Center for Laboratory Astrophysics

NNSA Center of Excellence

Carolyn Kuranz, Director

University of Michigan

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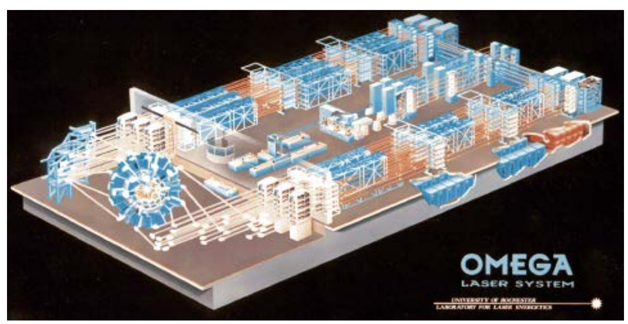
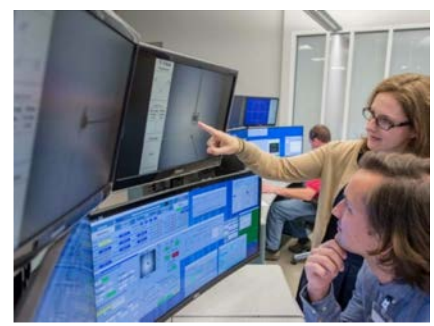
Outline for talk

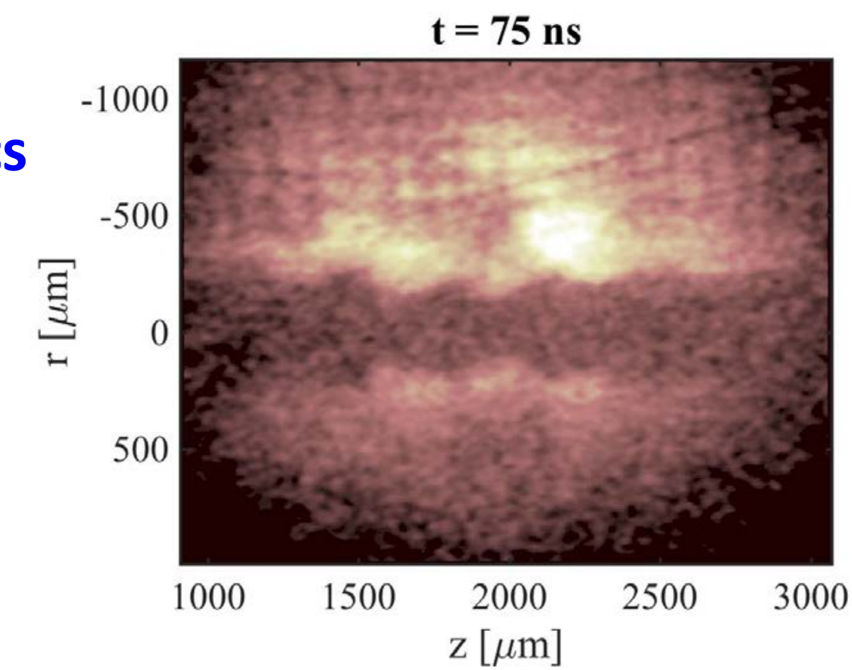
- Scientific Overview
- CLA students and education
- Kelvin-Helmholtz experiments on Omega EP
- Radiation-Matter Interaction experiments at Omega
- Radiative Heat Front experiments on Omega and Z





The Center Laboratory Astrophysics (CLA) studies high-energy-density phenomena that are relevant to astrophysics

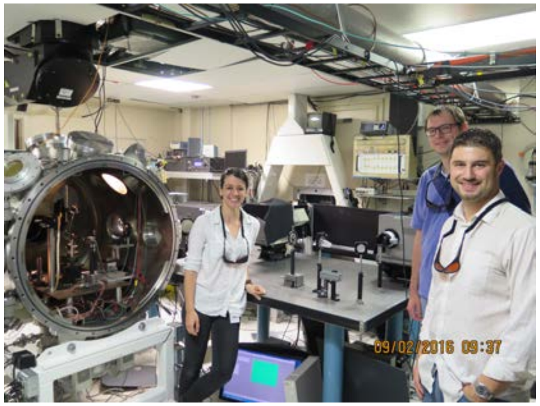
- **We advance fundamental understanding of HED dynamics relevant to astrophysics**
  - Radiation hydrodynamics
  - Complex HED hydrodynamics
  - Magnetized flowing plasma
- **While advancing the required infrastructure**
  - Computer simulation
  - Target fabrication
  - HEDP diagnostics
- **The ultimate goal of these activities is to train junior scientists**



X-ray radiography of Kelvin-Helmholtz instability from the Omega EP facility

The CLA team is oriented towards training students

- **Most of our students come through the UM Applied Physics Program**
  - Outstanding applicants; highly competitive
  - Diverse program – 30% women, 30% URM
  - Imes-Moore Fellowship (Underrepresented minorities, 1st generation citizen, 1st generation college, financial hardship)
- **We graduate about 1 – 2 students/year**
- **Publish about ~10 scientific articles/year**
- **Nuclear Engineering is #1 in the country**
  - UM is #4 public, UM COE is #5 overall



We have a history of placing excellent students at NNSA laboratories

Recent Graduates at NNSA labs:

- Mike MacDonald (2016, LLNL)
- Jeff Fein (2017, SNL)
- Rachel Young (2017, UM)
- Willow Wan (2017, LANL, LLNL)
- Alex Rasmus (2019, LANL)
- Laura Elgin (2019, SNL)
- We graduate about 1-2/year

Current Grad Students and Postdoc:

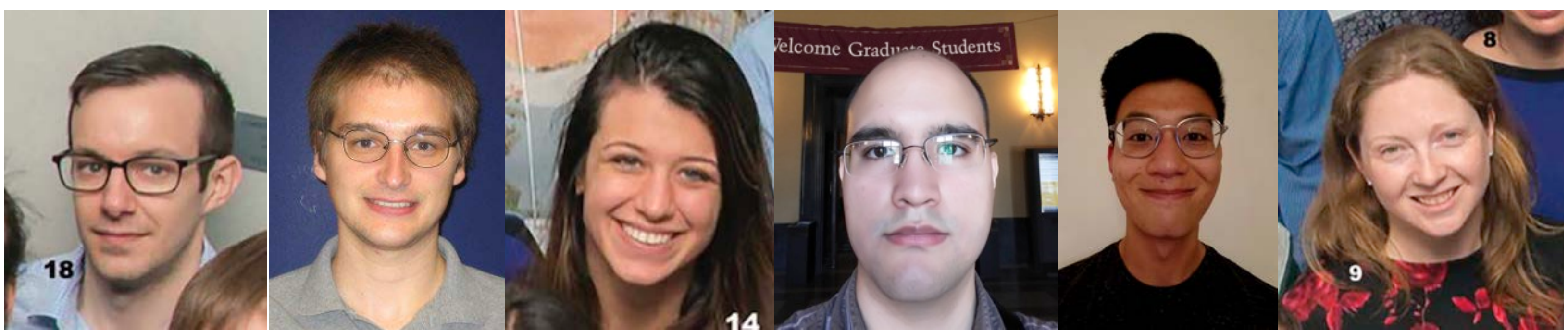
- Robert Vandervort (Omega)
- Joseph Levesque (Omega)
- Heath LeFevre (Omega, NIF, Z)
- Adrianna Angulo (LLNL, Omega, NIF)
- Shane Coffing (LANL)
- Raul Melean (MAIZE)
- Dr. Rachel Young (Omega)
- Kevin Ma (Omega, NIF)

New Grad Students:

- Kwyntero Kelso (Alabama A&M, LANL postbaccalaureate)
- Michael Springstead (University of Minnesota, LANL postbaccalaureate)
- Khalil Bryant (University of Michigan)

CLA Students at SSAP

Joseph Levesque, graduating 2020
Heath LeFevre, graduating 2020
Adrianna Angulo
Raul Melean
Kevin Ma
Dr. Rachel Young



HEDP Education at UM

- Students take a variety of plasma physics classes
  - 15 classes offered
  - Include theory, diagnostics, laboratory
  - 9+1 TT faculty, 4 research faculty
- We offer a HEDP course
  - This year we will remotely offer it to MSU
- We offer a biennial summer school
  - June 2020

HEDSS Lectures by Kuranz, Drake, Thomas, Willingale, McBride, Johnsen, Young, and Trantham

