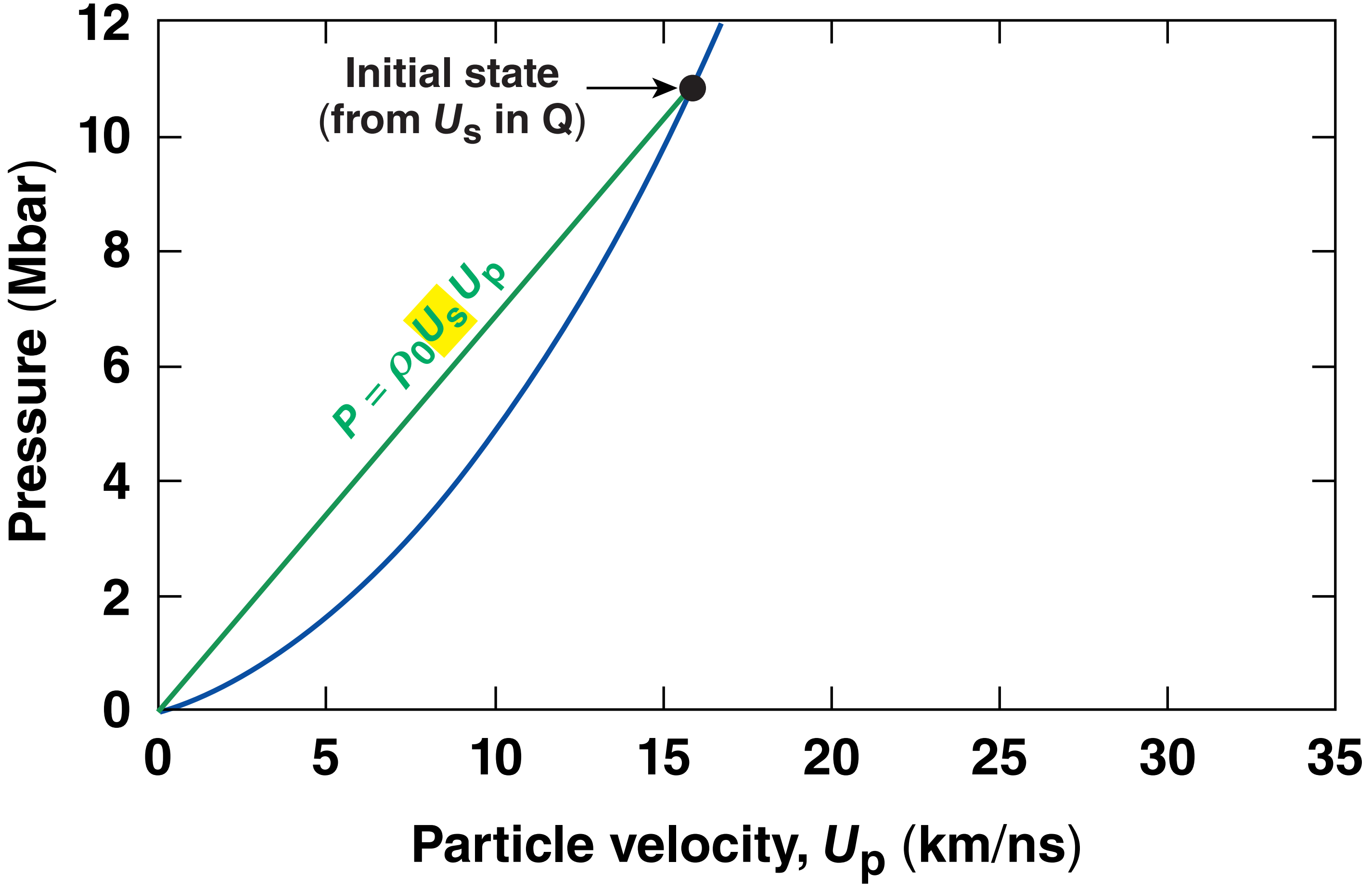
Equation-of-state data are obtained from the impedance-matching technique





$$U_s^Q = a + bU_p^Q - cU_p^Q e^{-dU_p^Q} + \alpha(\rho_0 - 2.65)$$

$$\alpha = 2.3 - 0.037\, U_p^Q$$

M. P. Desjarlais, M. D. Knudson, and K. R. Cochrane, J. Appl. Phys. 122, 035903 (2017);
S. Brygoo et al., J. Appl. Phys. 118, 195901 (2015).

