Equation-of-State Measurements of Precompressed CO$_2$
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

**Experimental Setup**

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

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

\[ P - P_0 = \rho_0 U_s U_p \]

\[ E - E_0 = \frac{1}{2}(P + P_0)\left(\frac{1}{\rho_0} - \frac{1}{\rho}\right) \]
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Equation-of-state data are obtained from the impedance-matching technique

\[ U_s^Q = a + b U_p^Q - c U_p^Q e^{-d U_p^Q} \]
\[ \alpha = 2.3 - 0.037 U_p^Q \]

M. P. Desjarlais, M. D. Knudson, and K. R. Cochrane, J. Appl. Phys. 122, 035903 (2017);
Equation-of-state data are obtained from the impedance-matching technique

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

\[
U_p = U_{p1} + \int_{p_1}^p \frac{V dP_s}{C_s}
\]

- Mie–Grüneisen linear reference model
- Release isentrope (known standard)

M. D. Knudson and M. P. Desjarlais, Phys. Rev. B 88, 184107 (2013);
Equation-of-state data are obtained from the impedance-matching technique.
Particle velocities were inferred from impedance matching to obtain $U_S(U_P)$.

The $U_s - U_p$ relation for CO$_2$ exhibits linear behavior when accounting for precompression.

\[ U_s = C_0 + sU_p + a \rho_0^{0.5} \]
\[ C_0 = 13.30 \]
\[ s = 1.28 \]
\[ a = -11.98 \]
\[ \chi^2_R = 6.16 \]
In the pressure–compression plane, the effect of precompression is readily apparent.
In the pressure–compression plane, the effect of precompression is readily apparent with the fit $U_s = C_0 + sU_p + a\rho_0^{0.5}$.
The current model for shocked CO$_2$ (Boates) predicts a softer behavior than our data indicates.
The Boates’ model reasonably predicts our observed temperatures; the effect of precompression is less pronounced.

Summary/Conclusions

Precompressed CO$_2$ was shocked to $\sim$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 $\sim$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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