Kelvin Helmholtz experiments at Omega EP

Design: Shane Coffing

Currently stationed at LANL

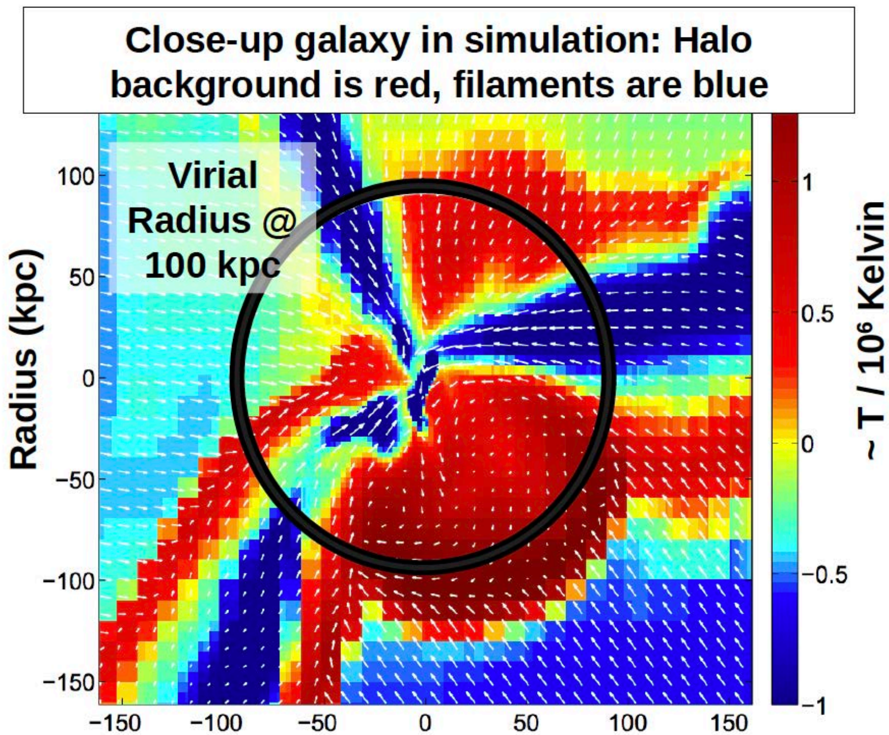
SX Coffing et al, "Design and Scaling of an Omega-EP experiment to study Cold Streams feeding Early Galaxies" ApJS, in press

Experiments: Adrianna Angulo

Currently stationed at LLNL

Chiyoe Yamanaka Award Winner

Streams of infalling matter from the cosmic web are thought to have fueled early galaxies



Galaxy bimodality due to cold flows and shock heating, Dekel and Birnboim, Mon. Not. R. Astron. Soc. 368, 2–20 (2006)

- Filaments may be Kelvin-Helmholtz unstable
- Galactic simulations are not well resolved
- We designed a well scaled experiment to study this

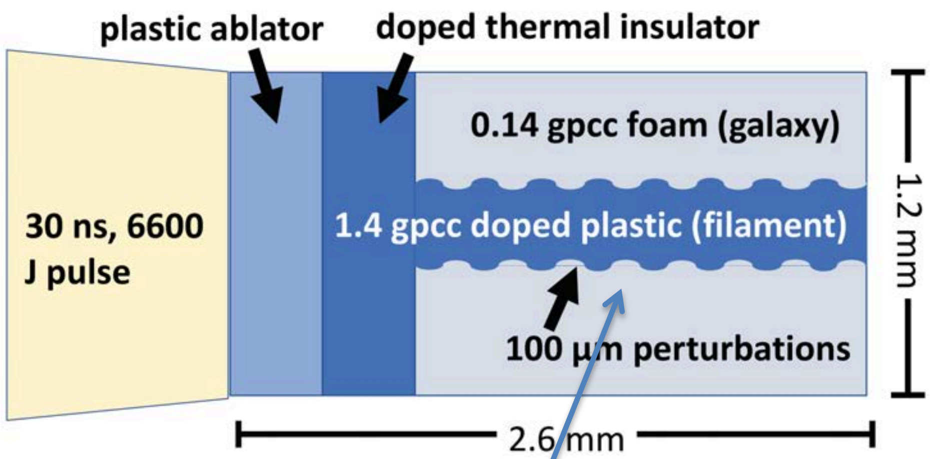
We have a well scaled experiment

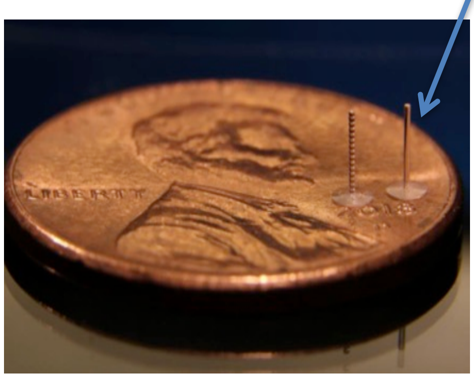
Parameter	Physical description	Symbol	Cold Stream	Experiment (filament)
Length scale (cm)	Filament radius	R	3×10^{21}	0.01
Velocity (cm/s)	(Virial) shock speed	U	2×10^{7}	3×10^{6}
Density (gpcc)	Filament density	ρ_s	10^{-26}	1.4
Temperature (eV)	Filament temperature	T_s	86	2
Effective ionization	Average of shocked plasmas	Z	2	10.25
Effective mass number	-	A	1	0.1
Ion Density (cm^{-3})	-	n_i	0.003	1.67×10^{27}

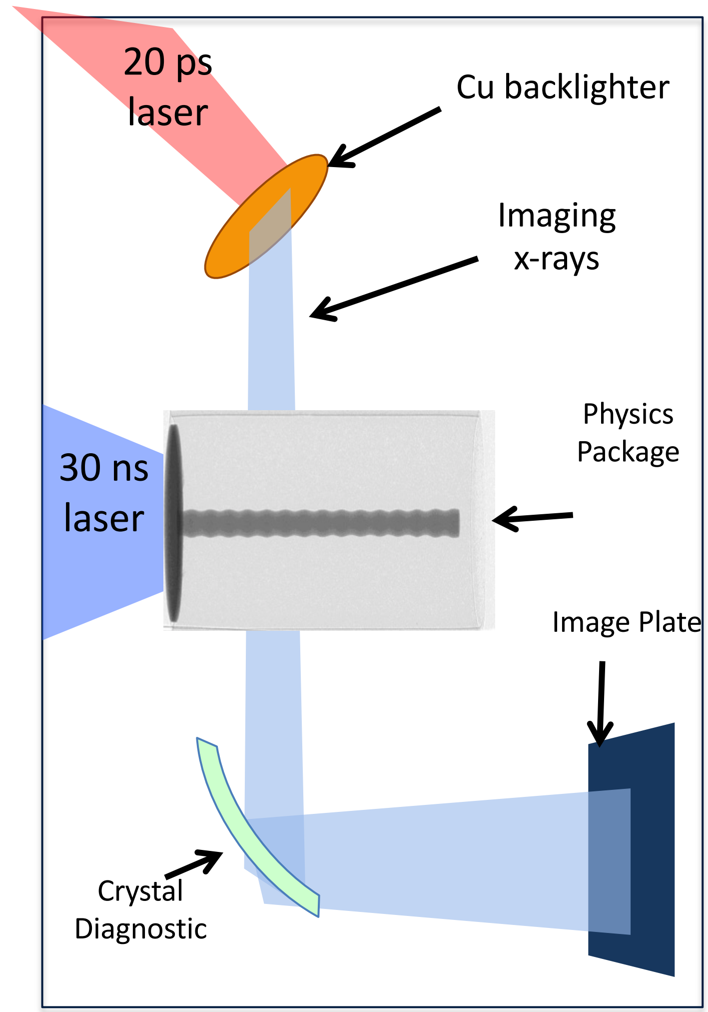
Parameter	Symbol	Cold Stream	Experiment
Hydrodynamics:			
Localization	l_c/h	1.8×10^{-5}	4.9×10^{-6}
Ryutov number	$\tilde{v}\sqrt{\tilde{\rho}/\tilde{p}}$	2.2	2.3
Heat transport:			
Thermal diffusivity ($cm^2\ s^{-1}$)	χ	2.4×10^{26}	5.1
Peclet number	Pe	2.5×10^{3}	6×10^{3}
Momentum transport:			
Thermal viscosity ($cm^2\ s^{-1}$)	ν	3.2×10^{24}	4.41×10^{-2}
Reynolds number	Re	1.9×10^{5}	6.8×10^{5}

