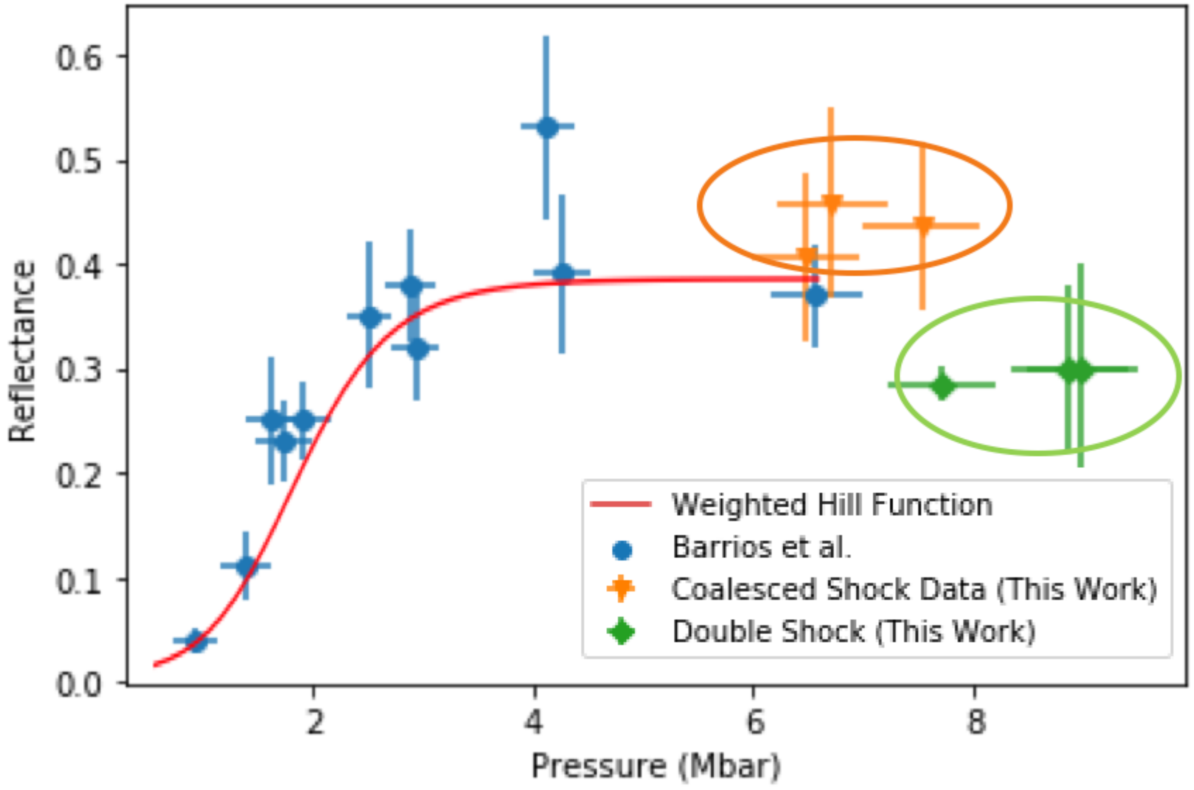
Double Shock Compression in Polystyrene to ~8 MBar



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We observe doubly shocked states in polystyrene (CH) up to pressures of ~8 Mbar and temperatures of 3 eV

- Double shocks allow us to explore off-Hugoniot states of materials pertinent to planetary and ICF physics
- Our doubly shocked CH data shows cooler, less dense, and less reflective states than those on the principal Hugoniot for similar pressures
- Using a Drude Model we infer that the reduced reflectivity is a result of the lower ionization in the cooler and denser double-shock states and compare these data to similar experiments on CH

Double Shock Compression allows us to probe states off a material's Principal Hugoniot

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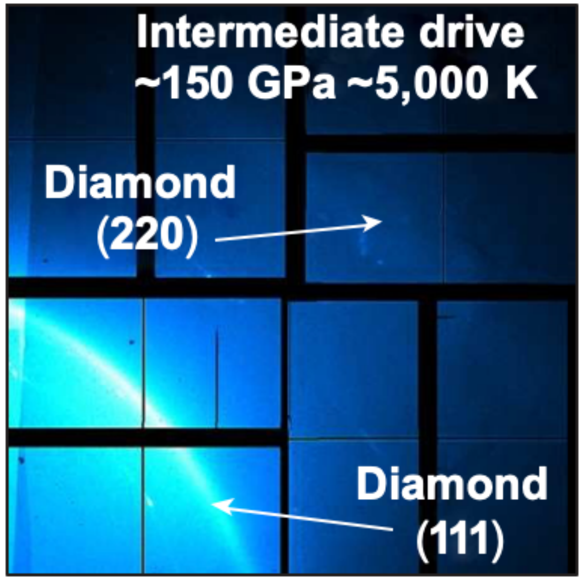
- Recent studies have observed diamond formation in doubly shocked polystyrene, an important result for the study of ice giant interiors

- This result has important implications for ICF where it is thought that formation of diamond in CH ablators lends itself to RT instability growth



High-pressure chemistry of hydrocarbons relevant to planetary interiors and inertial confinement fusion

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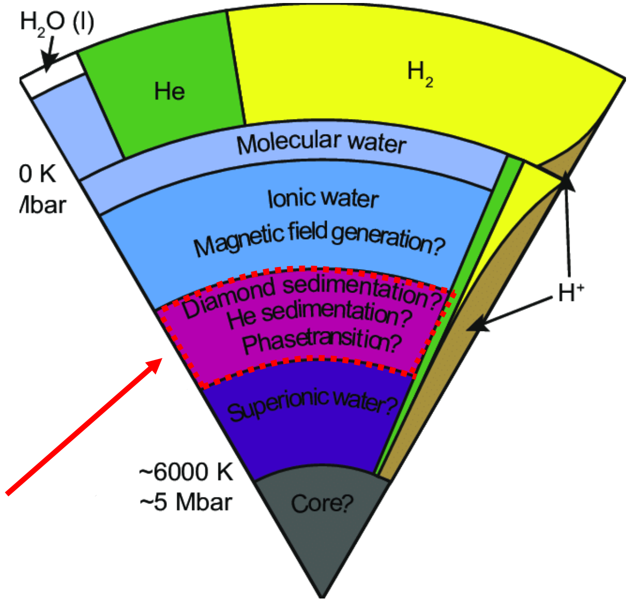
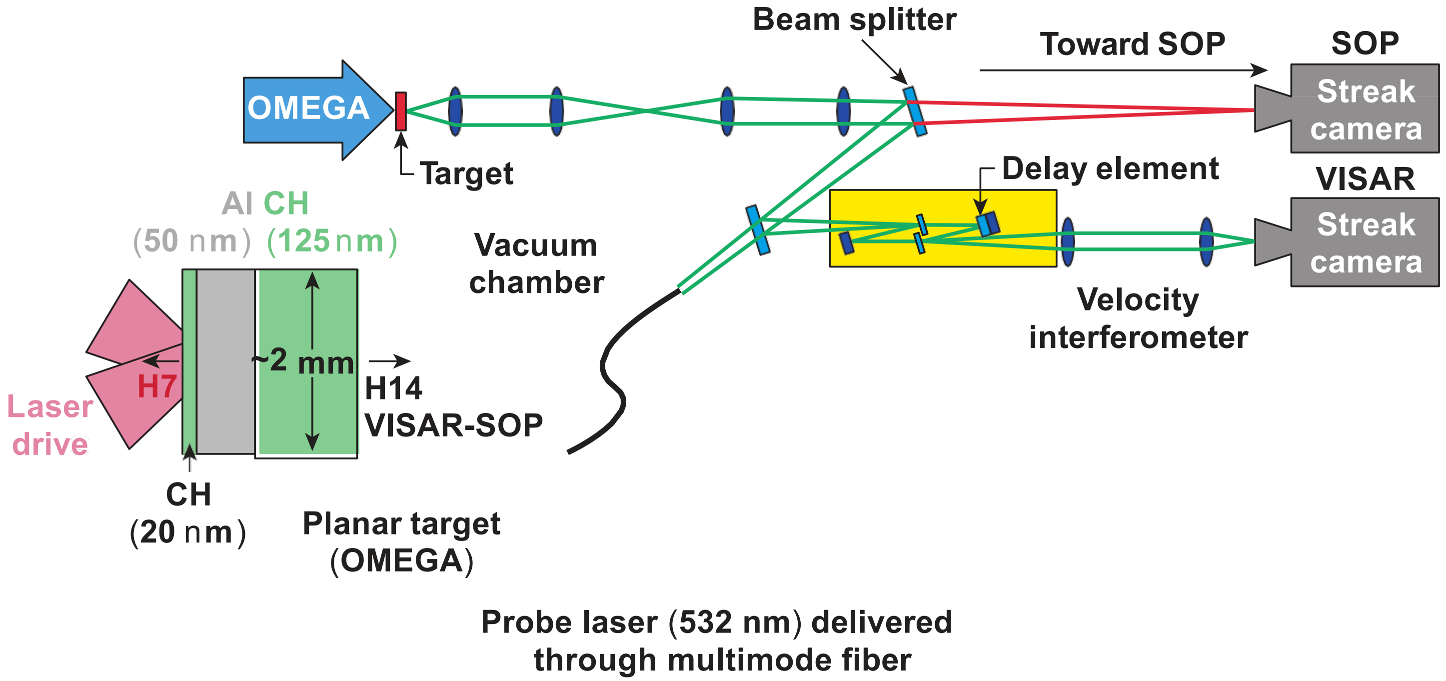