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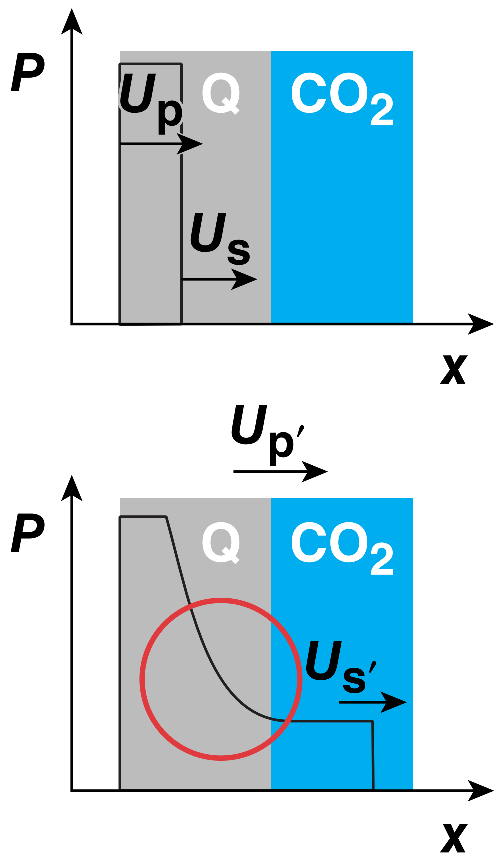

