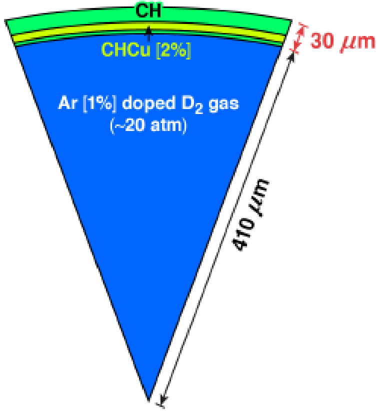
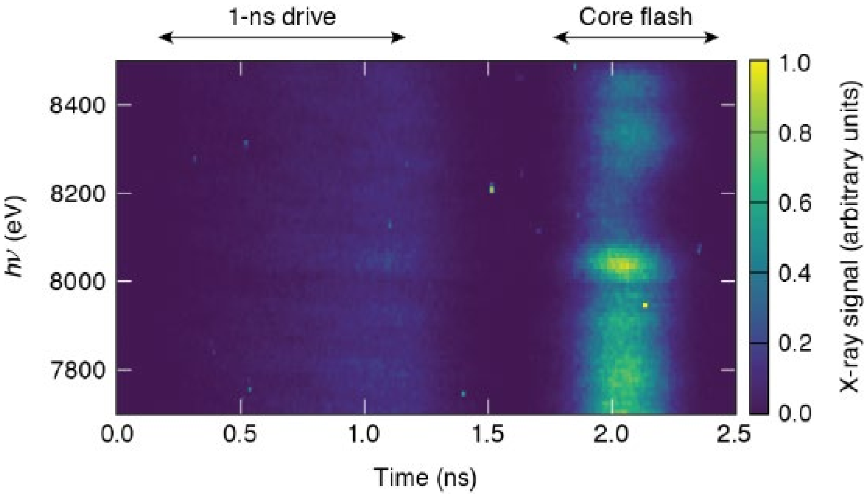
Extreme Atomic Physics in Plasma Mixtures at Gbar Pressure





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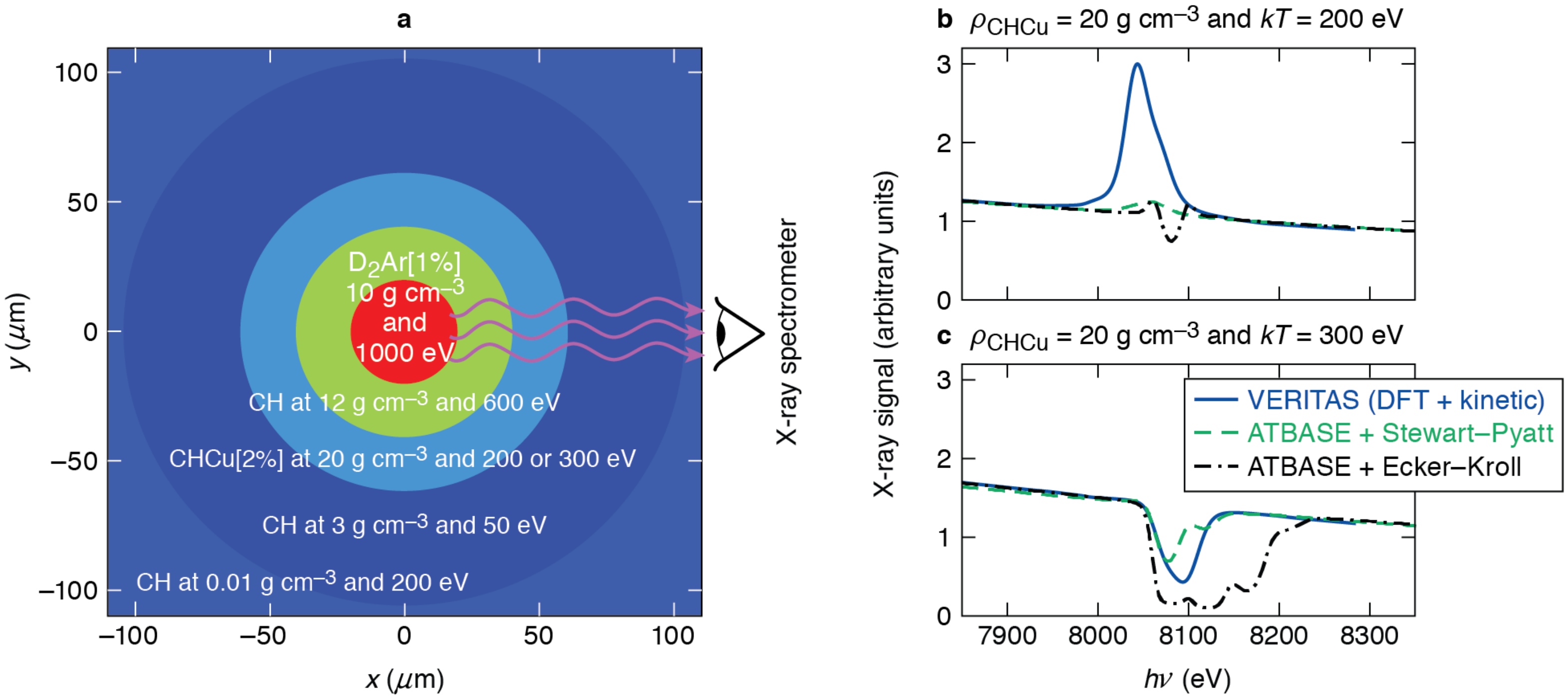
A reliable atomic physics model is essential to interpret x-ray spectroscopy signals for diagnosing dense plasmas