C.S. Arridge et al. / Planetary and Space Science 104 (2014) 122–140123

ICF: Inertial Confinement Fusion

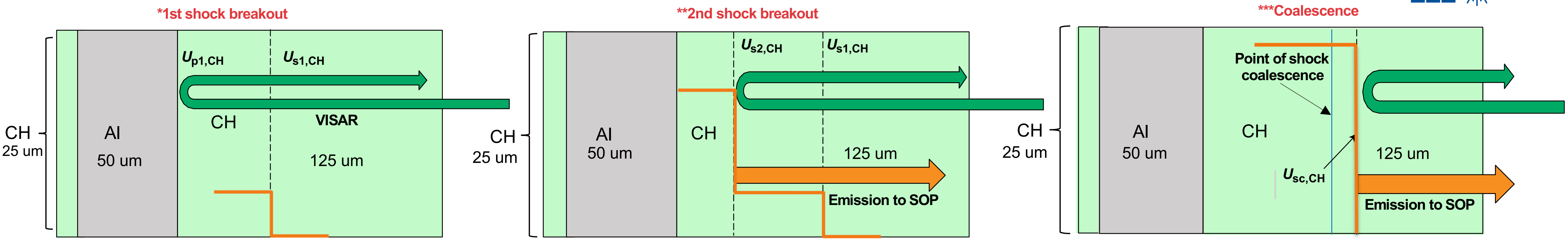
VISAR traces the motion of reflective surfaces while SOP records shock self-emission

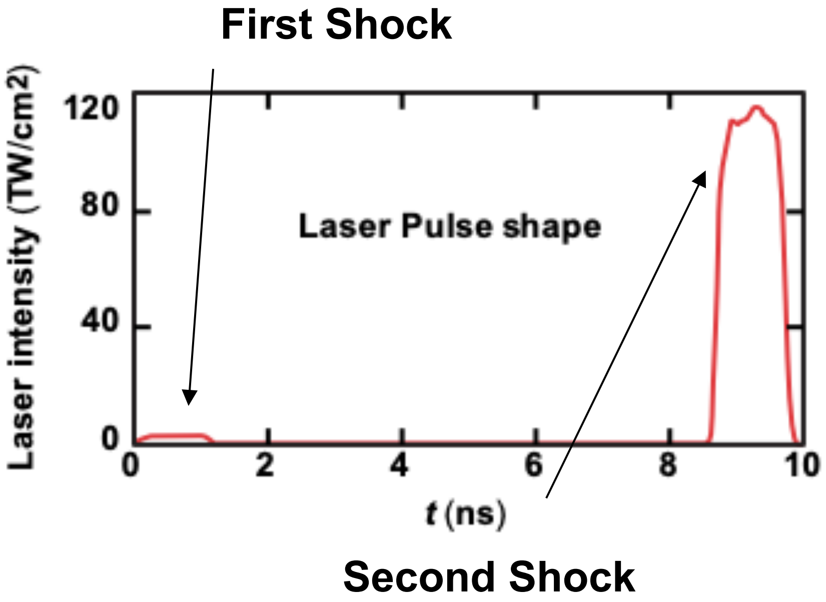


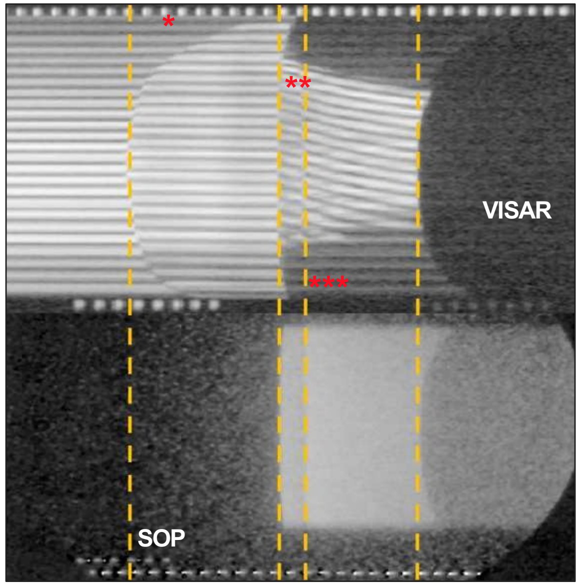
- A 532-nm laser probes reflecting shocks and surfaces
- Temperature data are obtained by SOP

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

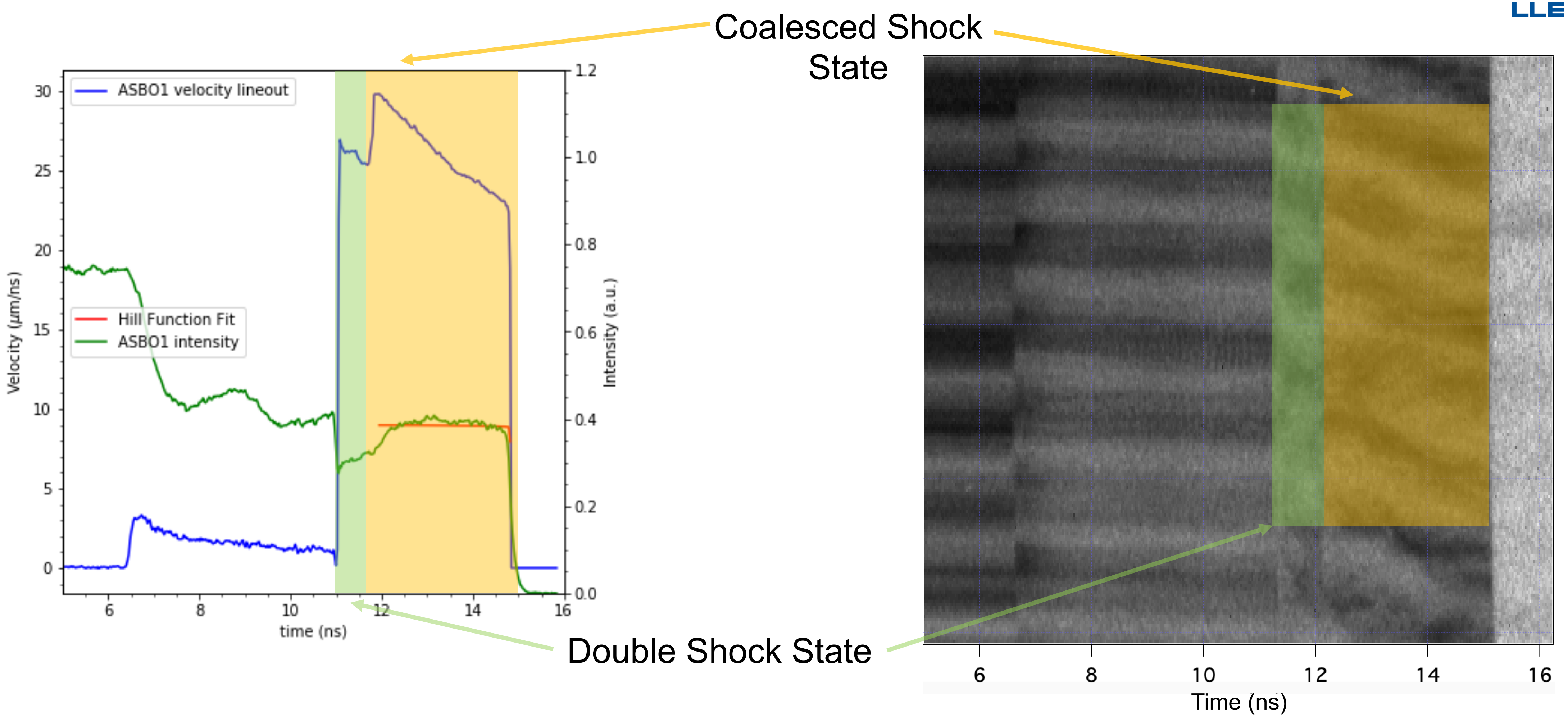
VISAR is able to detect the single, double, and coalesced shocks in our experiment