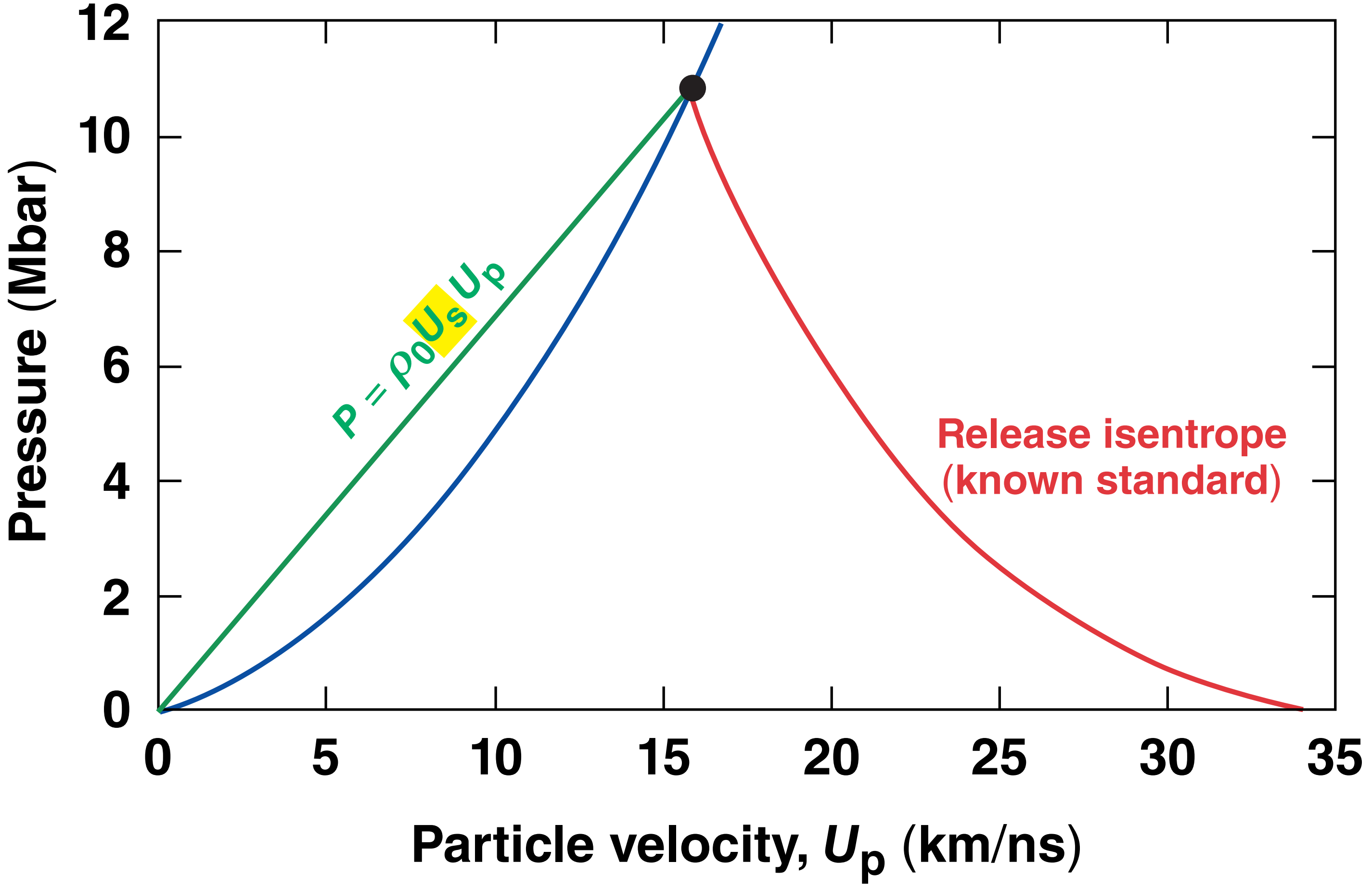

Mie–Grüneisen linear reference model

$$P_s - P_H = \frac{\Gamma}{V}(E_s - E_H)$$