Graduate Student: Shane Coffing

The experimental target has a micro-machined pattern to seed the KH instability

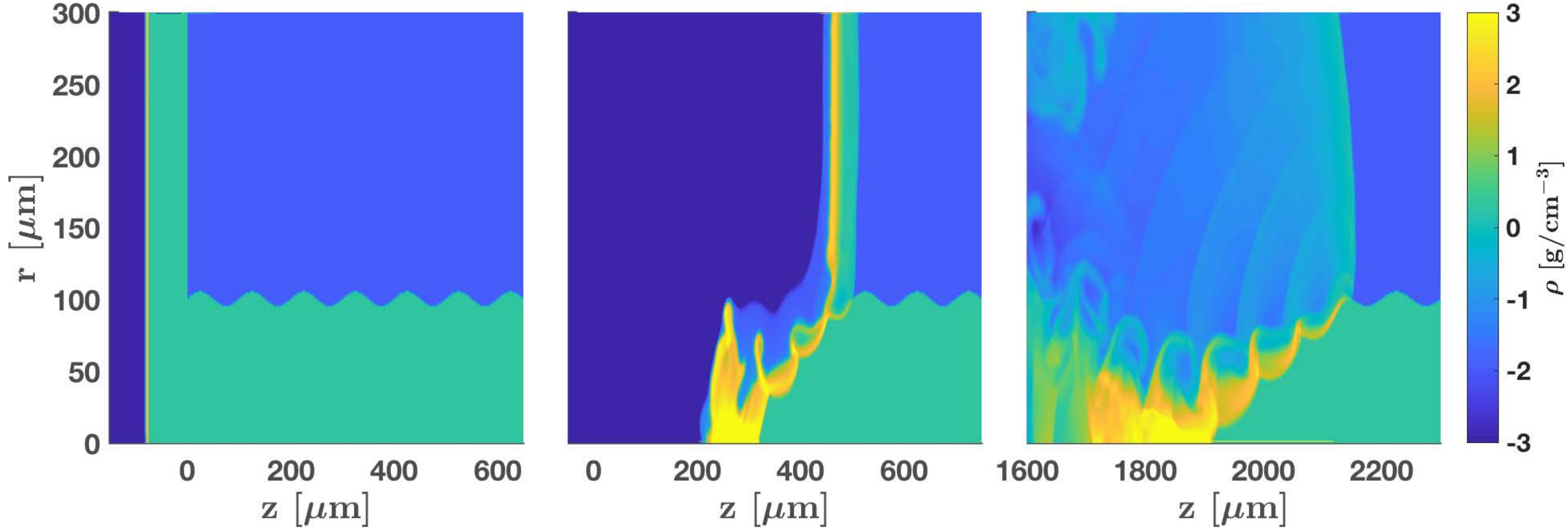






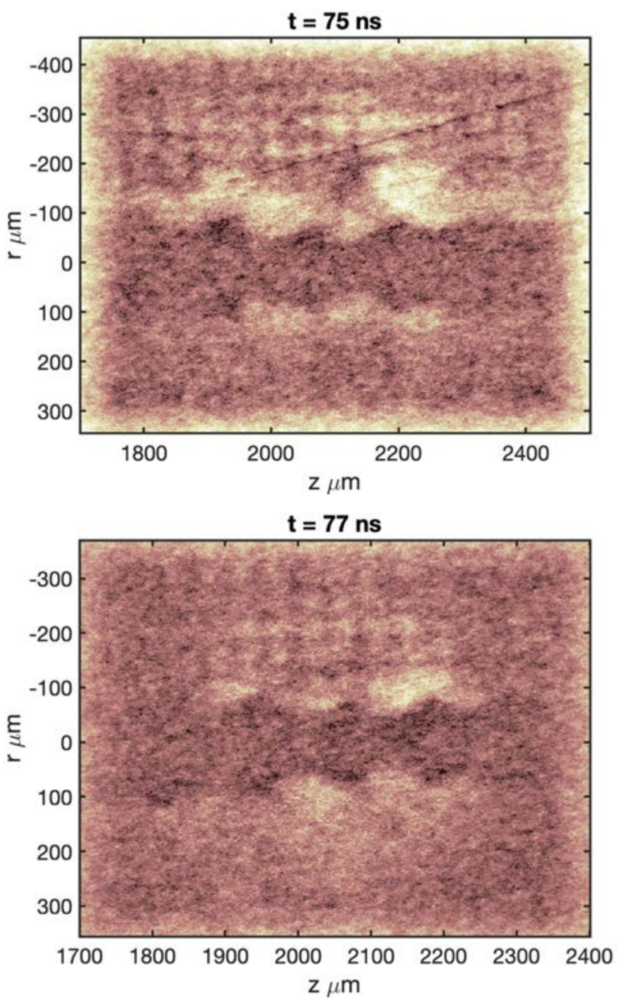
Graduate Student: Adrianna Angulo

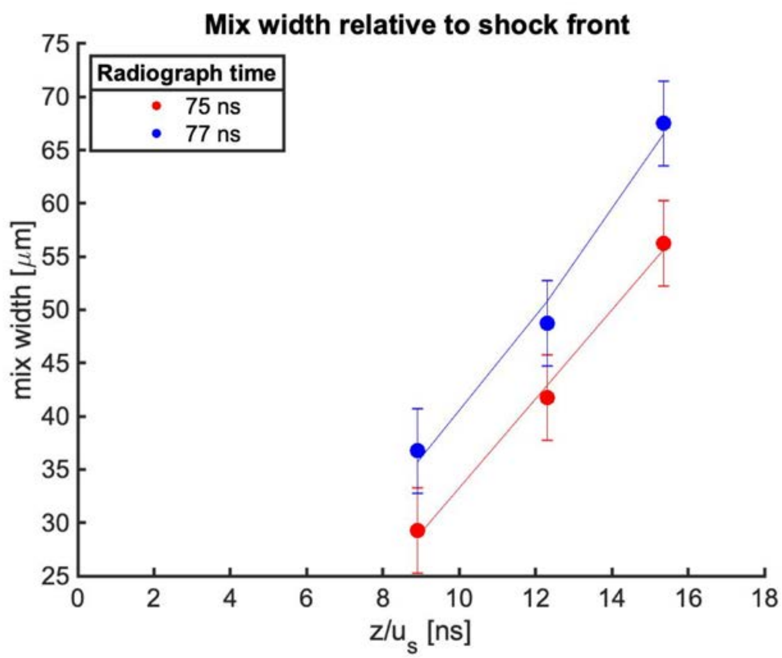
CRASH aided in the design of this experiment



Graduate Student: Shane Coffing

Early experiments on this system have produced promising results





u_{shock} = 30 um/ns

Graduate Student: Adrianna Angulo

Next experiment in March

Radiation-Matter Interaction experiments at Omega

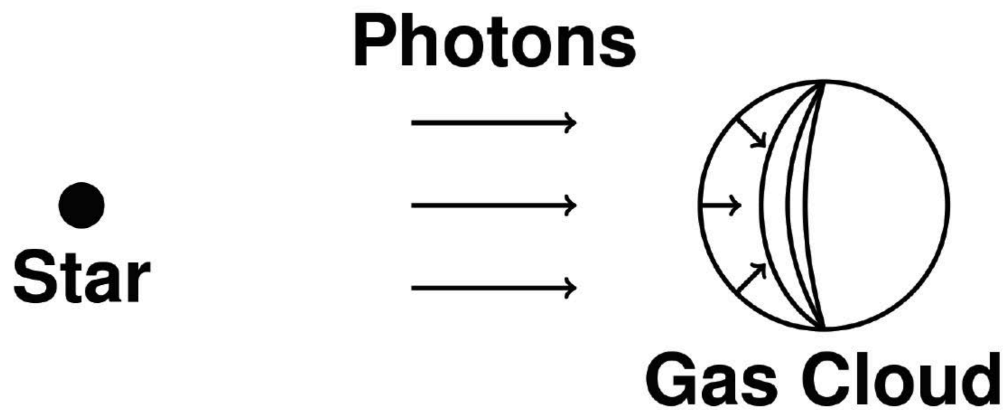
Experiment: Robert “Woody” VanDervort

Design: Griffin Cearly

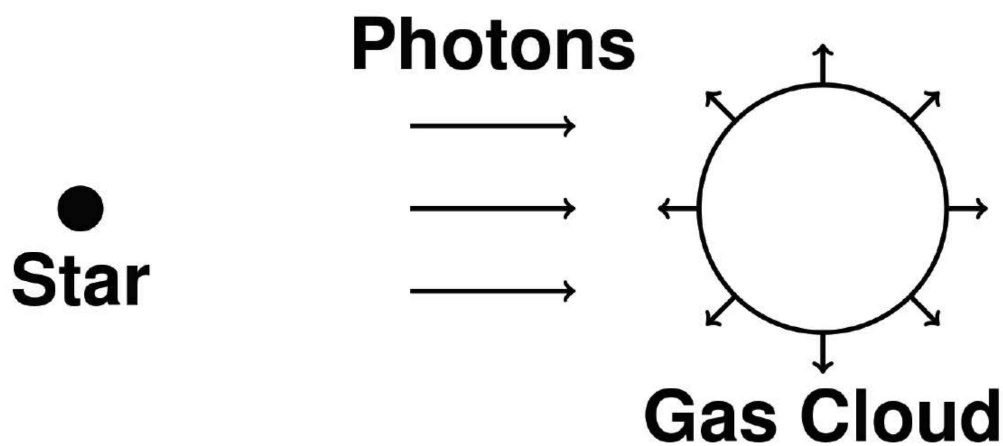
R. VanDervort, et al., Development of a backlit-multi-pinhole radiography source 2018, Rev. Sci. Instrum., 89, 10G110