Shock velocity and reflectivity are obtained from VISAR



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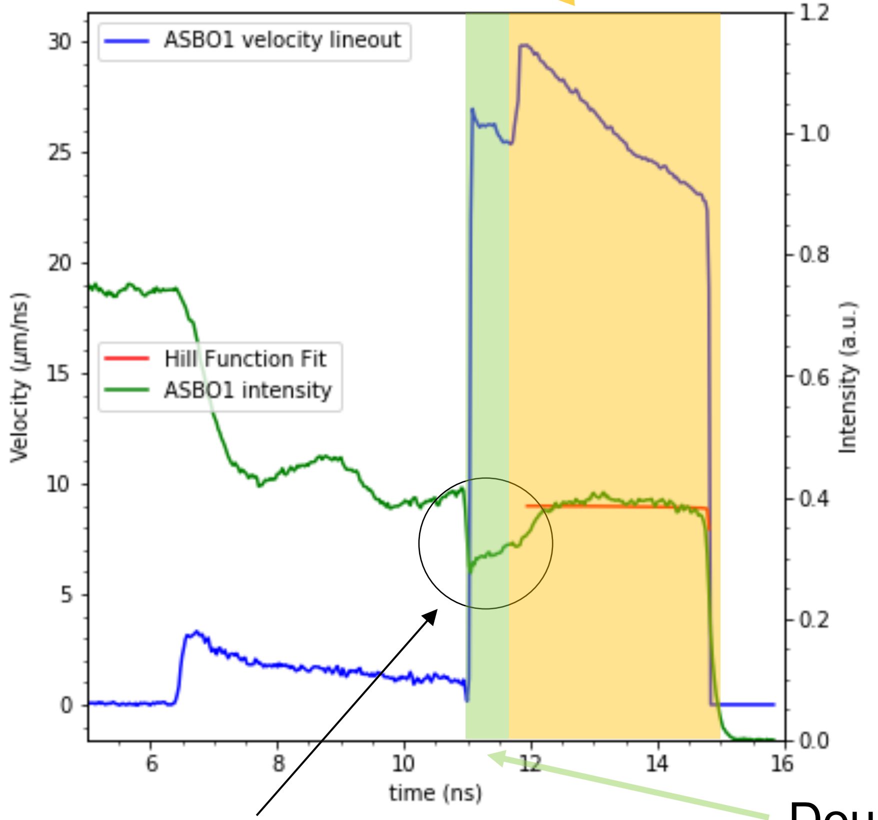
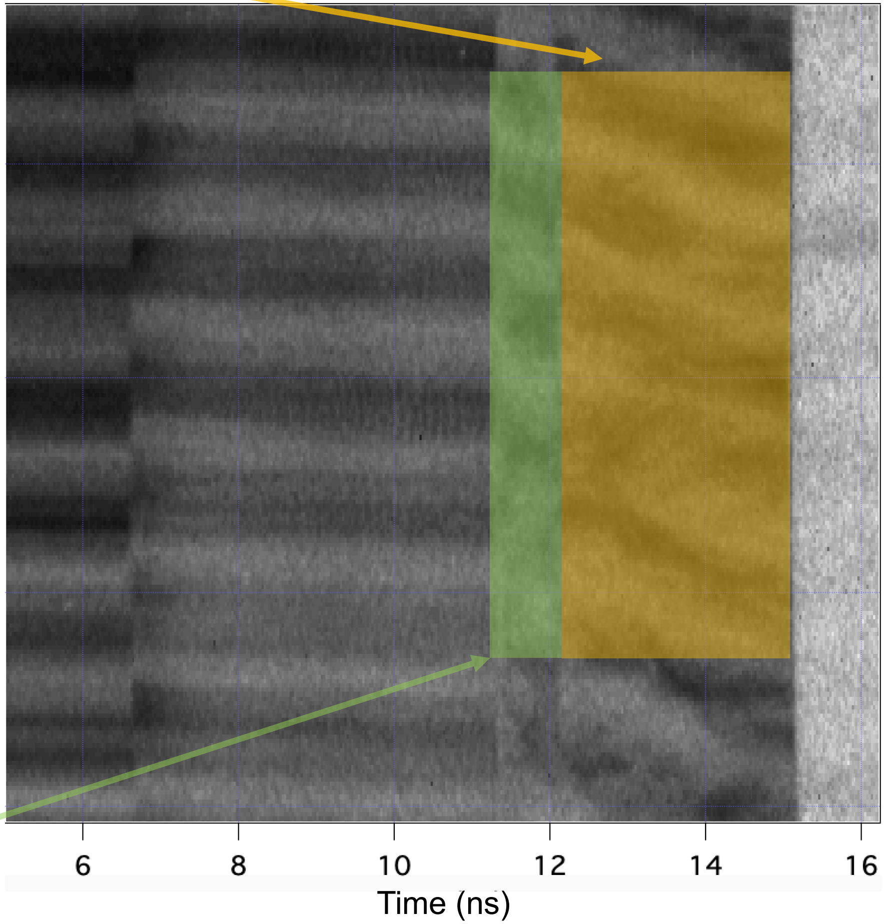