$$U_p = U_{p1} + \int_{p1}^{p} \frac{VdP_s}{C_s}$$

M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013);
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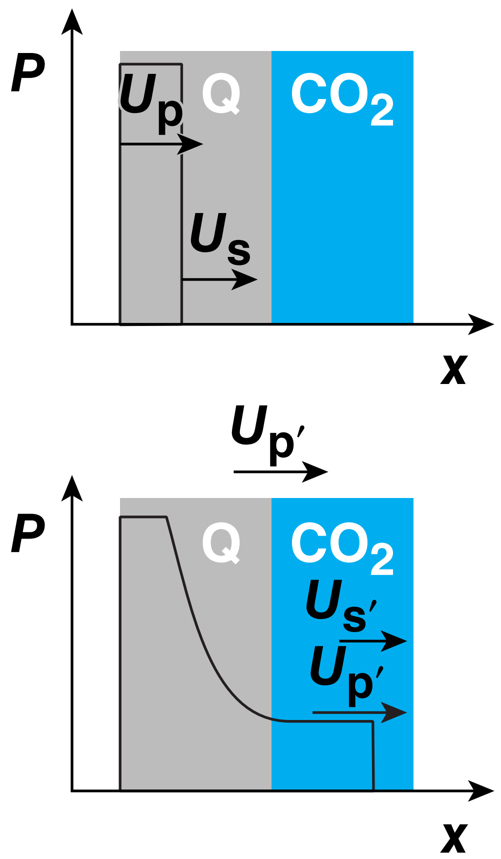
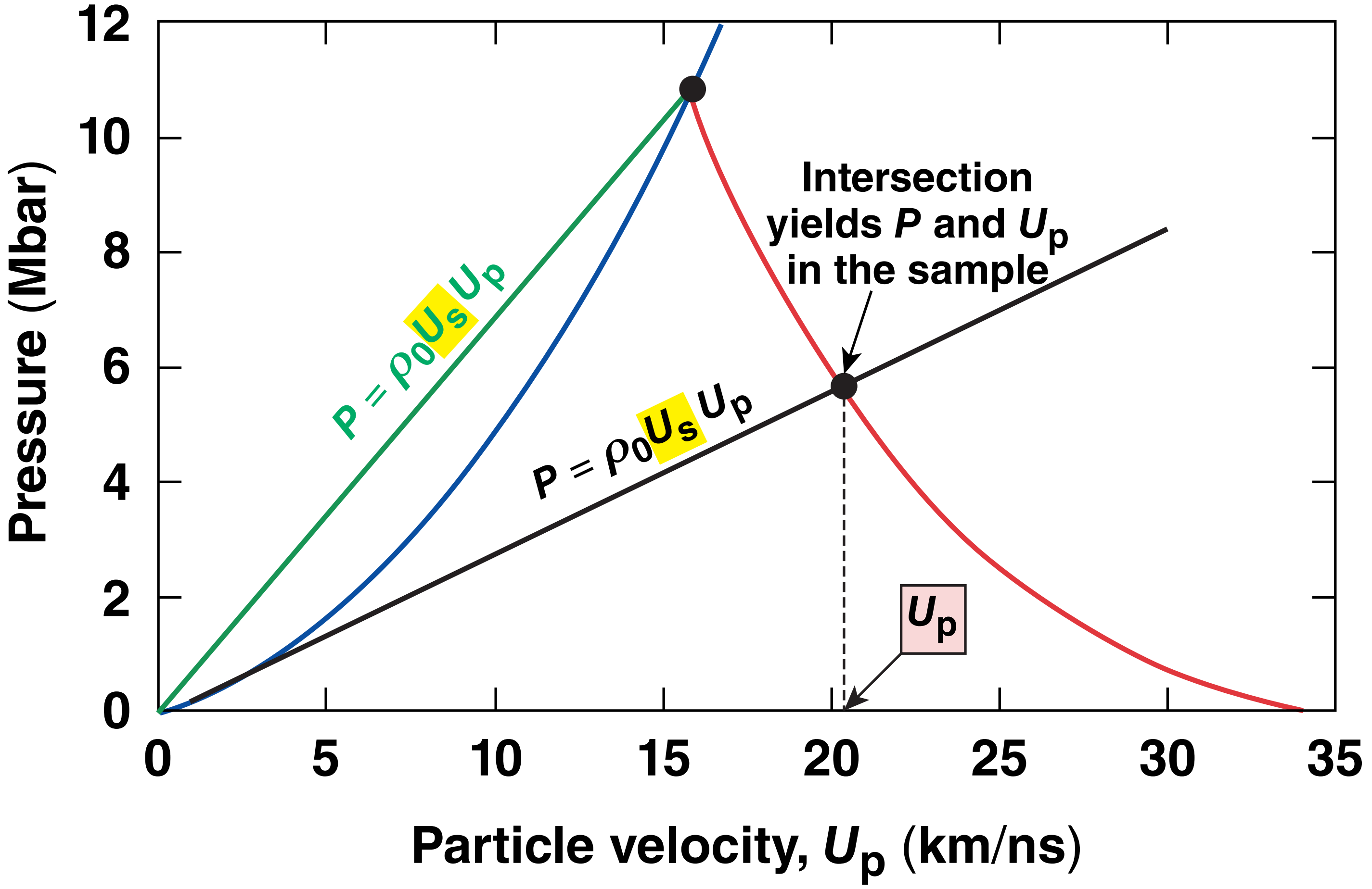
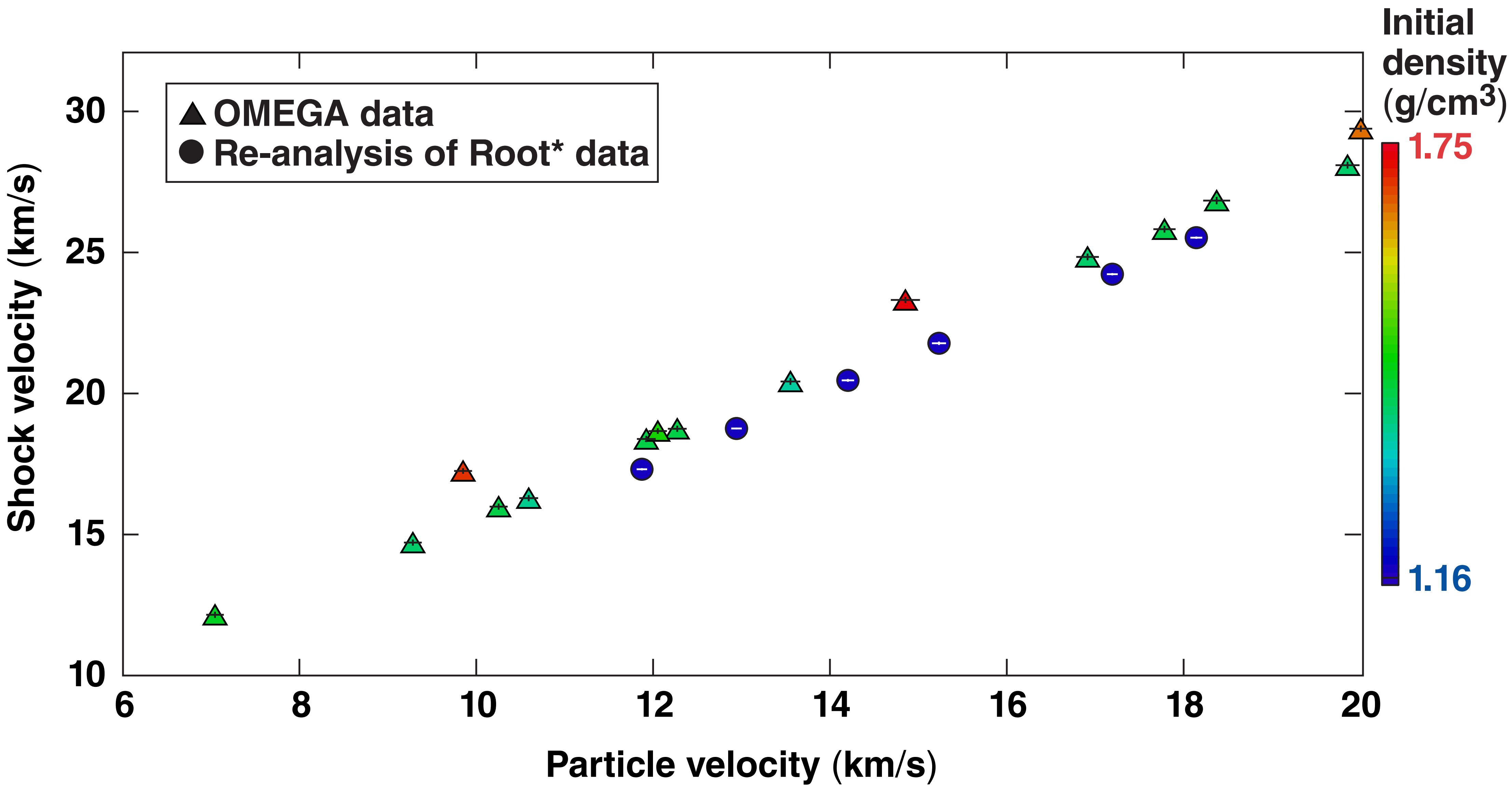