Our goal is to probe star formation at moderate optical depth

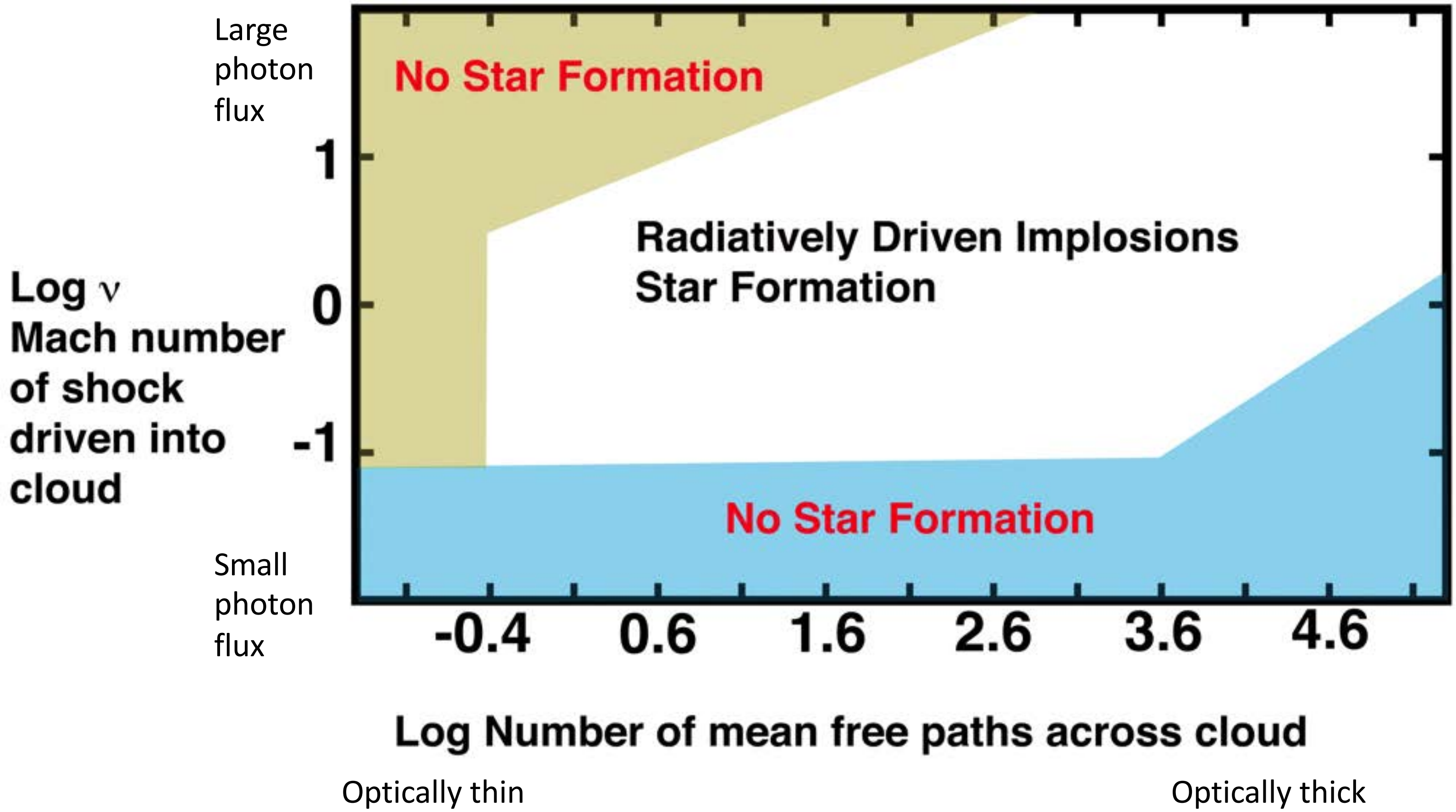
Optically thick: Photons absorbed at one cloud edge drives asymmetric shock



Optically thin: Photons permeate and heat cloud and it explodes



Stars are not predicted to form if the photon flux is too low or the radiation mean free path is larger than the cloud size



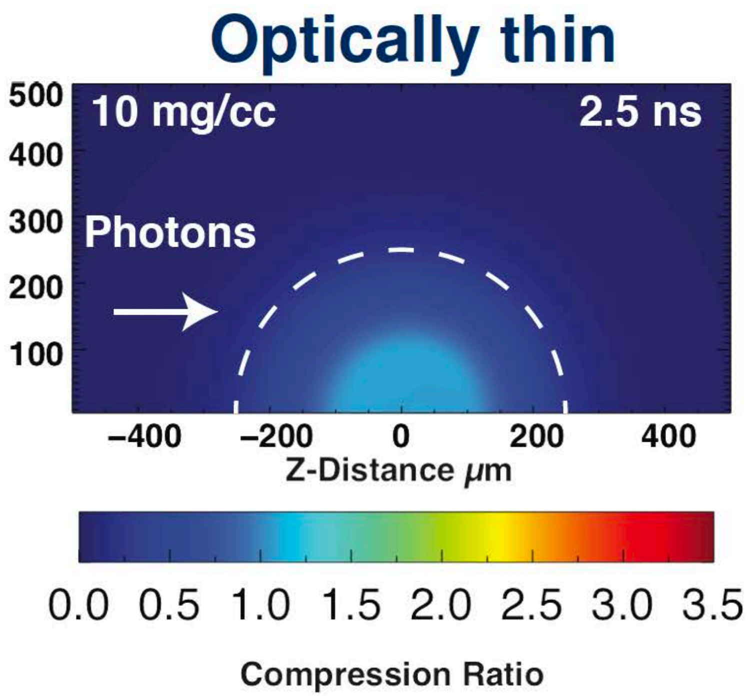
Adapted from Bertoldi Astrophys. J. 1989

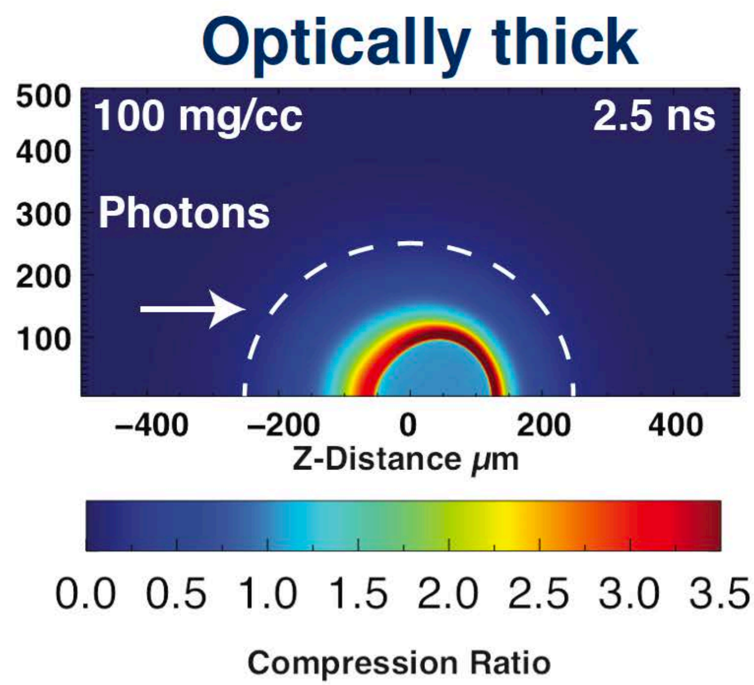
The experiment is in a similar regime as a typical, radiation-driven, astrophysical implosion

Parameter and Units	**Potential Radiation Driven Implosion**	**Omega Experiment**
c_s (cm s^{-1})	$\sim 10^7$	$\sim 6 \times 10^6$
n_o (cm^{-3})	~ 500	10^{20} - 10^{22}
N (photons s^{-1} cm^{-2})	10^8 - 10^9	10^{27} - 10^{29}
ν	0.1 - 10	0.1 - 10
τ	a few - 10^5	a few - 10^3

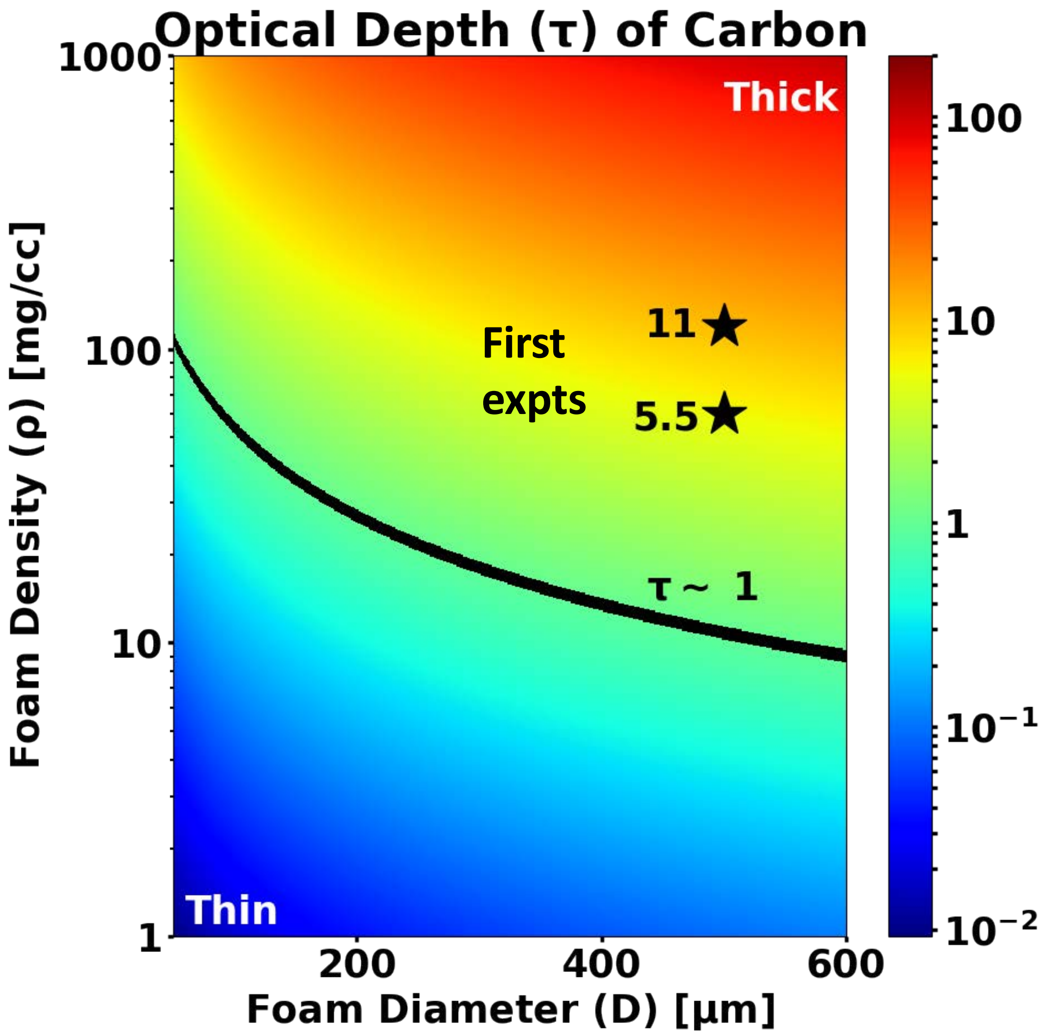
Mach *ν* - ratio of the speed of the shock driven into the cloud on axis to the sound speed corresponding to the ionization front produced by the source