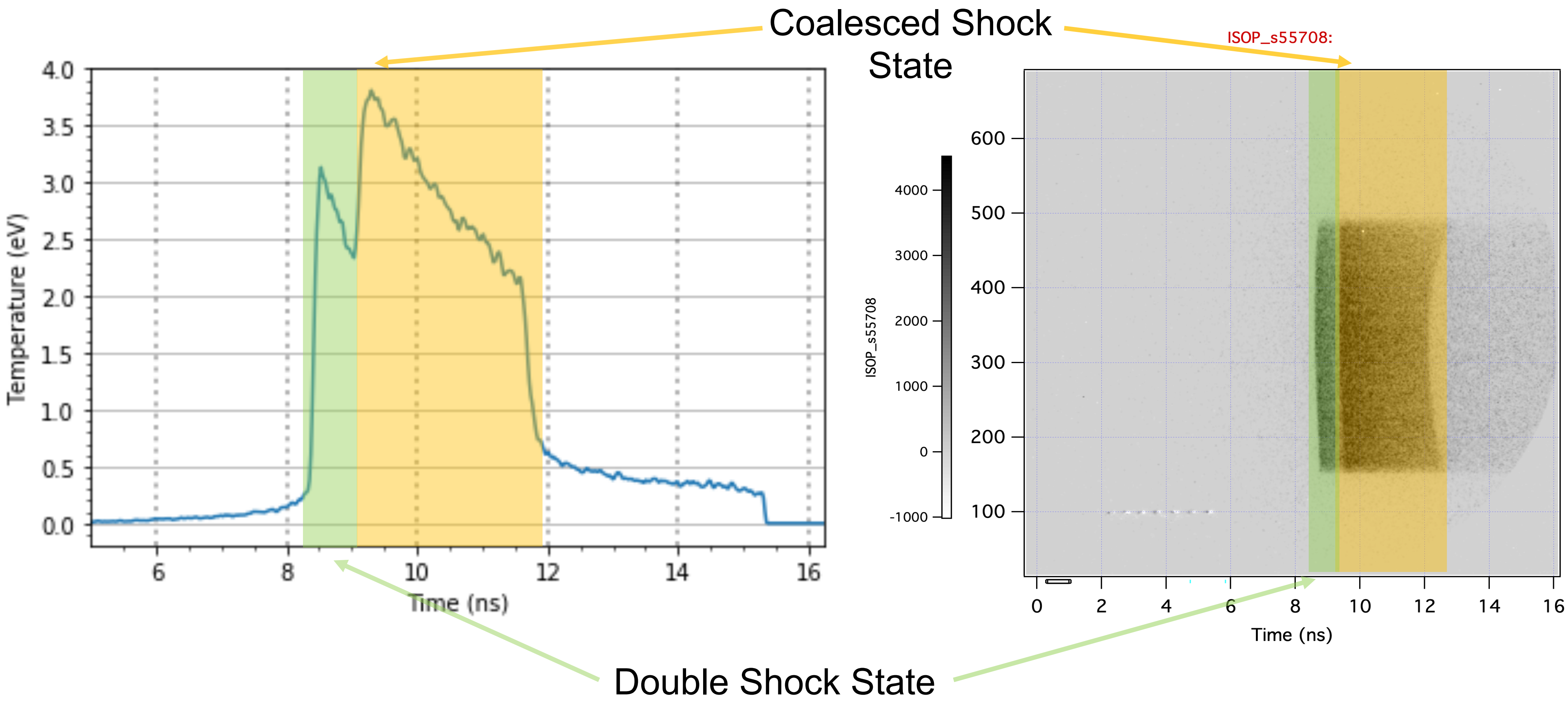
Coalesced Shock State

Double Shock State

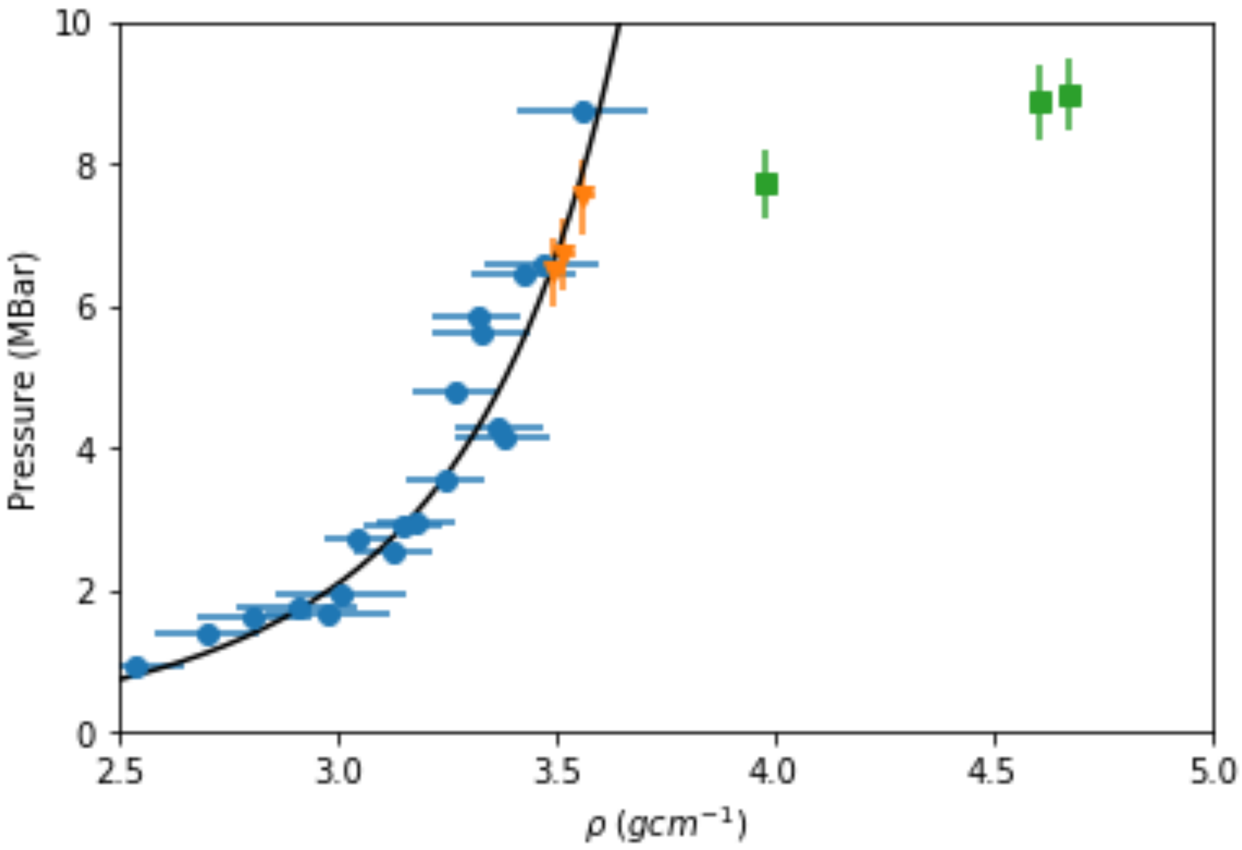


Double shock state shows significant drop in reflectance

We use SOP to infer temperature



We observe double shocked states with densities of ~4.0 g/cc up to ~4.7 g/cc



- We use published EOS to obtain single-shock state[1]
- To obtain the pressure and density of the double shocked states we use a self impedance matching[2]

[1]Barrios et al. 2010
[2]Guargaglini et al. 2019

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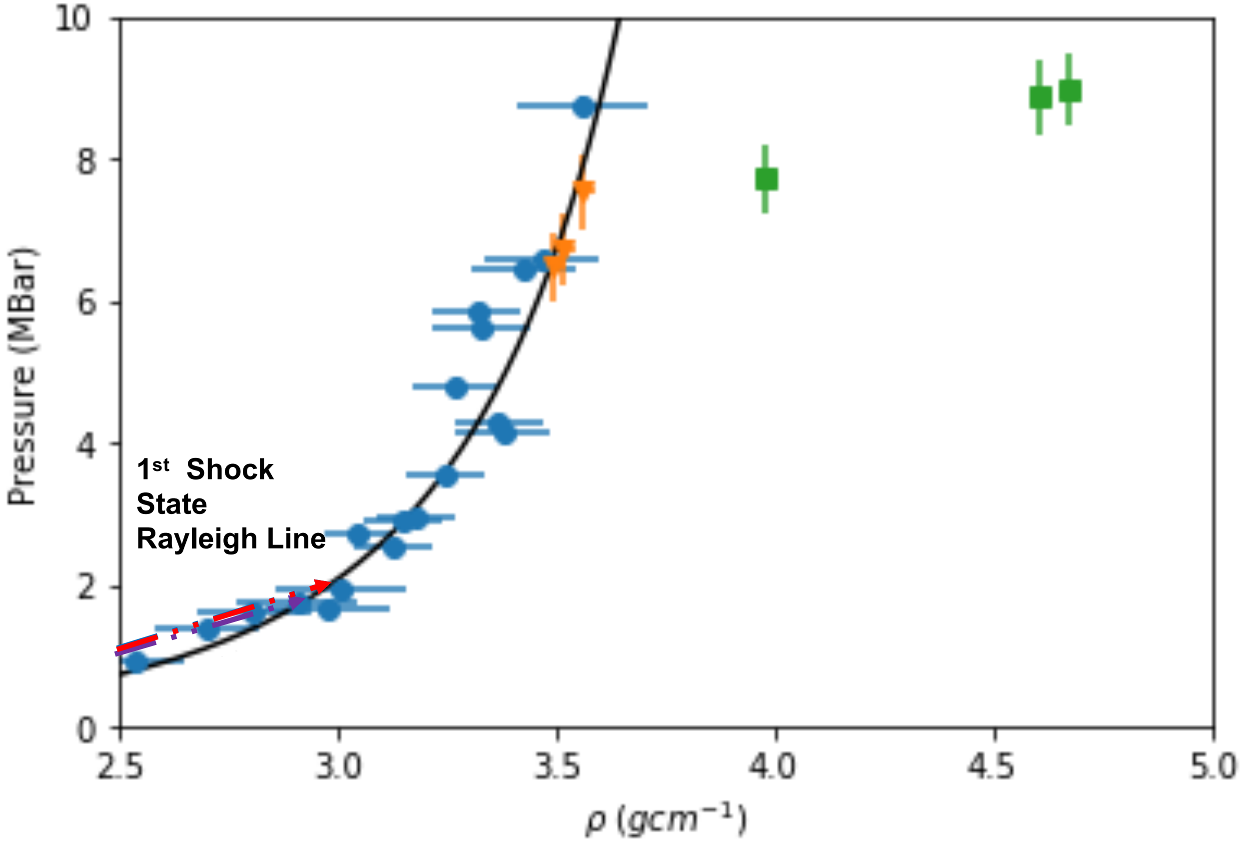

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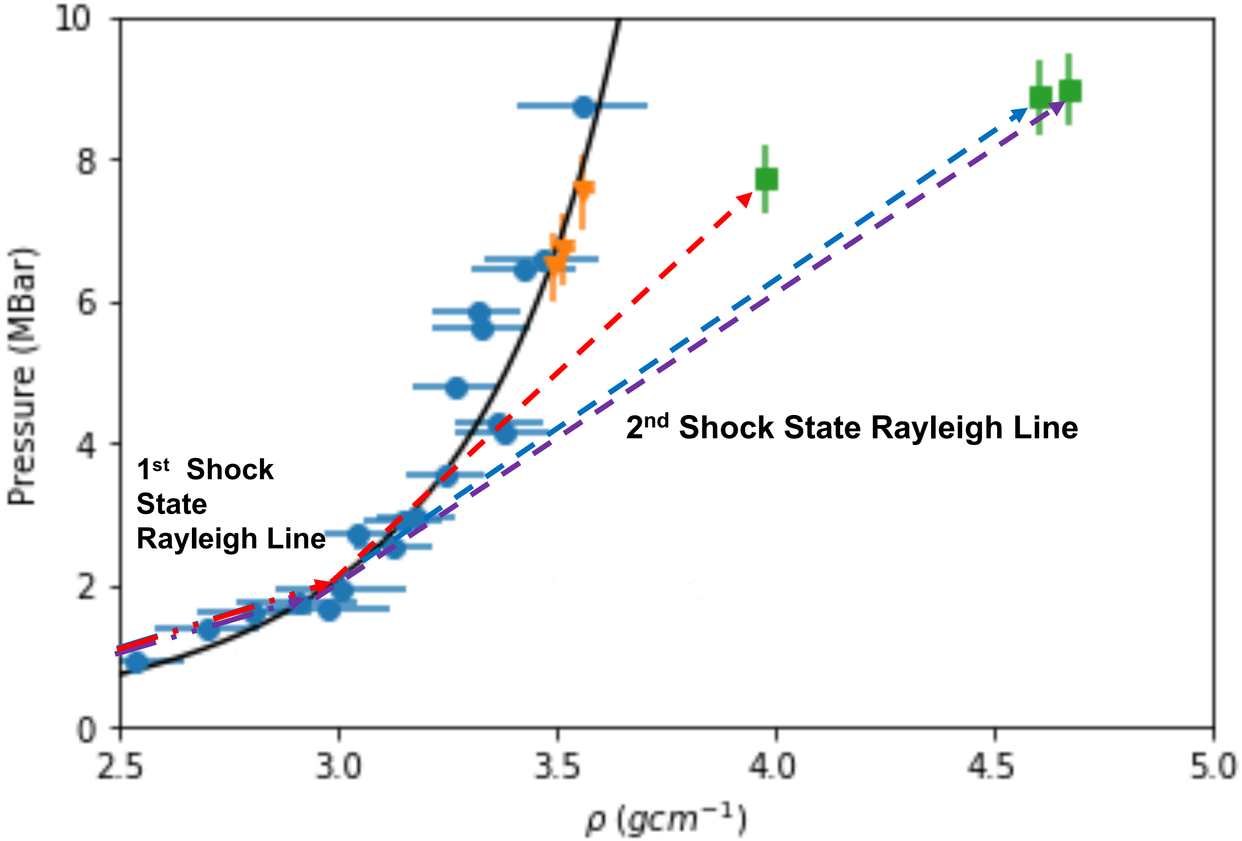