Particle velocities were inferred from impedance matching to obtain $U_s(U_p)$



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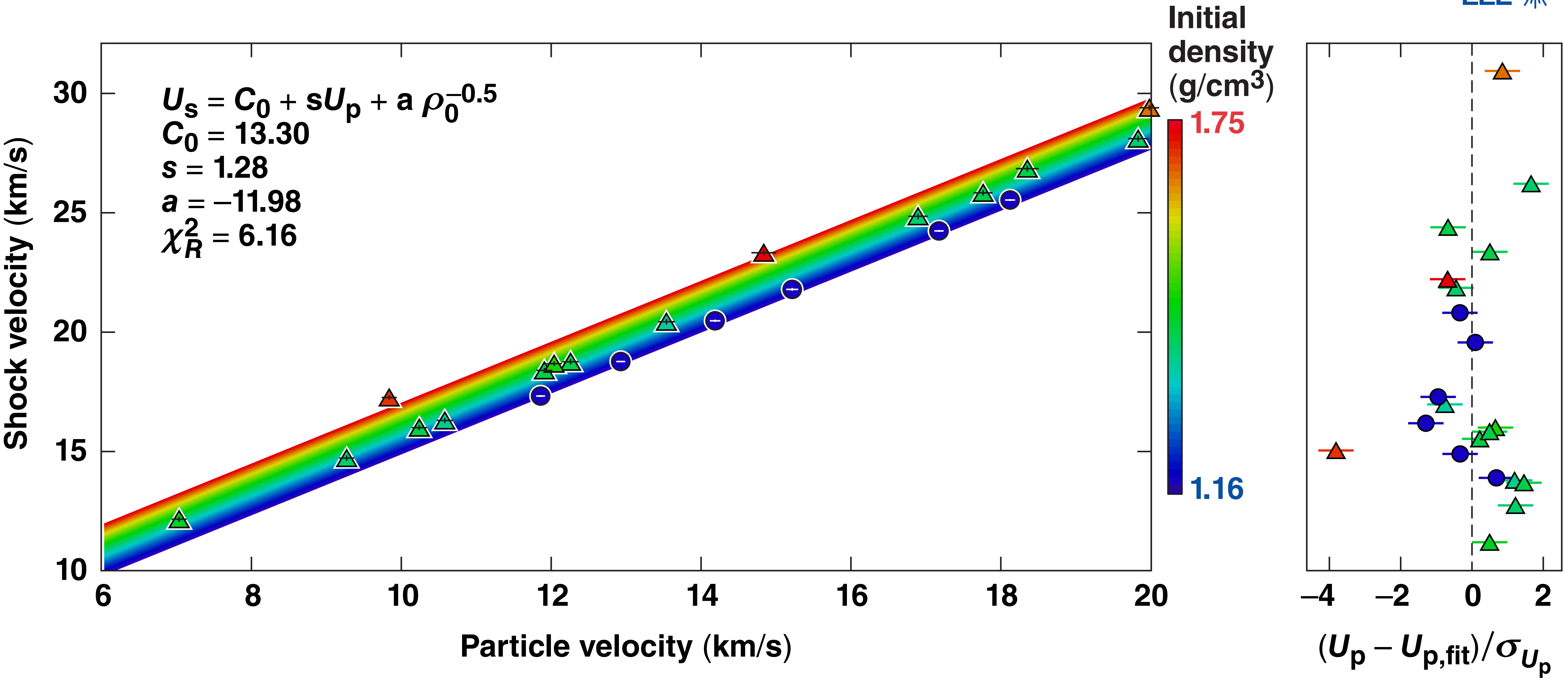
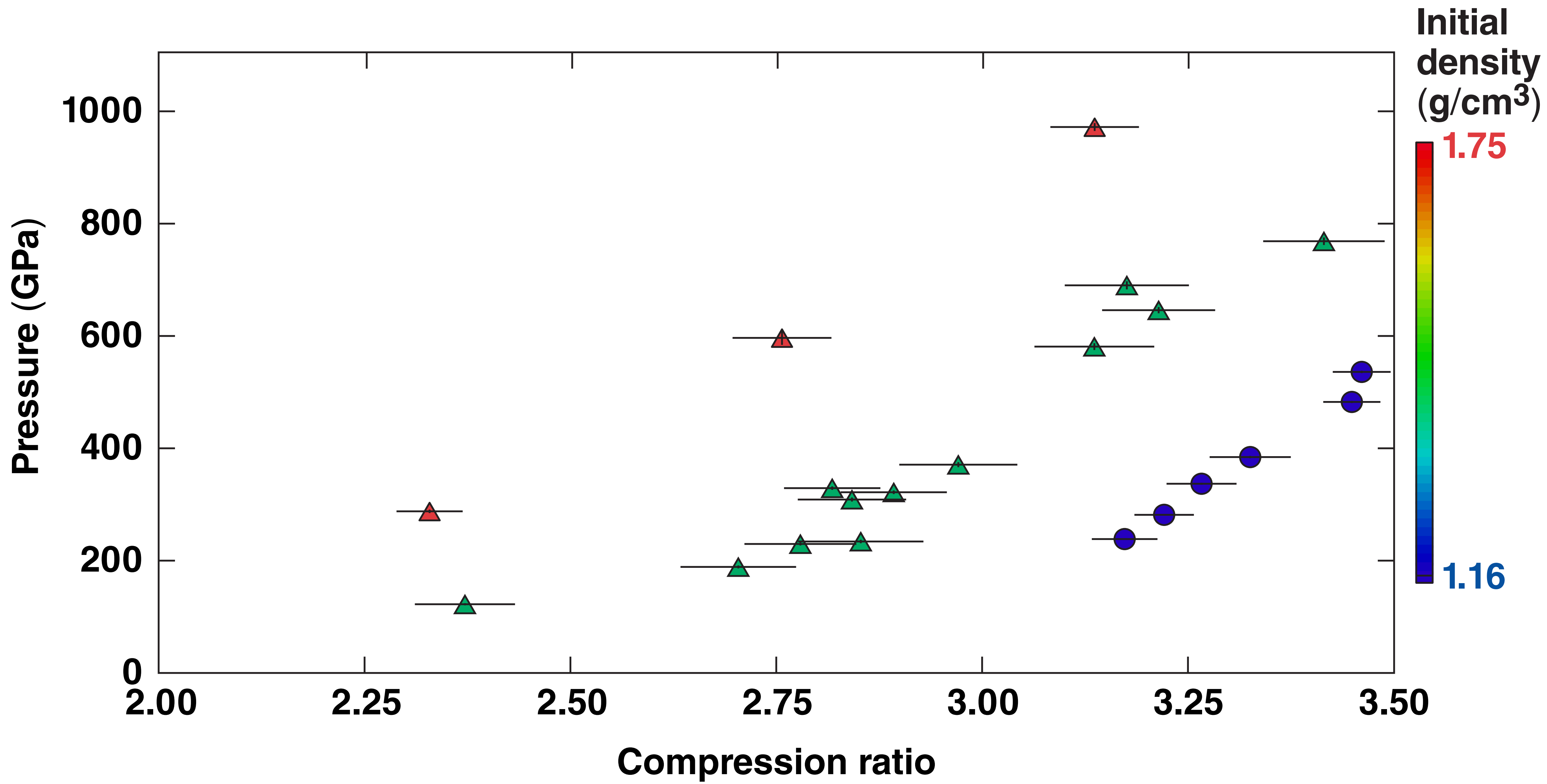
*S. Root *et al.*, Phys. Rev. B 87, 224102 (2013).