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DFT: Density-Functional Theory ; **ATBASE**: Atomic Database

Convergent-geometry on OMEGA can provide a platform to do x-ray spectroscopy at ultra-high pressure for testing our understanding of atomic physics in dense plasmas

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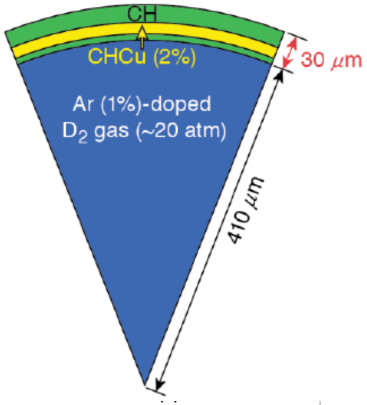
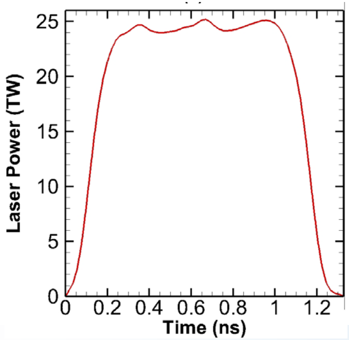
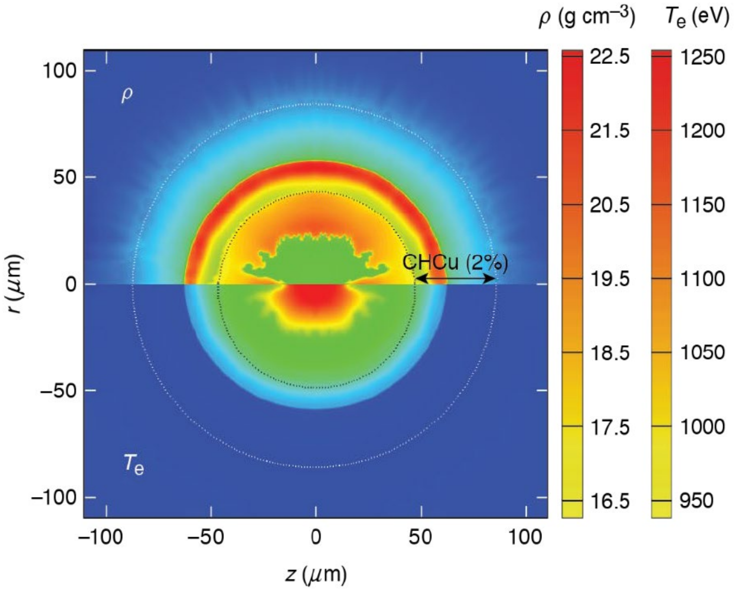
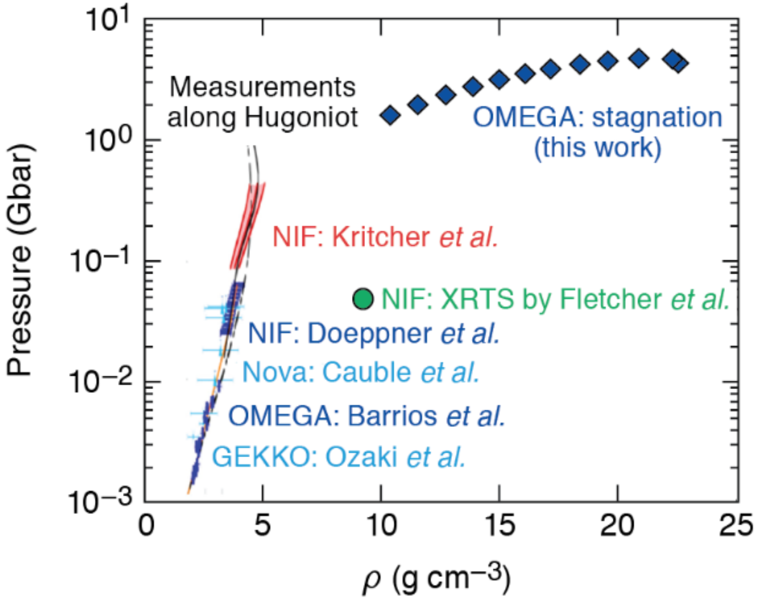