CRASH simulations show compression or explosion based on the initial foam density





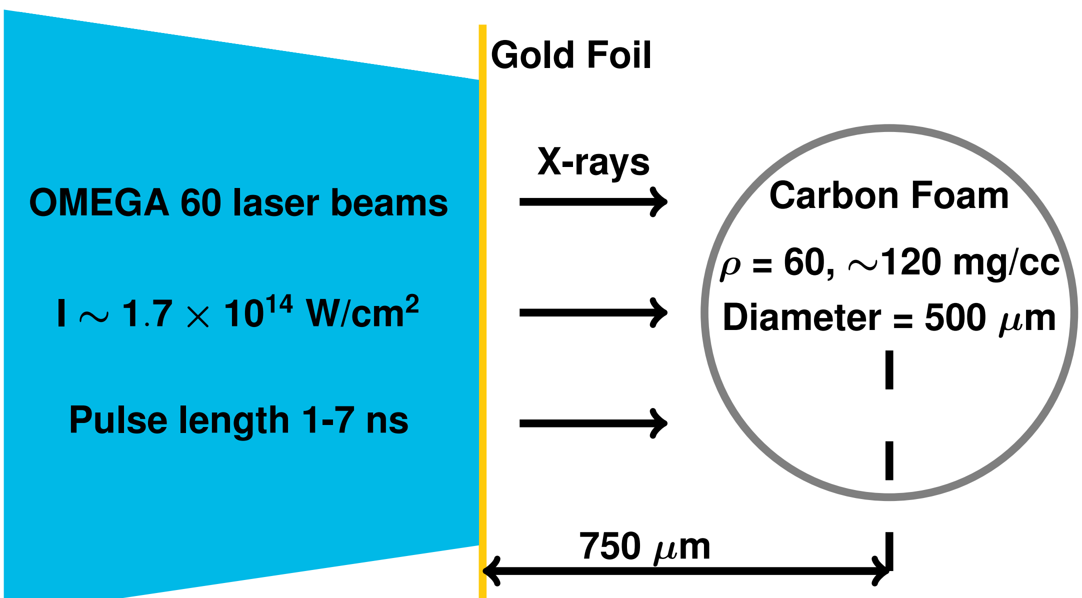
A range of optical depths is accessible by changing the sphere diameter and density

