Equation-of-State Measurements of Precompressed CO₂

L. Crandall
University of Rochester
Laboratory for Laser Energetics

60th Annual Meeting of the American Physical Society
Division of Plasma Physics
Portland, OR
8 November 2018
Precompressed CO\textsubscript{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\textsubscript{2}, which may contribute to planetary dynamics
- Shock velocity and self-emission were measured to provide Hugoniot, reflectivity, and temperature data
- Shock-compressed CO\textsubscript{2} exhibits stiffer behavior than predicted by density functional theory (DFT)
- Higher initial density corresponds to a lower specific heat in this regime of CO\textsubscript{2}
Collaborators

J. R. Rygg, G. W. Collins, T. R. Boehly, and M. Zaghoo

University of Rochester
Laboratory for Laser Energetics

P. Celliers, D.E. Fratanduono, M.C. Gregor, A. Jenei, M. Millot, and J. H. Eggert

Lawrence Livermore National Laboratory

D. Spaulding

University of California, Davis
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
Simultaneous VISAR and pyrometer data provided a temporal profile of the shock velocity and temperature.

Results
Simultaneous VISAR and pyrometer data provided a temporal profile of the shock velocity and temperature.
Equation-of-state data are obtained from the *impedance-matching technique*

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

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

*Release isentrope (known standard)*

*To be further discussed: Greg Tabak, LLE U07.00004*

---

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.

\[ U_s = C_0 + sU_p + a\rho_0^{0.5} \]

- $C_0 = 13.30 \pm 0.69$
- $s = 1.28 \pm 0.00020$
- $a = -11.98 \pm 0.91$
- $\chi^2_R = 6.16$
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.

Initial density (g/cm$^3$)

- 1.75
- 1.40
- 1.16

Specific heat capacity, $c_V$, was determined using two methods: The Difference Method

$$c_V \equiv \left( \frac{\partial E}{\partial T} \right)_V \approx \frac{\Delta E}{\Delta T}$$

Specific heat capacity, $c_V$, was determined using two methods:

**The Slope Method**

\[
\begin{align*}
\Delta E_H &= \Delta E_S + \Delta E_V \\
\Delta T_H &= \Delta T_S + \Delta T_V \\
\end{align*}
\]

\[
\{c_V \equiv \left( \frac{\partial E}{\partial T} \right)_V = \frac{\Delta E_H - \Delta E_S}{\Delta T_H - \Delta E_S} = \frac{\left( \frac{\partial E}{\partial V} \right)_H - \left( \frac{\partial E}{\partial V} \right)_S}{\left( \frac{\partial T}{\partial V} \right)_H - \left( \frac{\partial T}{\partial V} \right)_S} \}
\]

Invoke thermodynamic derivatives:

\[
\Gamma \equiv - \left( \frac{V}{T} \right) \left( \frac{\partial T}{\partial V} \right)_S = V \left( \frac{\partial P}{\partial E} \right)_V
\]

\[
P \equiv - \left( \frac{\partial E}{\partial V} \right)_S
\]

Yields:

\[
c_V = \frac{\left( \frac{\partial E}{\partial V} \right)_H + P}{\left( \frac{\partial T}{\partial V} \right)_H + \frac{\Gamma T}{V}}
\]

Preliminary results indicate that initial conditions strongly affect specific heat.
Precompressed CO₂ was shocked to ~1 TPa and is less compressible than predicted by current models

- Ice giants (Uranus, Neptune) and their moons (Triton) contain CO₂, which may contribute to planetary dynamics
- Shock velocity and self-emission were measured to provide Hugoniot, reflectivity, and temperature data
- Shock-compressed CO₂ exhibits stiffer behavior than predicted by density functional theory (DFT)
- Higher initial density corresponds to a lower specific heat in the regime of CO₂