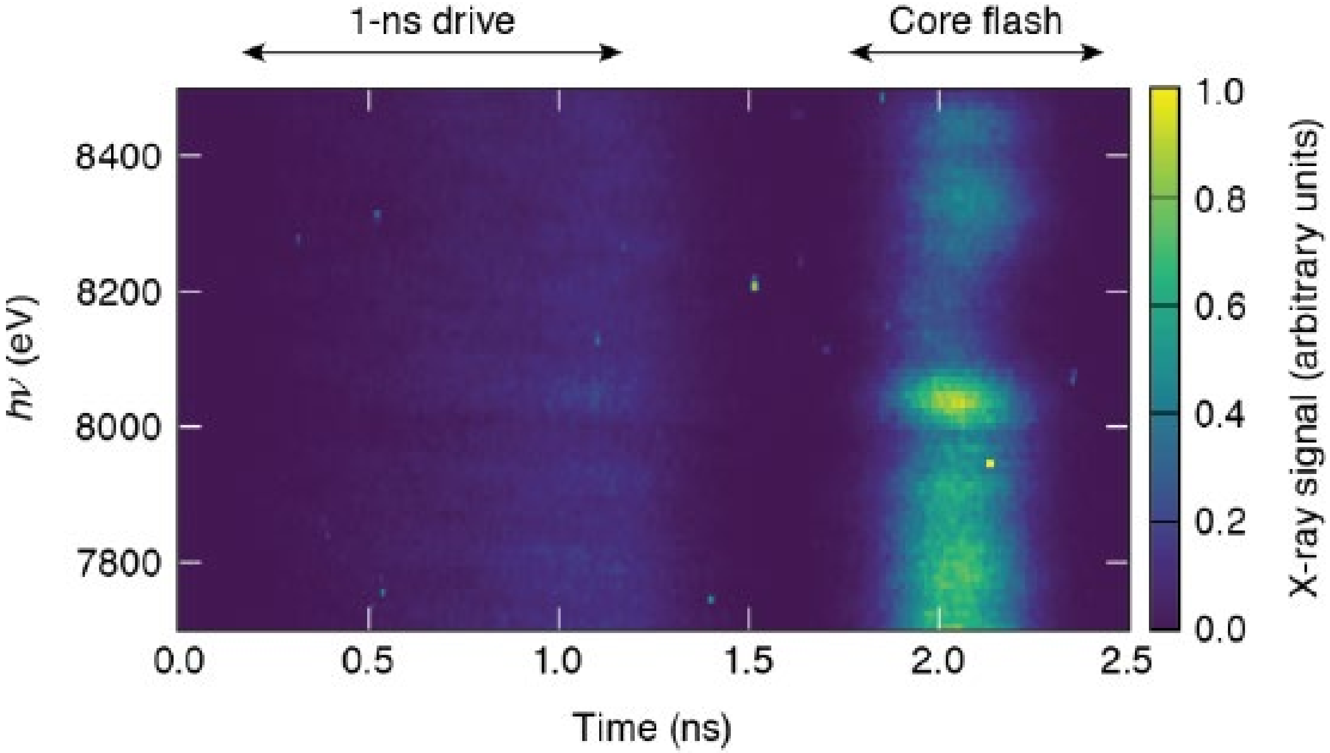
Radiation-hydrodynamic simulations with *DRACO* indicate ~Gbar pressure in the stagnating shell (CHCu-mixture)