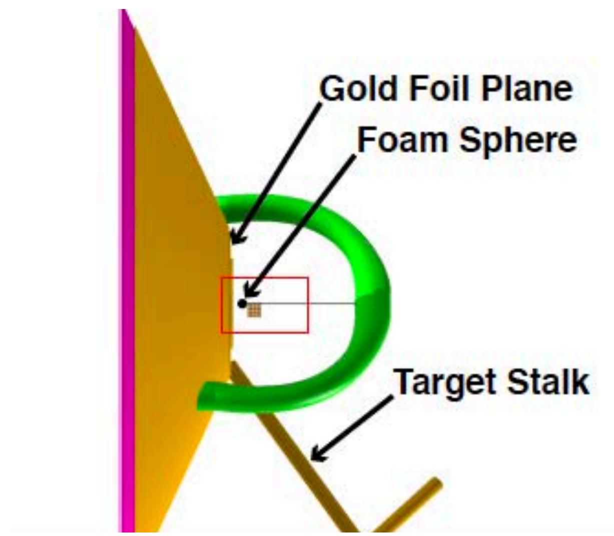


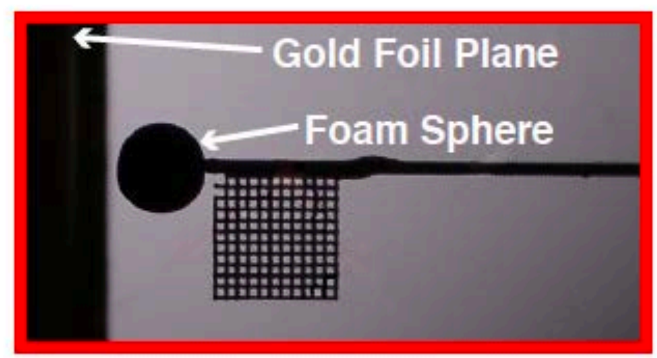
$$\tau = \frac{D}{\lambda_{mfp}}$$

$$\lambda_{mfp} = \frac{1}{\rho\sigma}$$

Optically thick limit provides a starting point to test the platform

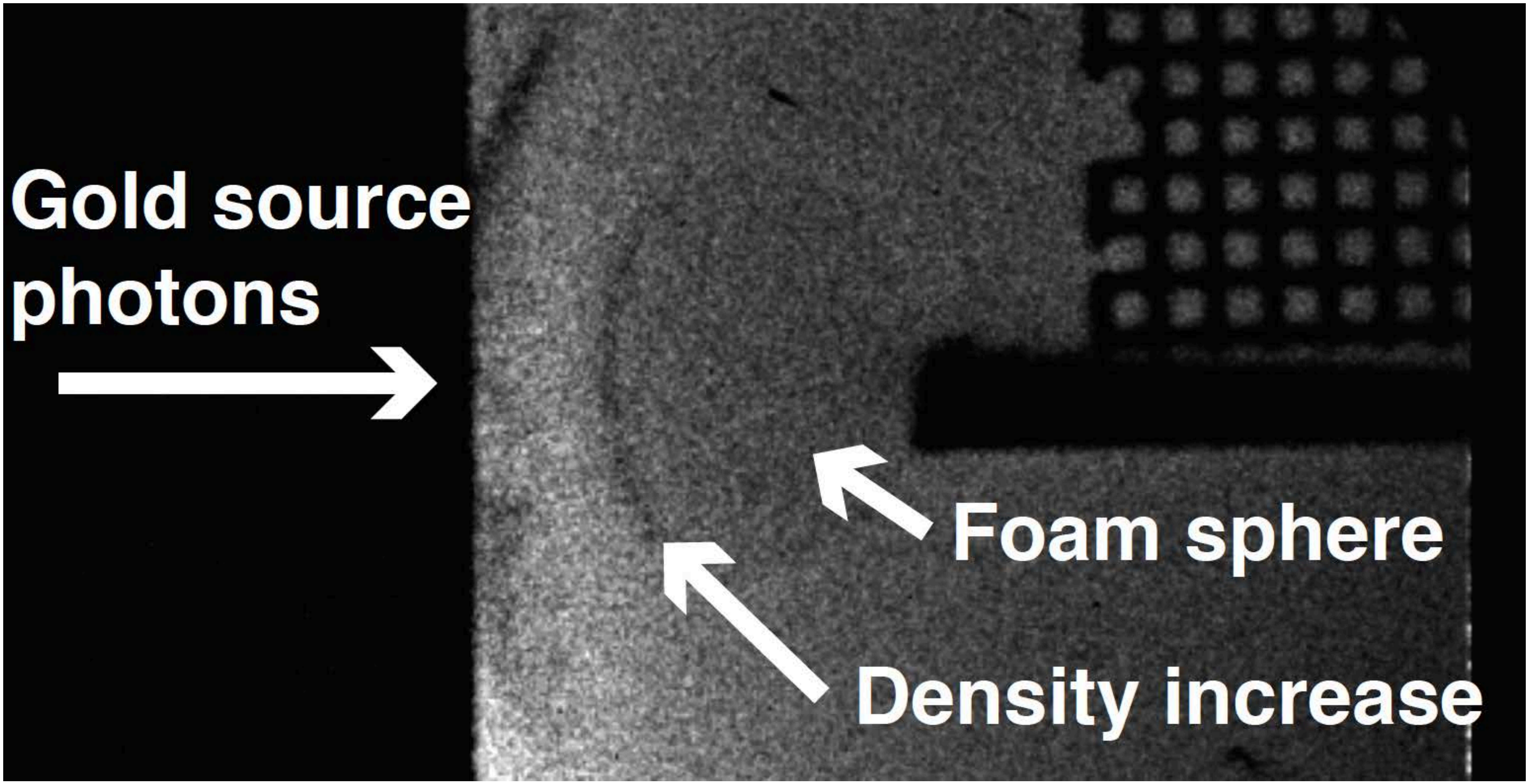






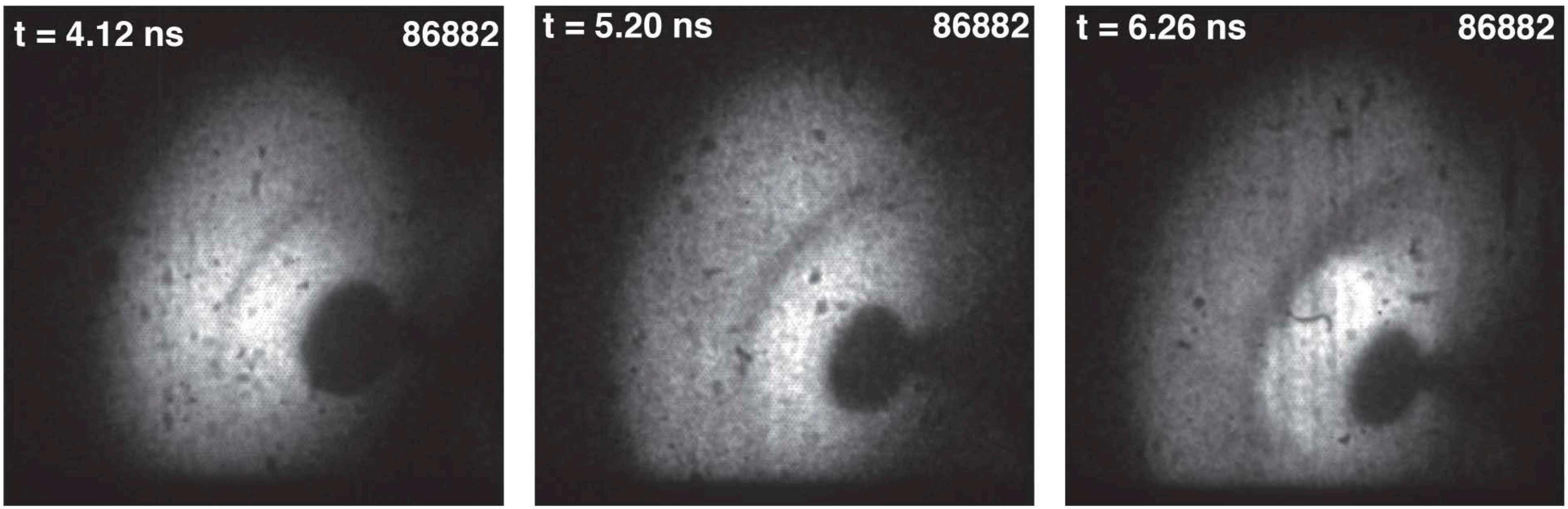
Graduate Student: Robert Vandervort

Backlit-pinhole radiography shows an asymmetrically-compressed sphere



Graduate Student: Robert Vandervort

Soft x-ray radiographs suggest an asymmetric compression



Graduate Student: Robert Vandervort

Radiative Heat Fronts

Heath LeFevre

Michael Springstead

Kwyn Kelso

H.J. LeFevre, “A platform for x-ray Thomson scattering measurements of radiation hydrodynamics experiments on the NIF", Review of Scientific Instruments 2018

Photoionization fronts on Omega and the Z machine

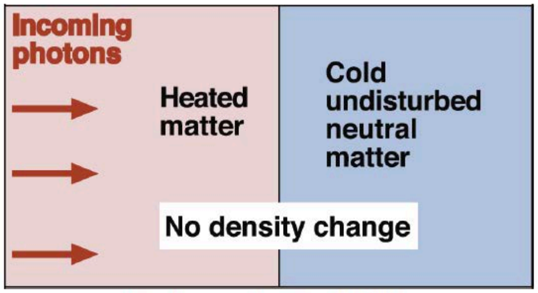
$$\alpha = \frac{n_{i+1}}{n_i}\frac{R_{i+1,i}n_e}{\Gamma_{i,i+1}},$$
$$\beta = 1 + \frac{n_i}{n_{i+1}}\frac{<\sigma_{ei}v>_{i,i+1}}{R_{i+1,i}}$$

Photoionization needs to dominate recombination and

Recombination needs to dominate electron collisional ionization

For a PI front to form $\alpha << 1$ and $\beta \approx 1$

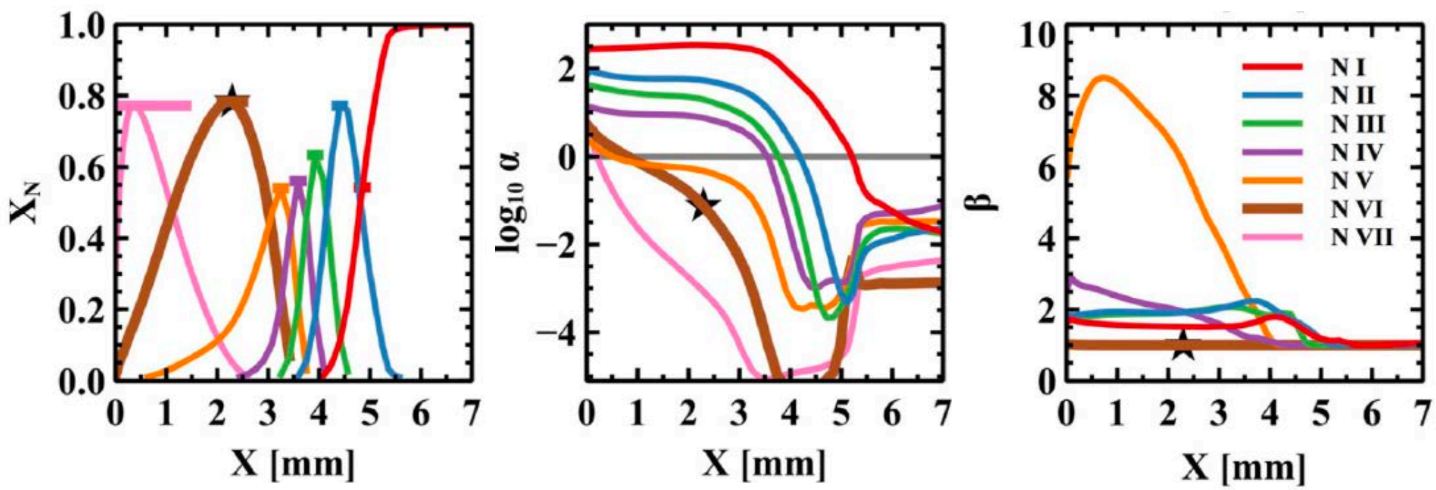
$R_{i+1,i}$	Recombination rate coefficient(cm^3 s^{-1})
n_i	Ion number density(cm^{-3})
$\Gamma_{i,i+1}$	Photoionization rate(s^{-1})
$< \sigma_{ei}v >_{i,i+1}$	Electron impact ionization rate(cm^3 s^{-1})
n_e	Electron number density(cm^{-3})



Drake et al. ApJ 2016

We can meet the requirements for a PI front in N at HED facilities

HELIOS Simulation



$$\alpha = \frac{n_{i+1}}{n_i}\frac{R_{i+1,i}n_e}{\Gamma_{i,i+1}},$$

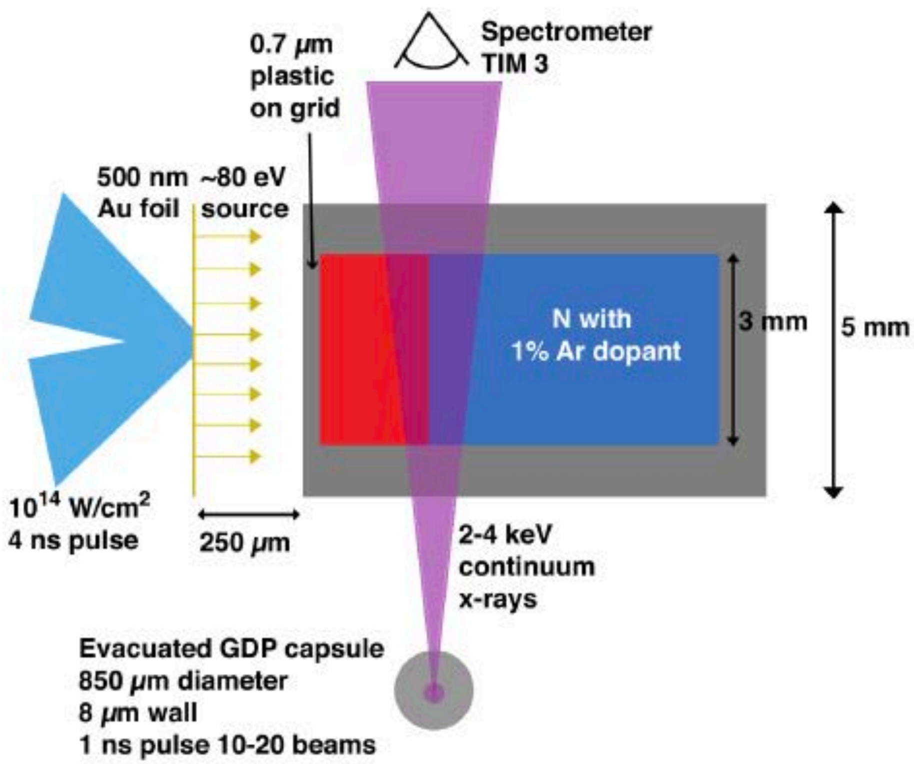
$$\beta = 1 + \frac{n_i}{n_{i+1}}\frac{<\sigma_{ei}v>_{i,i+1}}{R_{i+1,i}}$$