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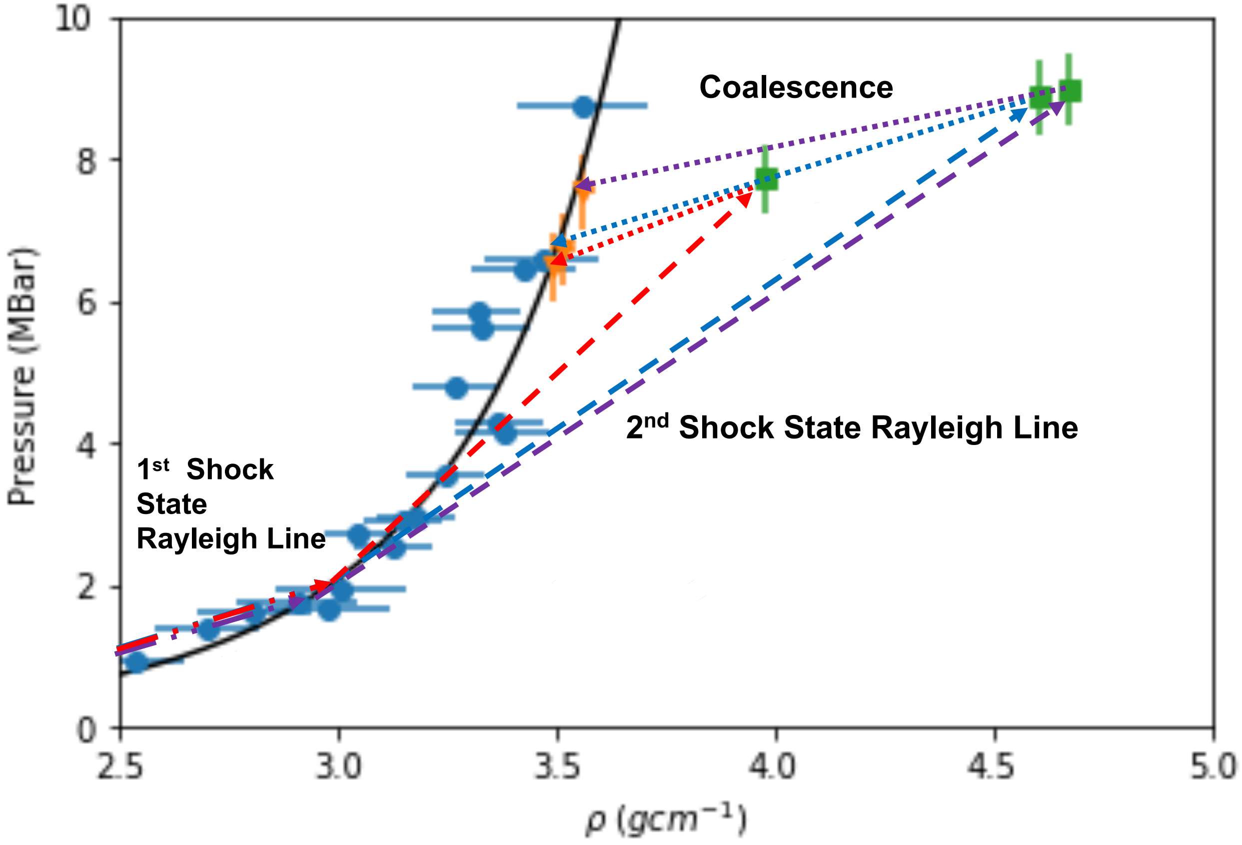

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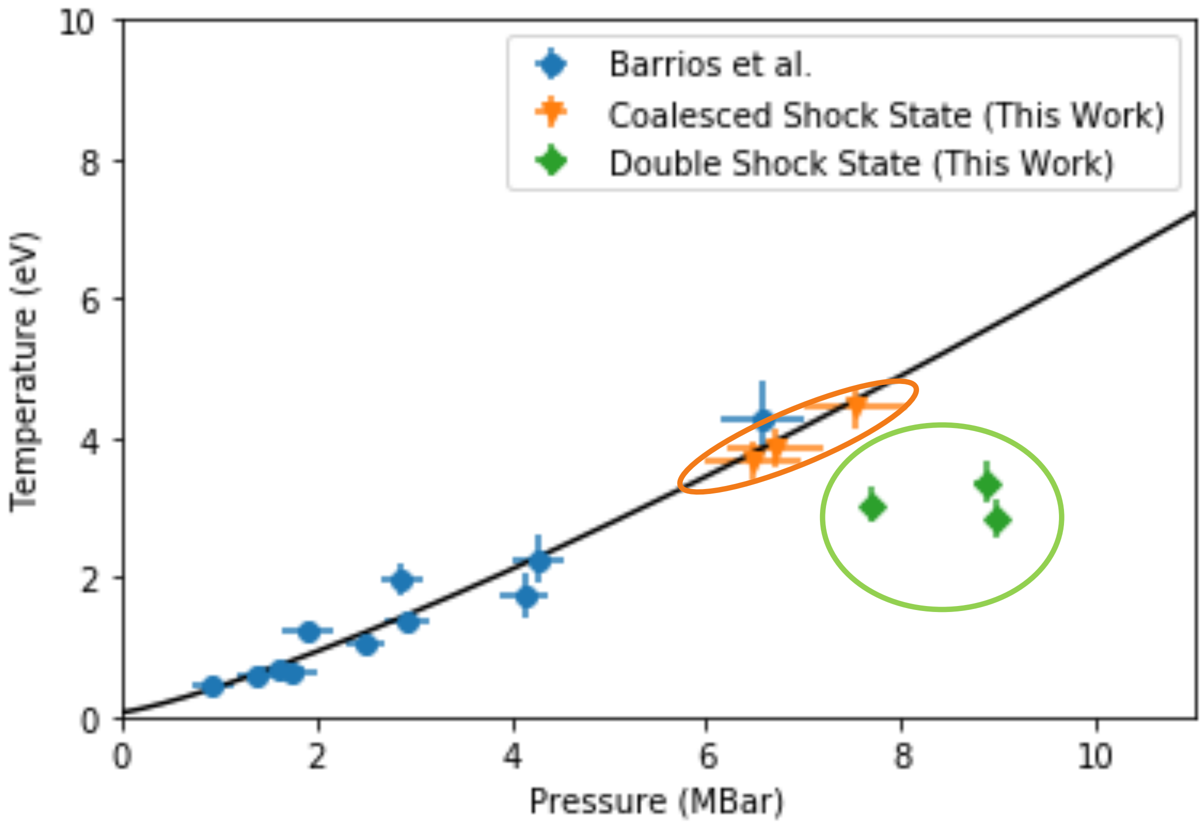
We observe temperatures around 3 eV for the double shocked states and 4 eV for coalesced states



- We use published EOS to obtain temperatures of single-shock state[1]

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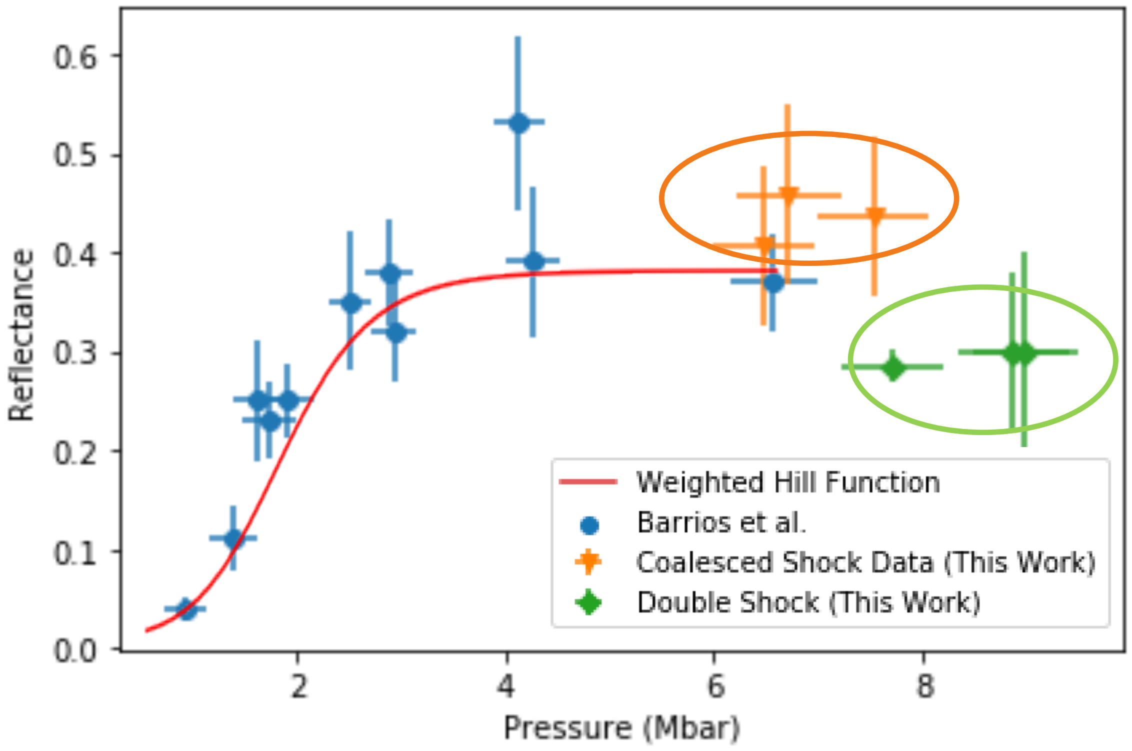
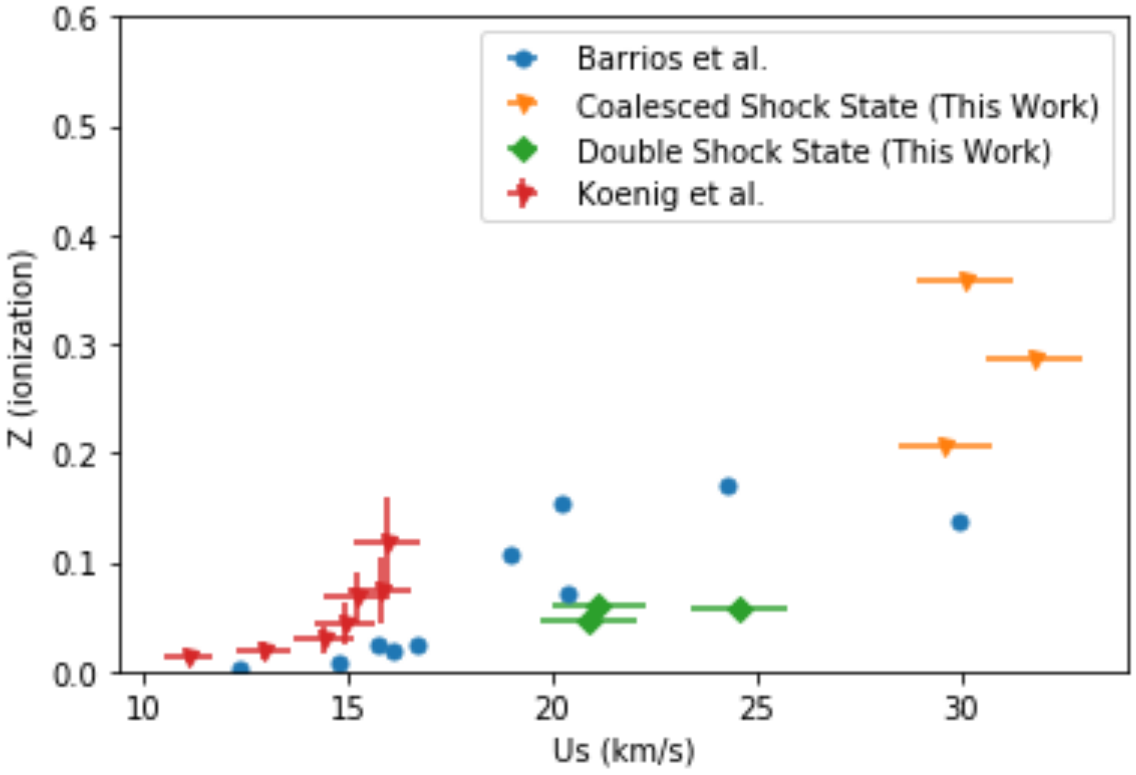
Reflectivity of states on Principal Hugoniot saturates at ~40% while for double shocked states we observe reflectivity at ~30%