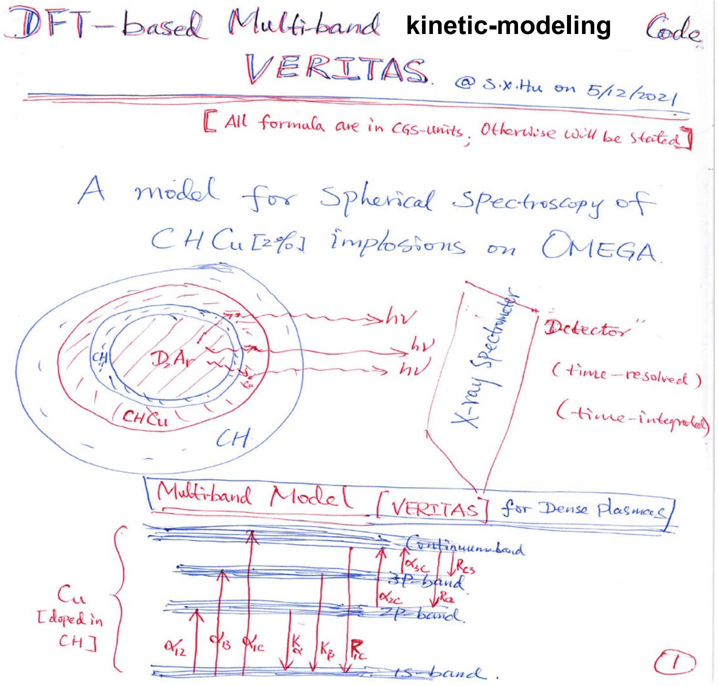


The hot-spot radiation serves as "*backlighter*" for x-ray spectroscopy measurements of the stagnating plasma

Both time-integrated and time-resolved x-ray spectroscopic measurements were conducted through implosions on OMEGA



To understand experimental measurements, we have developed a DFT-based multi-band kinetic model (*VERITAS*)