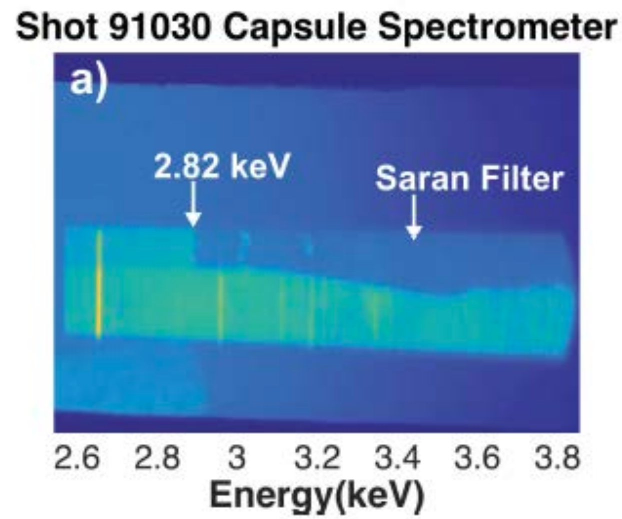
Photoionization needs to dominate recombination and

Recombination needs to dominate electron collisional ionization

For a PI front to form α << 1 and β ≈ 1

On Omega we use absorption spectroscopy to find the population density of different ionization states

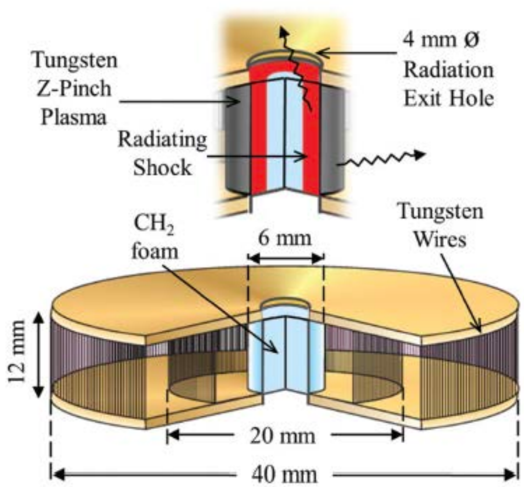


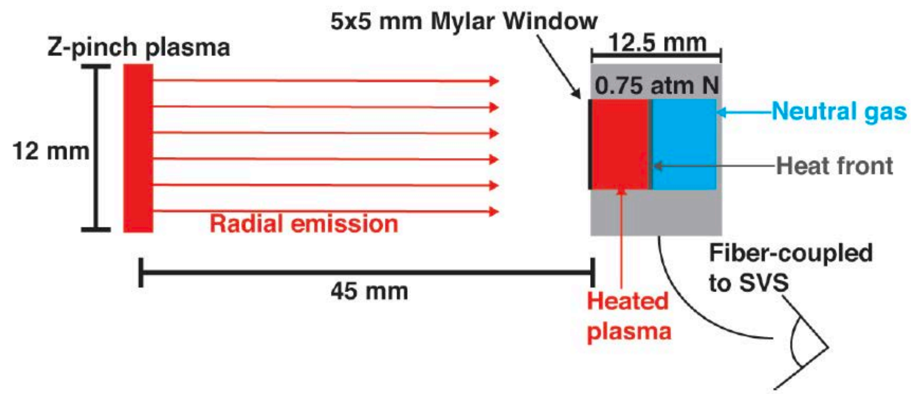


Graduate Student: Heath LeFevre

We have experimental time in April and June

On Z we will use various streaked spectrometers to detect the front evolution



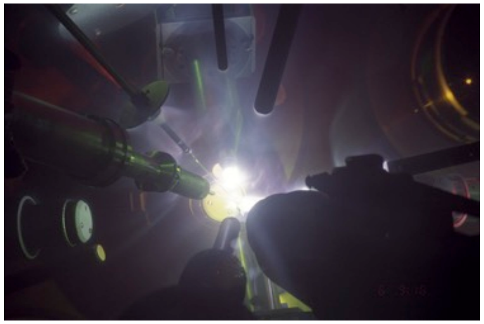


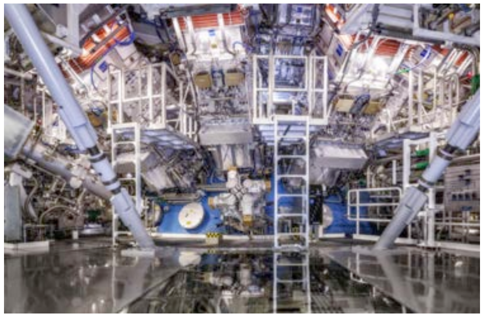
Graduate Student: Heath LeFevre

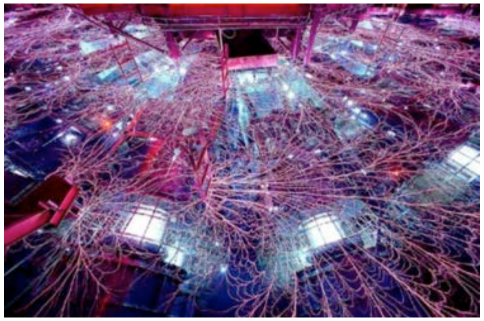
We have experimental time from FY20-22 for proof-of-principle experiments

We use a variety of HEDP "tools" to do our work…

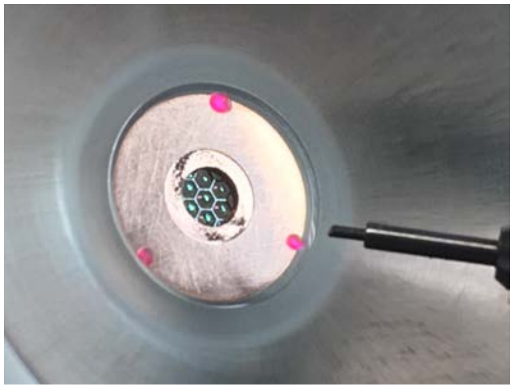
- Omega Laser Facility – LLE
- National Ignition Facility – LLNL
- Z Machine - SNL
- MAIZE LTD – UM
- HERCULES/ZEUS - UM
- BELLA – LBL
- Jupiter Laser Facility – LLNL
- Trident Laser Facility – LANL
- ORION – AWE
- LULI2000 – LULI







We have been fabricating targets for our experiments since 2004

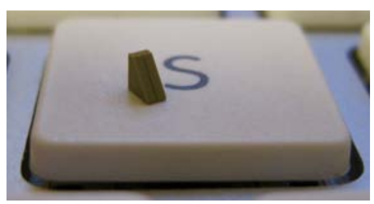


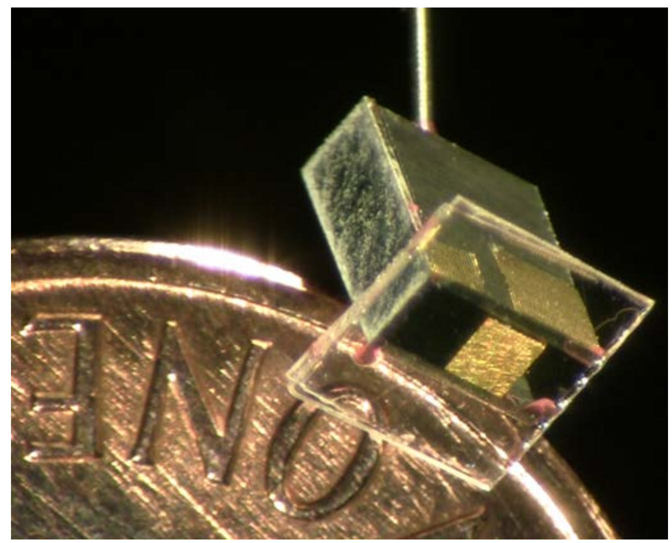
Components for photoionization front gas target