- Double shock reflectivity is significantly lower that that of single shock CH

Using a Drude Model we infer the ionization *Z* in our singly shocked and double shocked states



- We assume a fully dissociated CH throughout the shock, $\boldsymbol{R = f(n_e), n_e = Z * n_i}$
- The inferred ionization $Z \equiv \frac{n_e}{n_i}$ was:

  ~0.3 e⁻/scatterer for coalesced shocks

  ~0.05 e⁻/scatterer for double shocks

We observe doubly shocked states in polystyrene (CH) at pressures of ~8 Mbar and temperatures of 3 eV

- Double shocks allow us to explore off-Hugoniot states of materials pertinent to planetary and ICF physics
- Our doubly shocked CH data shows cooler, less dense, and less reflective states than those on the principal Hugoniot
- Using a Drude Model we infer that the reduced reflectivity is a result of the lower ionization in the cooler and denser double-shock states and compare these data to similar experiments in the literature

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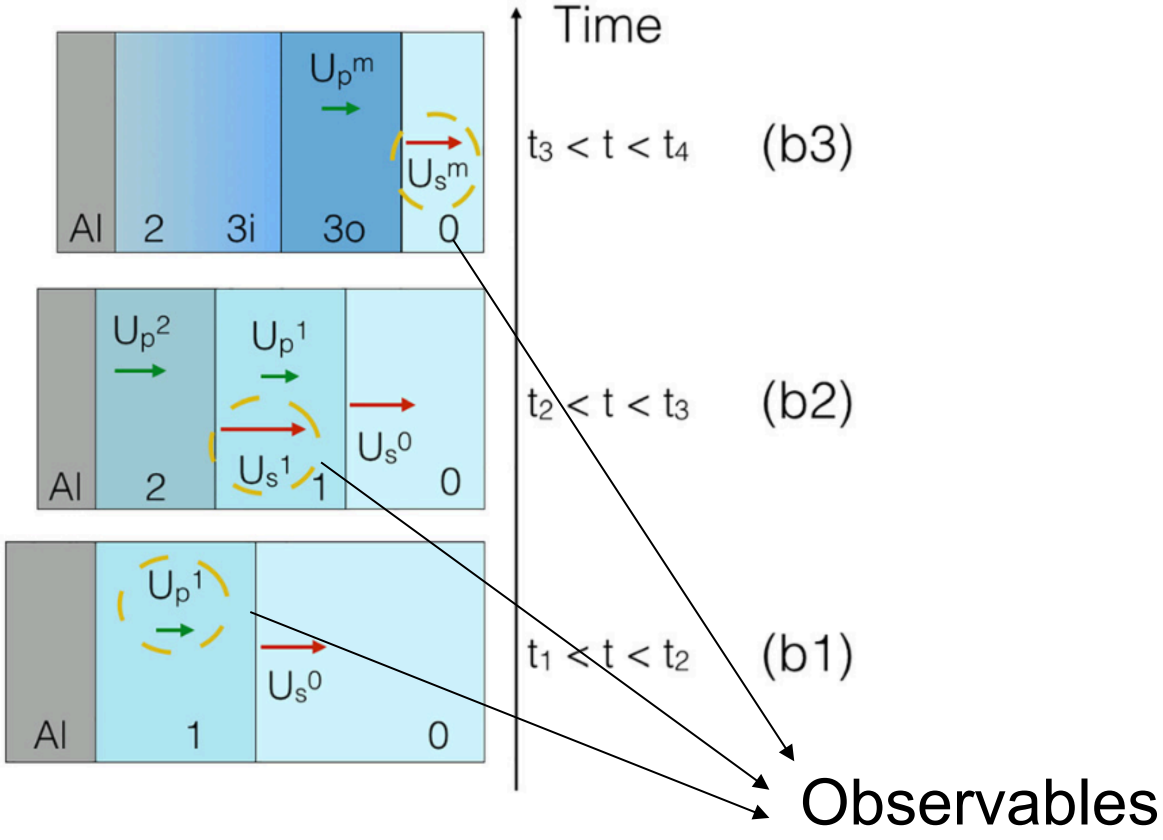
Guarguaglini Self-Impedance Match

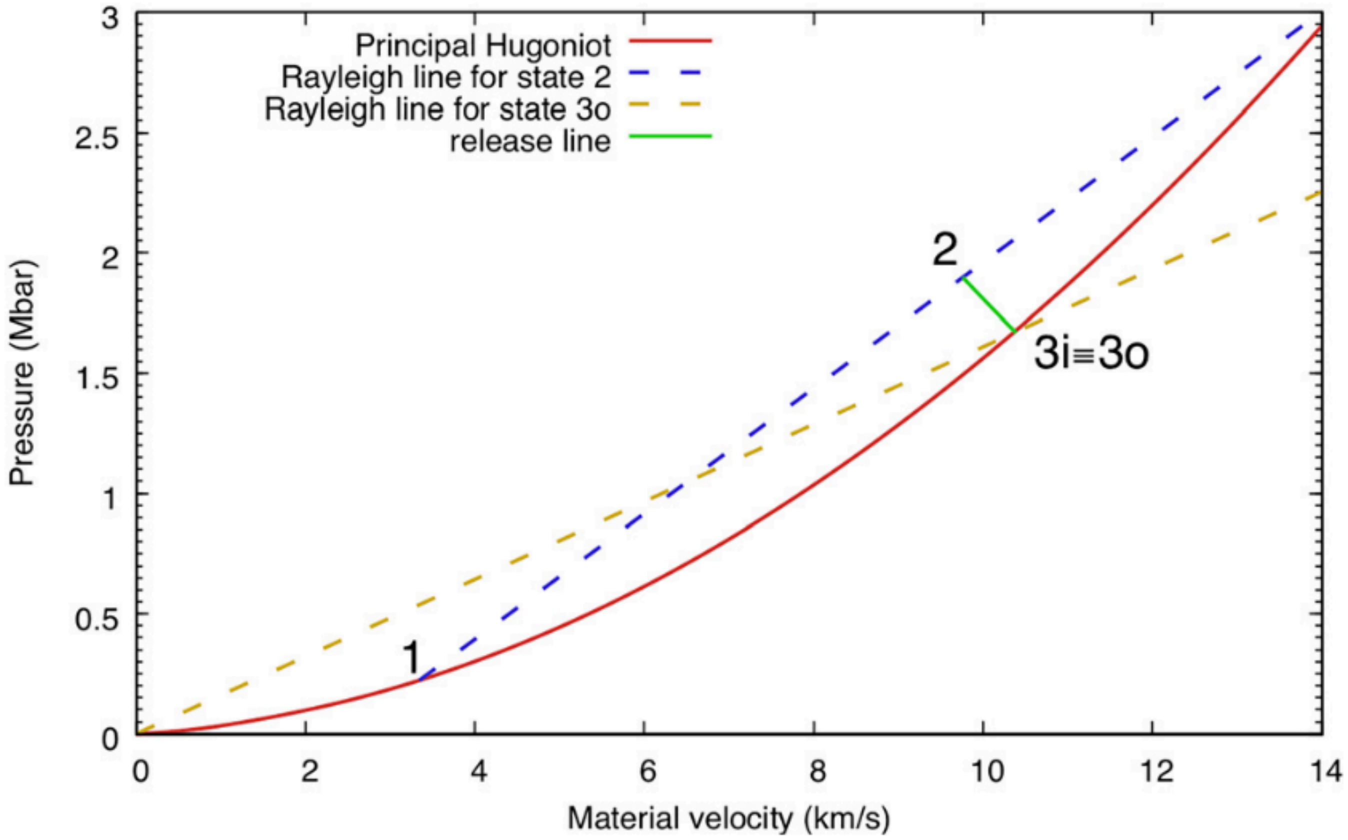


Schematic picture of the shocked target for:

$t_1 < t < t_2$ (b1)
$t_2 < t < t_3$ (b2)
$t_3 < t < t_4$ (b3)

Guarguaglini Self-Impedance Match

- Self-impedance mismatch analysis in the (Up, P) plane for the determination of the double-shocked state
- States 3i and 3o have the same pressure and material velocity



Guarguaglini Self-Impedance Match

Rayleigh Line for State 2

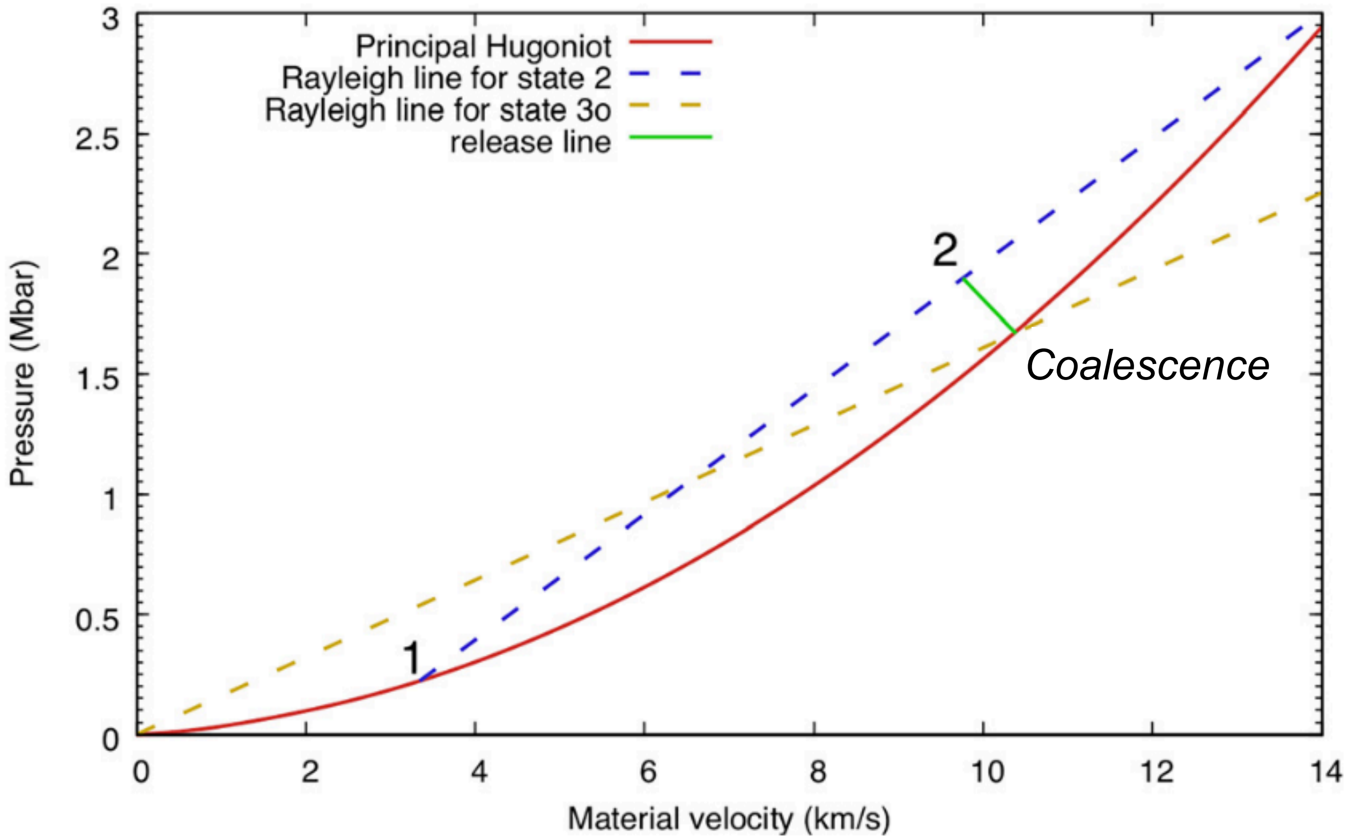
$$P(U_p) = P_1 + \rho_1(U_{s2} - U_{p1})(U_p - U_{p1})$$

Rayleigh Line for Coalescence

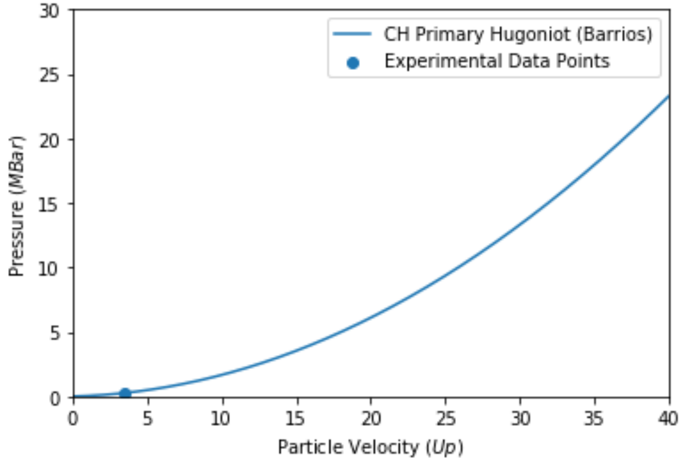
$$P(U_p) = \rho_0 U_{sc} U_p$$

-To model the transition from state 2 to state 3i, **the adiabatic release path must be followed starting from 3o** (the Hugoniot state corresponding to 3i in pressure and material velocity).

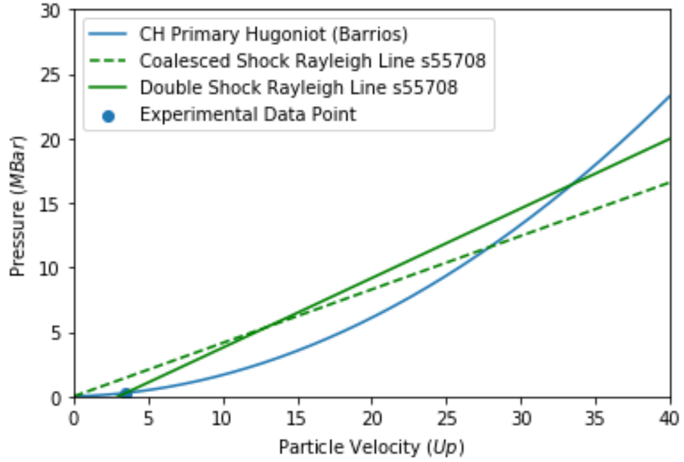
-If the adiabatic release line of the material crossing state 3o is not known, **a suitable approximation consists in taking the mirror reflection of the principal Hugoniot with respect to the line $U_p = U^{3o}$**



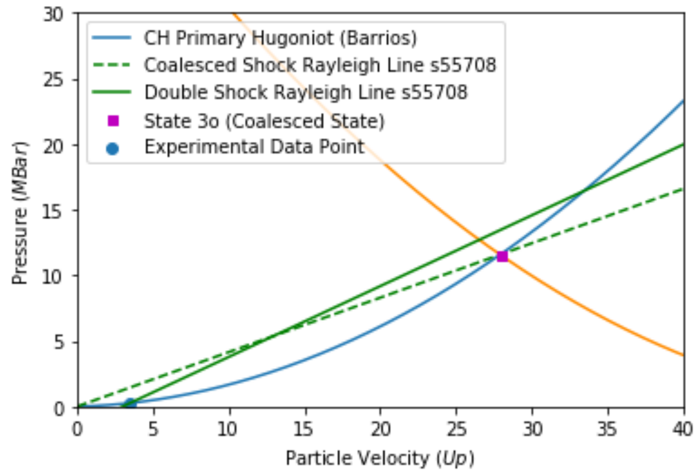
Data (s55708)



CH Primary Hugoniot (Barrios)
Experimental Data Points
Pressure (MBar)
Particle Velocity (Up)



CH Primary Hugoniot (Barrios)
Coalesced Shock Rayleigh Line s55708
Double Shock Rayleigh Line s55708
Experimental Data Point
Pressure (MBar)
Particle Velocity (Up)