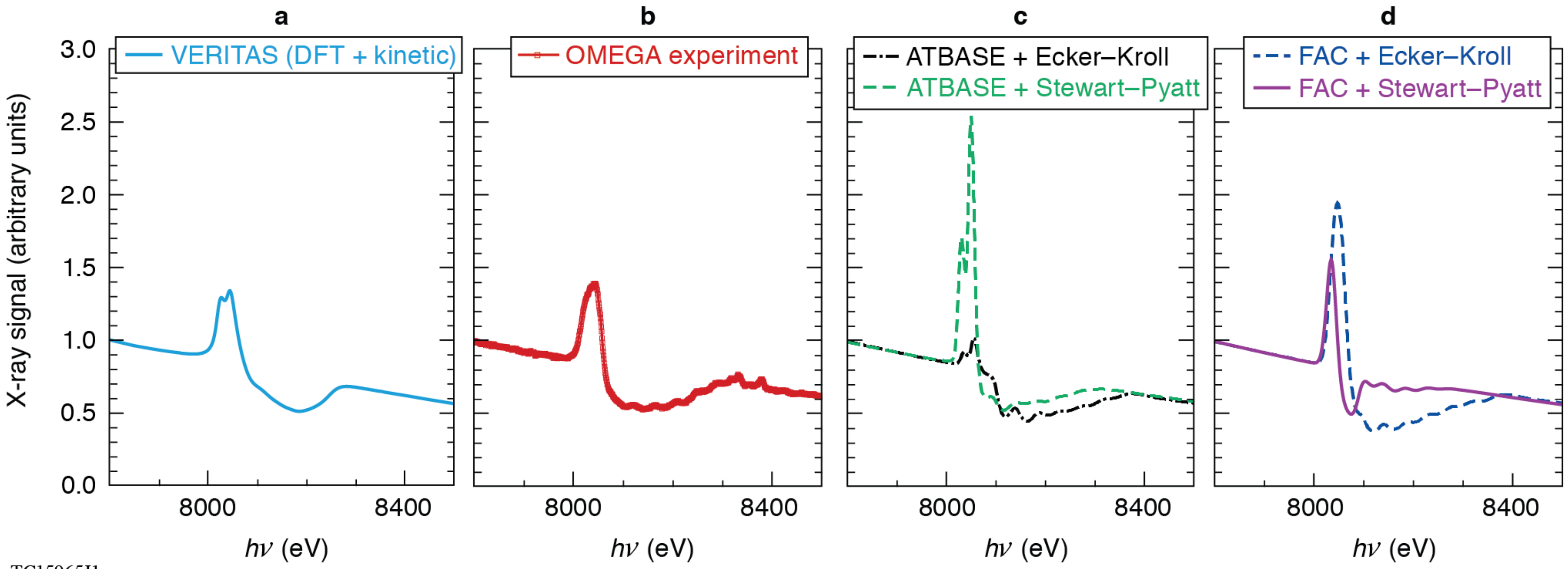
VERITAS: DFT-based multi-band kinetic modeling

$$\begin{cases} \dfrac{dn_i}{dt} = -n_i \sum_{j \neq i}^{N} W_{ij}(I, \nu) + \sum_{j \neq i}^{N} n_j W_{ji}(I, \nu) = 0, \text{ for band } i \\ \mu \dfrac{\partial I(r,\nu)}{\partial r} + \dfrac{(1-\mu^2)}{r} \dfrac{\partial I(r,\nu)}{\partial \mu} = \eta(r,\nu) - \chi(r,\nu) I(r,\nu) \end{cases}$$

- **The above coupled kinetic & rad-transfer equations can be solved for the *self-consistent* radiation field and band populations**
- **Instead of using a traditional atomic-physics model to calculate the Einstein coefficients (rates W_{ij}) for bound-bound and bound-free transitions, we extract them (oscillator strength) from DFT simulations!**

DFT: Density-Functional Theory

The measured time-integrated X-ray spectra* can differentiate *VERITAS* from traditional *CRE* models