The $U_s - U_p$ relation for CO_2 exhibits linear behavior when accounting for precompression



In the pressure–compression plane, the effect of precompression is readily apparent



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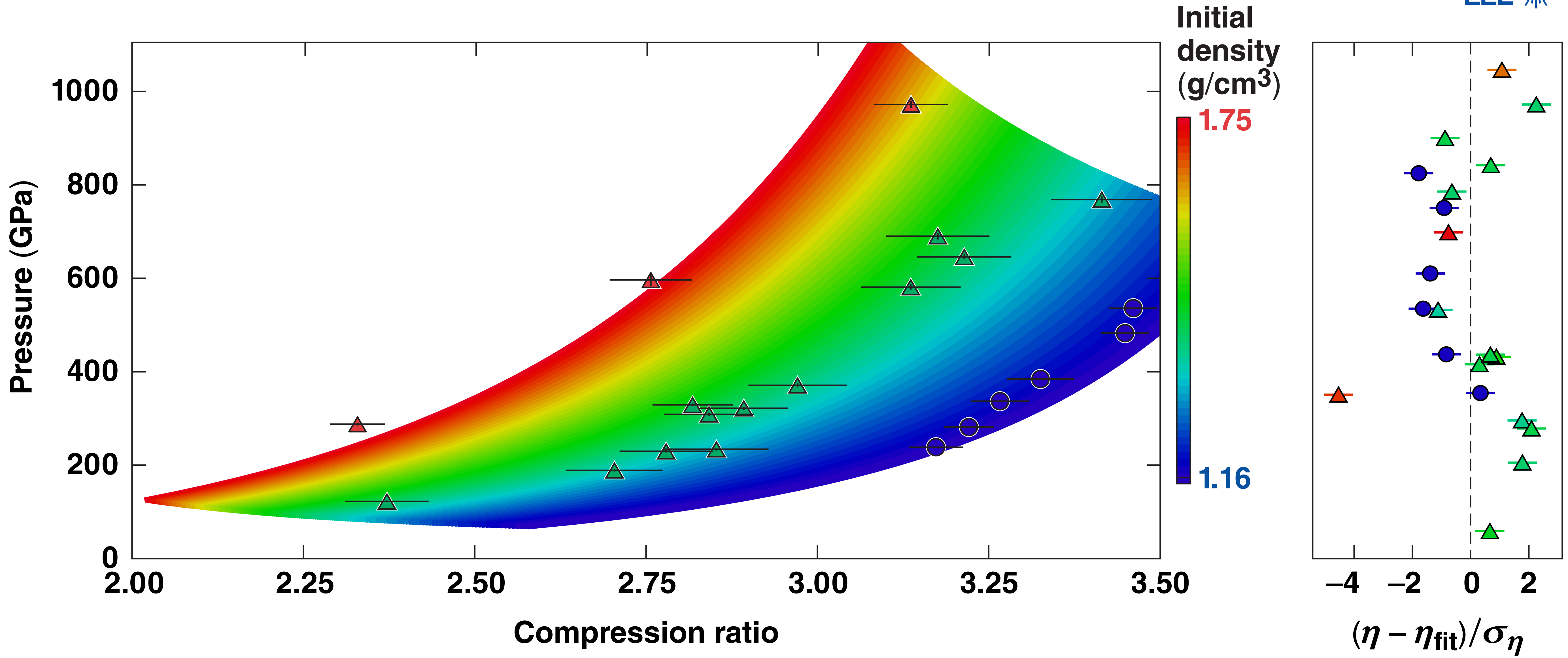
In the pressure–compression plane, the effect of precompression is readily apparent with the fit $U_s = C_0 + sU_p + a\rho_0^{-0.5}$



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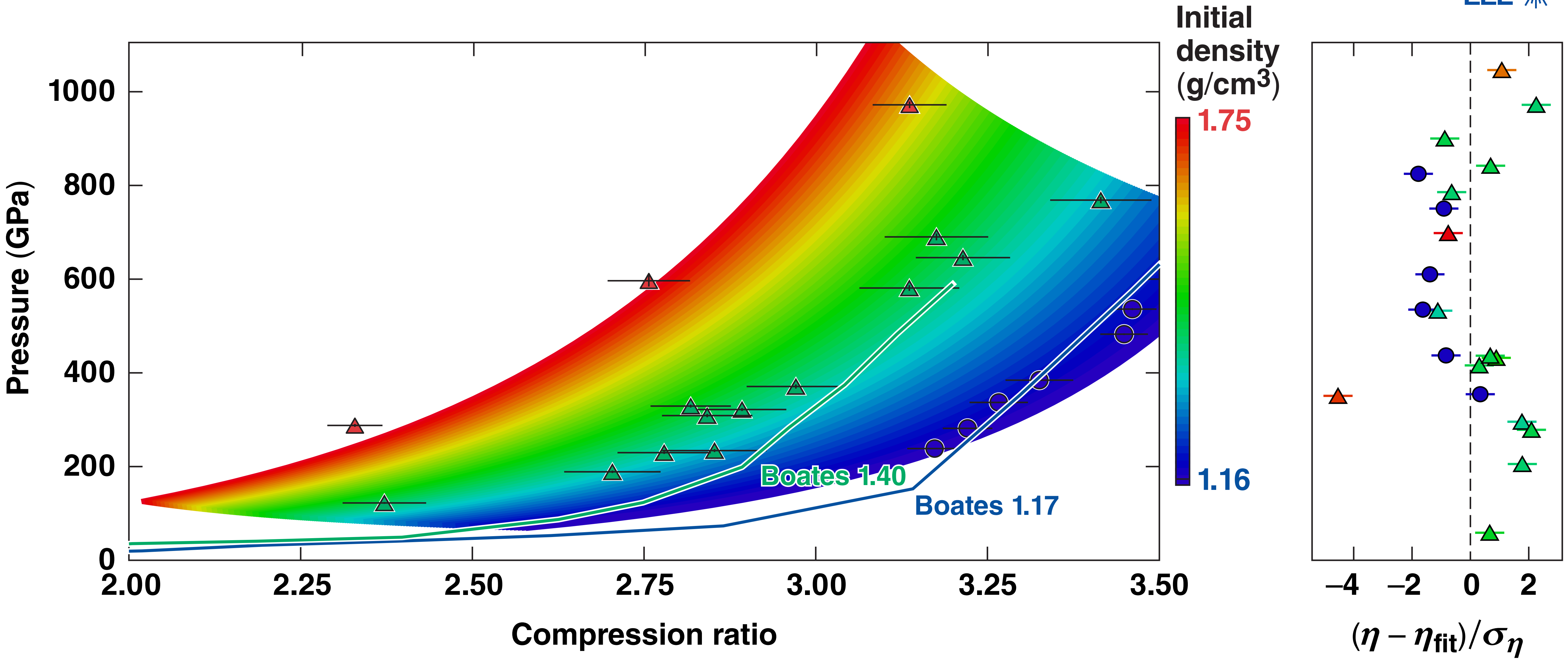
The current model for shocked CO_2 (Boates) predicts a softer behavior than our data indicates