Sallee Klein is CLA target fab engineer

UM target

Some components are fabricated at GA





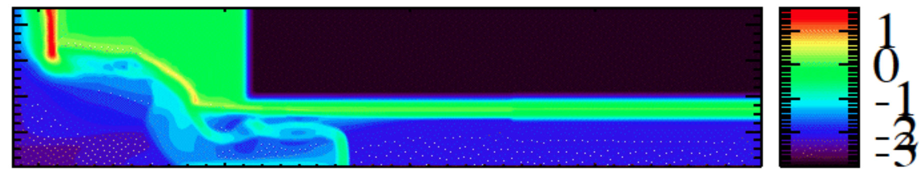
Omega EP Kelvin Helmholtz target

We use the CRASH code for experimental protoyping, prediction, and analysis

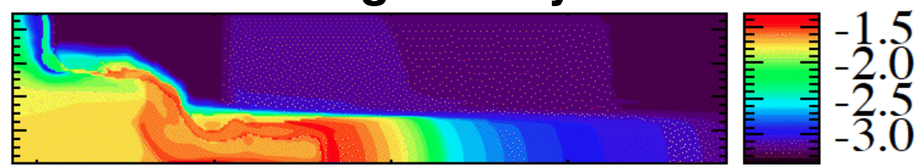
- 1D, 2D or 3D
- Dynamic adaptive mesh refinement
- Level set interfaces
- Self-consistent EOS and opacities
- Multigroup-diffusion radiation transport
- Electron physics and flux-limited electron heat conduction
- Laser package
  - 3D ray tracing for 2D or 3D runs

CRASH code: Van der Holst et al, Ap.J.S. 2011

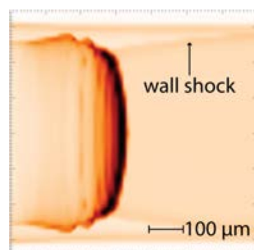
Material & AMR

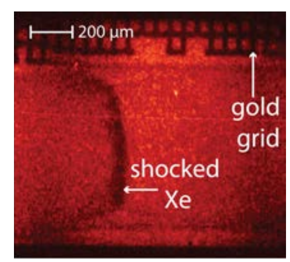


Log Density



Log Electron Temperature





Matt Trantham is CLA computer engineer

We value our scientific collaborators*

LLNL – Huntington, Park, Moody, Remington, Doeppner, MacDonald

LANL – Flippo, Li, Liao, Kline, Keiter, Montgomery, Di Stefano

SNL – Knapp, Doss, Hansen, Loisel

NRCN Israel – Malamud, Elbaz, Shimony

Rice – Hartigan

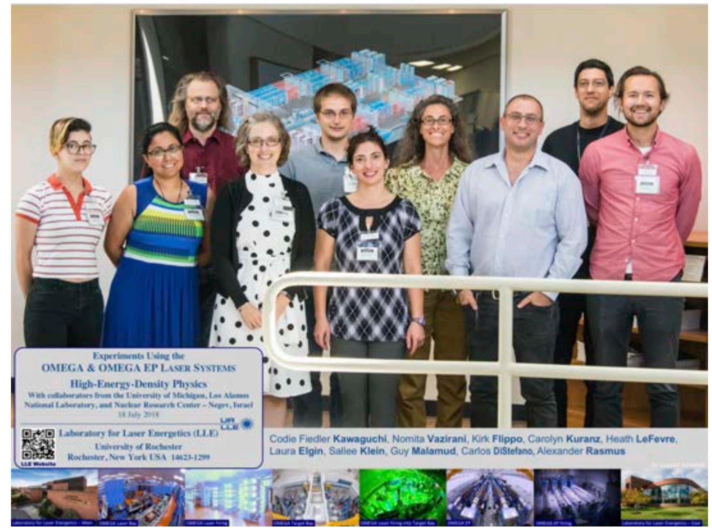
LLE/Rochester –Theobald, Frank, Blackman

Florida State – Plewa

University of Nevada – Mancini

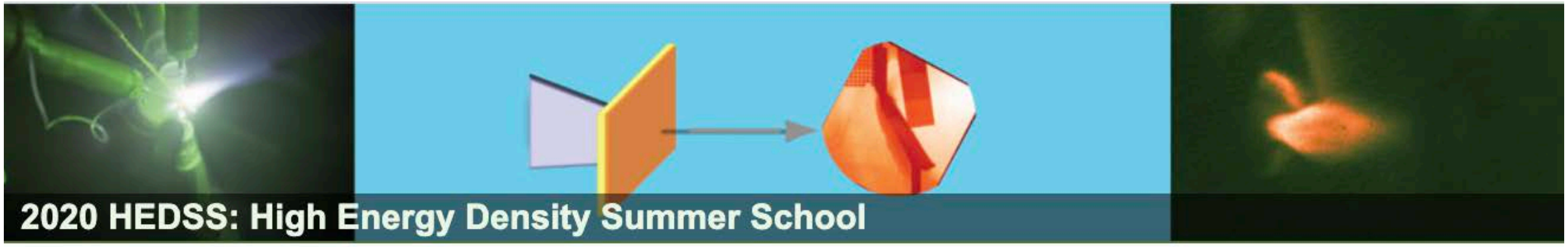
UT Austin – Winget, Montgomery

MIT - Li



Center for Laboratory Astrophysics, Los Alamos National Laboratory, Nuclear Research Center– Negev HED Hydrodynamic collaboration

*a partial list



- Home
- Registration
- Student/Postdoc Support
- Schedule of Lectures
- Class Schedule
- Lodging
- Venue and Parking
- Transportation
- Contact

2020 High Energy Density Summer School
Foundations of High Energy Density Physics

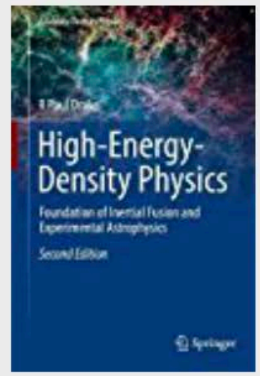
June 22- July 3, 2020
University of Michigan
Ann Arbor, MI

High-energy-density physics is an actively growing field that exploits the ability of various modern devices to create pressures of millions of atmospheres in dynamic, high-temperature, and even relativistic systems. This field of physics is essential to inertial fusion research, to using such tools to address issues in astrophysics, and to other fundamental studies and applications.

In an effort to promote the spread of broad, fundamental knowledge in this new field, and to help train the new entrants to it, we're offering this summer school.

Topics to be covered include:

1. Fundamental Equations and Equations of State
2. Shocks, Rarefactions, and their Interactions
3. Hydrodynamic Instabilities
4. Radiative Transfer
5. Radiation Hydrodynamics
6. Creating High-Energy-Density Conditions
7. Magnetized Flows
8. Inertial Fusion
9. Experimental Astrophysics
10. Relativistic Systems
11. Magnetohydrodynamics



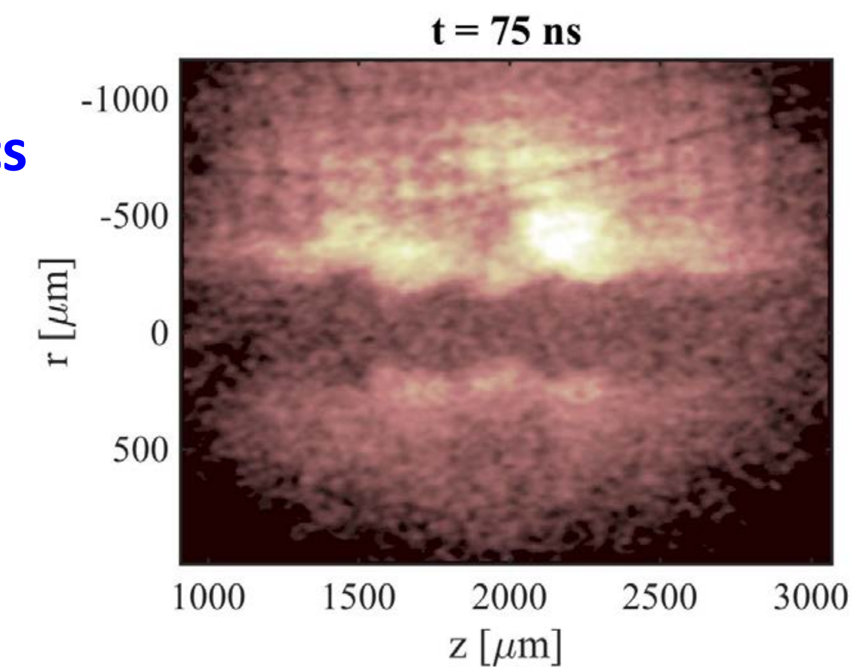
Prof. R Paul Drake's book is available for purchase from Springer Verlag

http://clasp-research.engin.umich.edu/workshops/hedss/

Google “umich HEDSS”, email jbeltran@umich.edu

The Center Laboratory Astrophysics (CLA) studies high-energy-density phenomena that are relevant to astrophysics

- **We advance fundamental understanding of HED dynamics relevant to astrophysics**
  - Radiation hydrodynamics
  - Complex HED hydrodynamics
  - Magnetized flowing plasma
- **While advancing the required infrastructure**
  - Computer simulation
  - Target fabrication
  - HEDP diagnostics
- **The ultimate goal of these activities is to train junior scientists**



X-ray radiography of Kelvin-Helmholtz instability from the Omega EP facility