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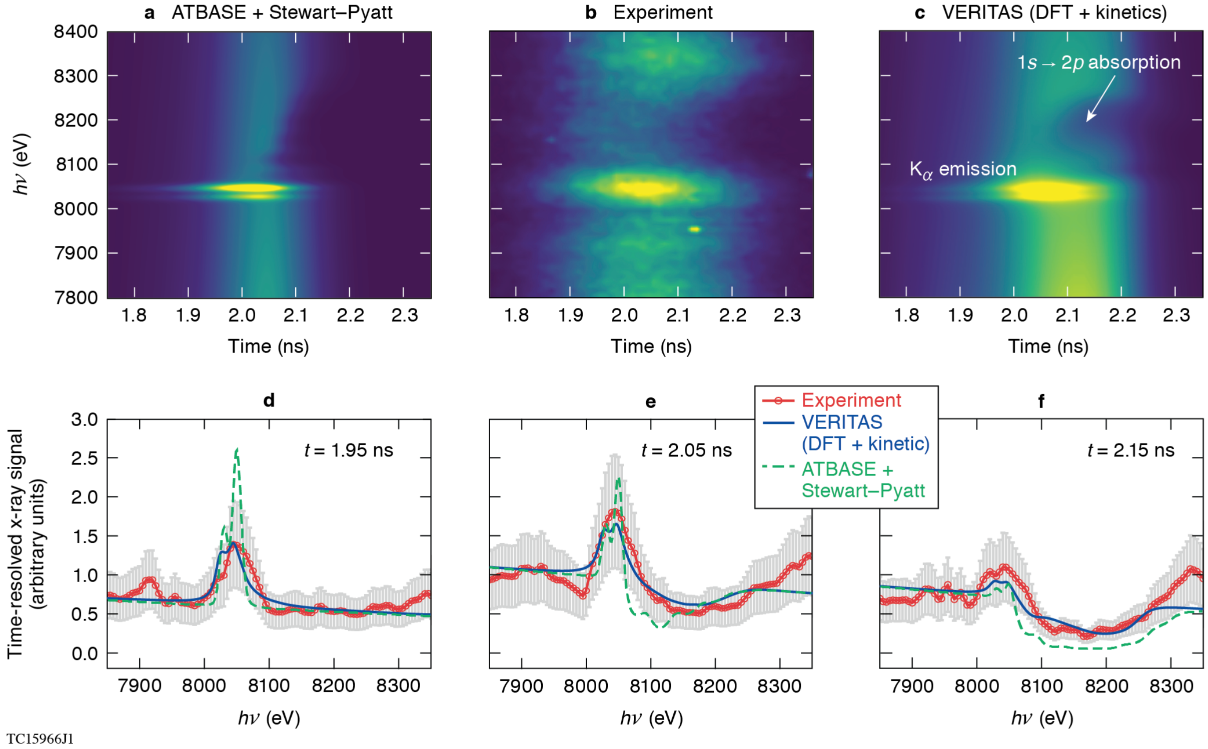
*S. X. Hu *et al.*, "Probing atomic physics at ultra-high pressure". *Nature Communications* (under review).

CRE: Collision-Radiative-Equilibrium

The *self-consistent* DFT treatment of dense plasma environment is key to understand the observed time-resolved X-ray spectra*



Spherically-convergent geometry can provide an efficient platform for precision x-ray spectroscopy of dense plasmas at ultra-high pressure

- **How atomic physics behaves in warm-/hot-dense plasmas at Gbar pressure has been investigated by time-integrated and time-resolved x-ray spectroscopy experiments on OMEGA***

- **Traditional collision-radiative-equilibrium (*CRE*) models are sensitive to which *ad hoc* continuum lowering model to use for reproducing experimental observations**

- **A DFT-based multi-band kinetic modeling code (*VERITAS*), which* self-consistent accounts for the ionization balance in such warm/hot dense plasma mixtures, can reproduce most of x-ray spectroscopy features observed in experiments**

These results indicate the necessity and viability of modeling dense plasmas with *self-consistent* methods like DFT

*S. X. Hu *et al*., "Probing atomic physics at ultra-high pressure". *Nature Communications* (under review).