CH Primary Hugoniot (Barrios)
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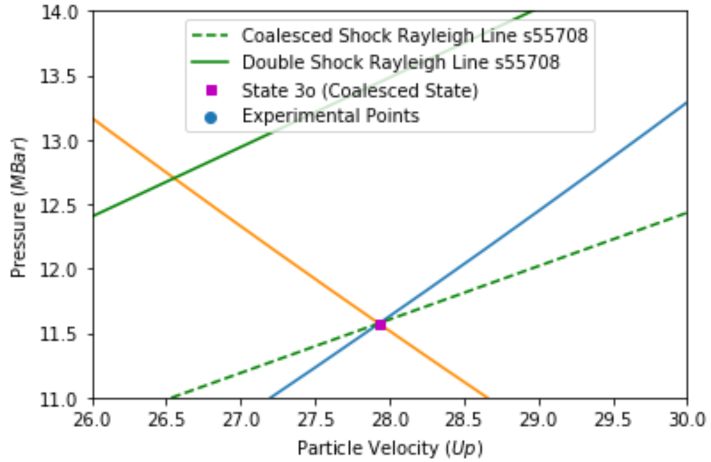
Double Shock Rayleigh Line s55708
State 3o (Coalesced State)
Experimental Data Point
Pressure (MBar)
Particle Velocity (Up)



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Double Shock Rayleigh Line s55708
State 3o (Coalesced State)
Experimental Points
Pressure (MBar)
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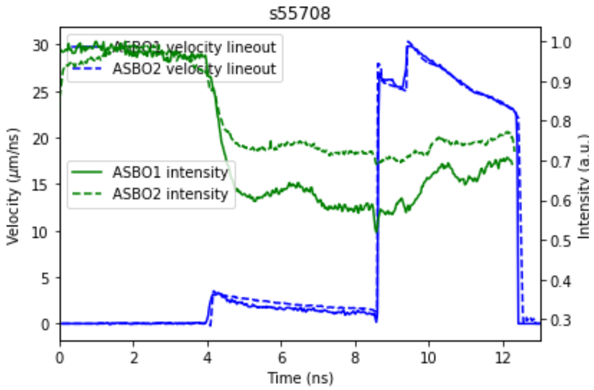
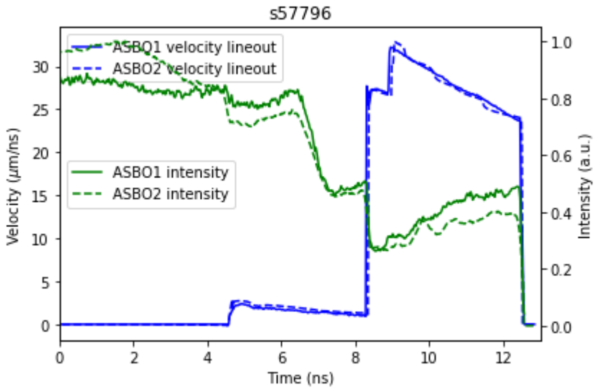
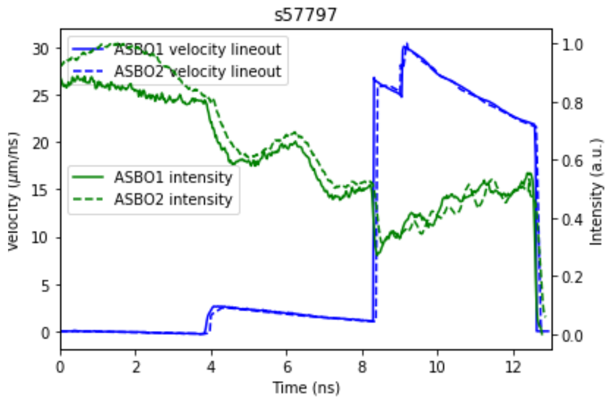
Preliminary Data



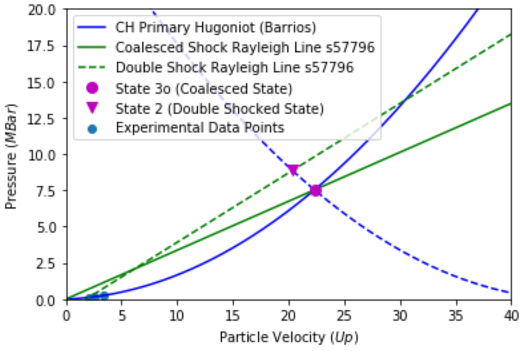


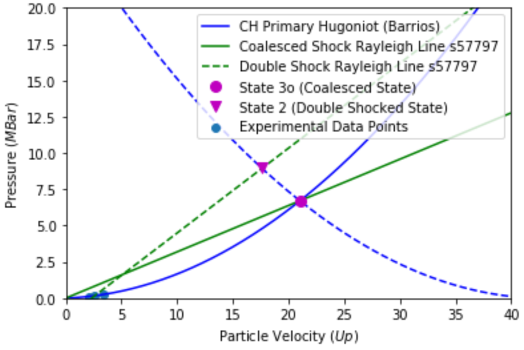


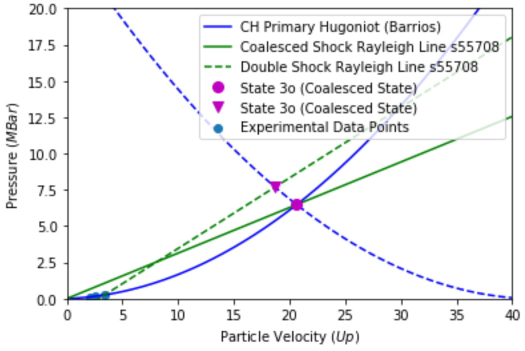
u_{p1} = 3.4 km/s
v_{s2} = 27.2 km/s
v_{s3} = 29.6 km/s

u_{p1} = 2.06 km/s
v_{s2} = 27.5 km/s
v_{s3} = 31.8 km/s

u_{p1} = 2.6 km/s
v_{s2} = 24.9 km/s
v_{s3} = 30.1 km/s







P_2 = 7.71 MBar
P_{3o} = 6.47 MBar

P_2 = 8.87 MBar
P_{3o} = 7.53 MBar

P_2 = 8.98 MBar
P_{3o} = 6.71 MBar

Semiclassical Drude Model

Using the Drude Model, we can express the dc conductivity as a function of n_e, the carrier density, as follows:

$$\sigma_0 = n_e e^2 \tau_e / m_e$$

The *complex* conductivity is given below:

$$\sigma(\omega) = \frac{\sigma_0}{(1 - i\omega t)}$$

Assuming that the shock fronts can be taken as Fresnel reflectors, i.e.

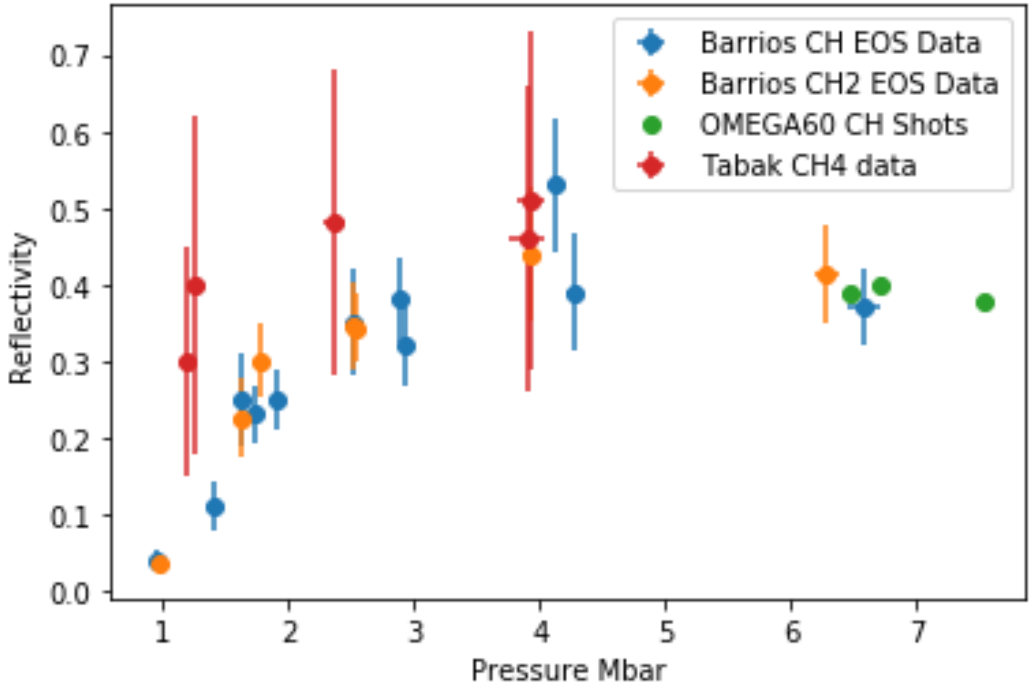
$$\boldsymbol{R(n_e) = \left|\frac{n_0 - \tilde{n}\,(\omega)}{n_0 + \tilde{n}\,(\omega)}\right|^2}$$

Taking advantage of the following equivalence, the ionization Z, (and equivalently the electron density n_e = Zn_i), can be obtained self-consistently by fitting the reflectivity and subsequently the dc conductivity:

$$n(\omega)^2 = \varepsilon_b - \frac{\omega_p(n_e)^2}{\omega^2}\left(1 + \frac{i}{\omega\tau_e}\right)^{-1} = 1 + i\,\sigma(\omega)/\varepsilon_0\omega$$

$$\omega_p(n_e)^2 = \frac{n_e e^2}{m_e \varepsilon_0} \qquad \tau_e = \frac{R_0}{v_f} \text{ (Ioffe-Regel limit)}$$

The parameter Z is varied until model R(532) matches observed reflectivity



- The observed reflectivity of the double shocked states fall significantly below the saturated reflectivity of ~40% observed in the literature
- This, coupled with the lower density and cooler temperatures observed, give insight into the interesting carbon/hydrogen chemistry in these regimes

BACKUP SLIDE