B. Boates *et al.*, J. Chem. Phys. 134, 064504 (2011).

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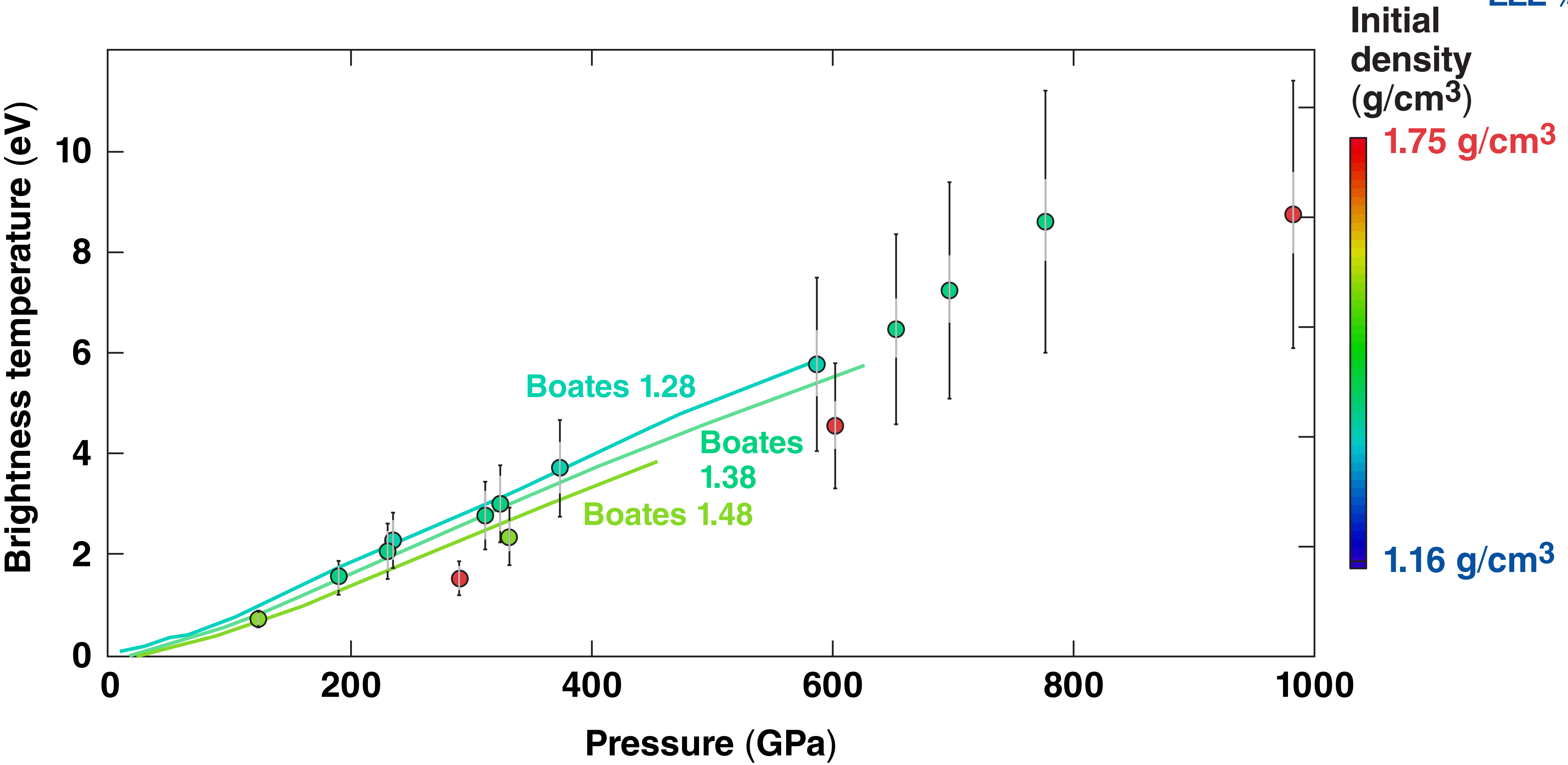
The Boates' model reasonably predicts our observed temperatures; the effect of precompression is less pronounced



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Summary/Conclusions

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- **CO_2 was precompressed in diamond-anvil cells to a liquid at ~1.16 GPa and shock compressed to 980 GPa**
- **Shock velocity and self-emission were measured to provide Hugoniot, reflectivity, and temperature data**
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