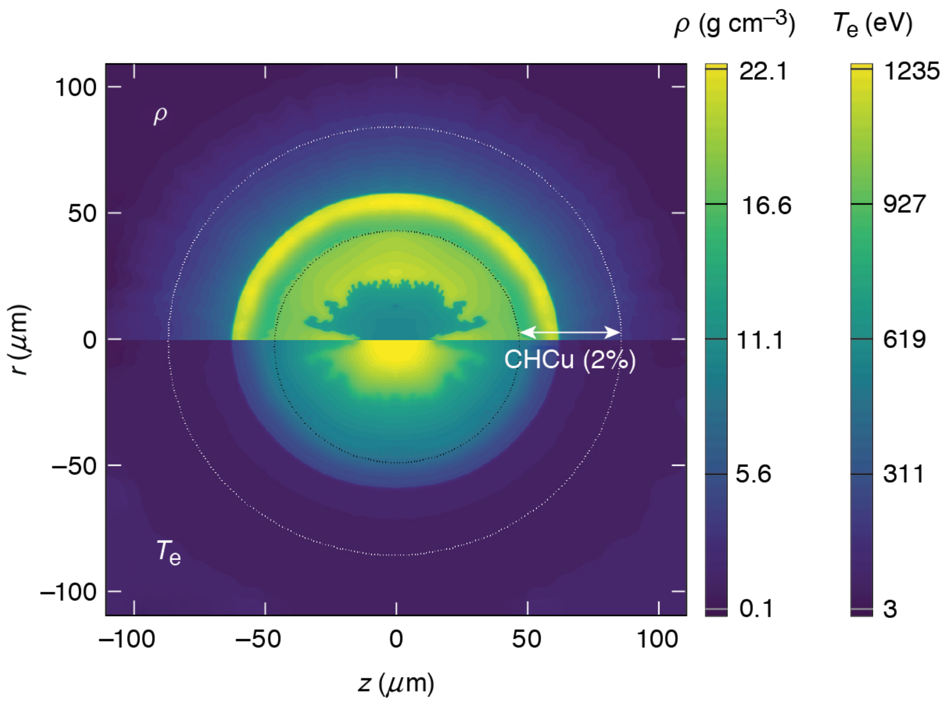
Thank You

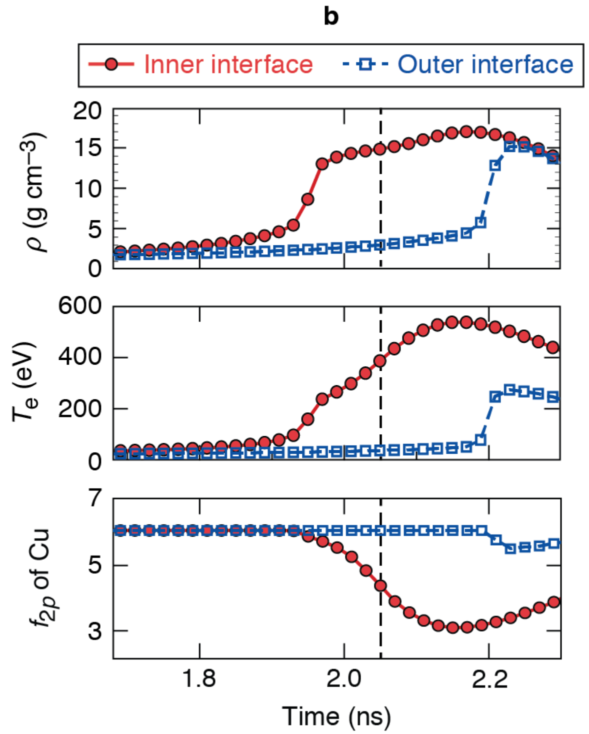
Integrated measurements give us some confidence on hydro-predicted plasma conditions in such high-adiabat implosions

Table 2 | Comparisons of implosion performance between experiments and *DRACO* simulations.

Shot# 97628	Experiment	*DRACO* Simulation
D-D Neutron Yield	$(7.3 \pm 0.4) \times 10^9$	6.2×10^9
$\langle T_i \rangle_n$ (keV)	2.2 ± 0.5	2.6
$\langle \rho R \rangle_n$ (mg cm^{-2})	67 ± 7	66.5
Neutron bang time (ns)	2.04 ± 0.05	2.08

The hot-spot radiation serves as "*backlighter*" for X-ray spectroscopy measurements for the stagnating plasma





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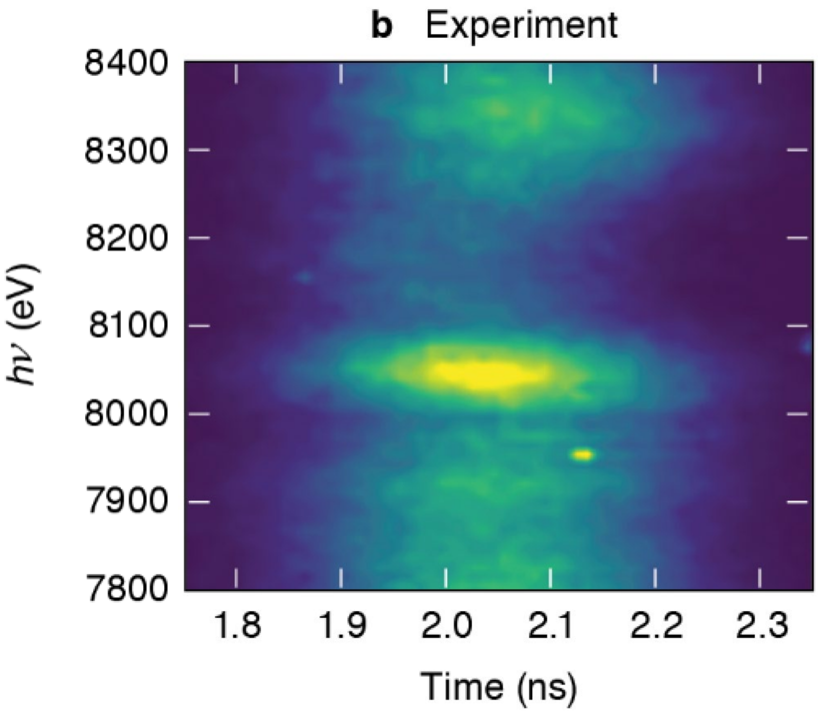
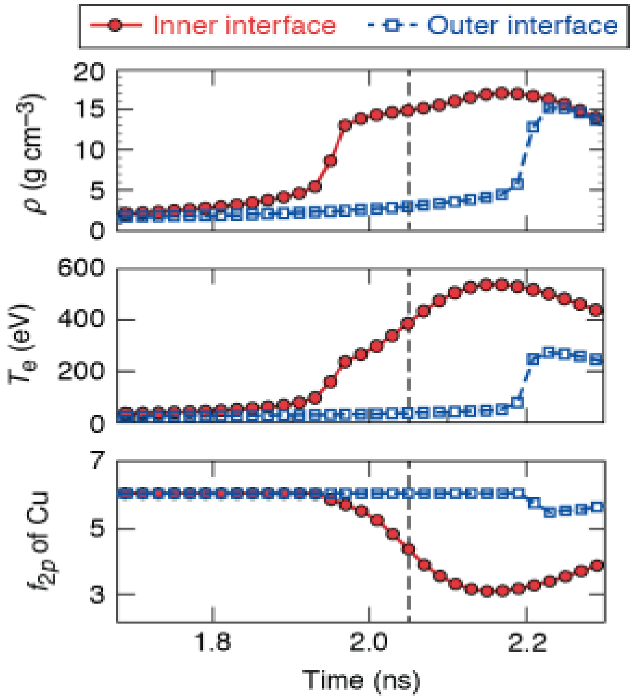
The *1s-2p* absorption signature is caused by the heat-wave induced depletion of Cu’s 2p-band





The ionization balance from traditional CRE models show differences from the DFT treatment of dense plasmas

CHCu[2%] at $\rho = 20\ g\ cm^{-3}$

Models	kT = 200 eV			kT = 300 eV		
	$n_e\ (cm^{-3})$	Z^*	f_{2p}	$n_e\ (cm^{-3})$	Z^*	f_{2p}
ATBASE + Stewart-Pyatt (*Spect3D*)	5.1×10^{24}	13.76	6.00	5.5×10^{24}	15.78	5.93
SCRAM + ion-sphere	5.1×10^{24}	14.39	5.84	5.5×10^{24}	16.37	5.25
DFT + QMD (*VERITAS*)	5.0×10^{24}	12.88	5.87	5.3×10^{24}	14.96	5.27
DFT + AA (*Muze*)	5.0×10^{24}	12.52	5.87	5.5×10^{24}	14.43	5.24
FAC + AA (*FAC*)	4.2×10^{24}	12.86	5.87	4.9×10^{24}	15.19	5.19

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