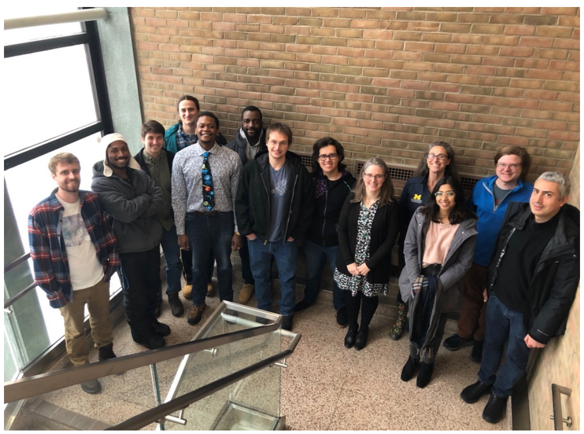
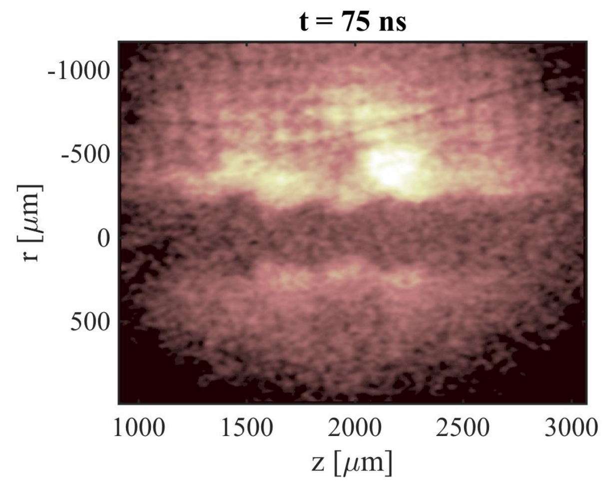
Center for Laboratory Astrophysics





NNSA Center of Excellence,

Carolyn Kuranz, Director

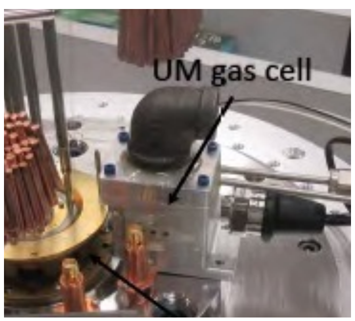
University of Michigan

This work is funded by the Stockpile Stewardship Academic Alliances through cooperative agreement DE NA0003869
The Center also has or has had support from NLUF, LLE, LLNL, DTRA, LANL, NRL, NSF, and ASC

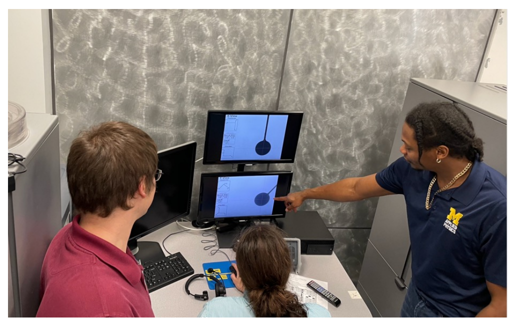
Outline for talk

Center for Laboratory Astrophysics (CLA) goals:

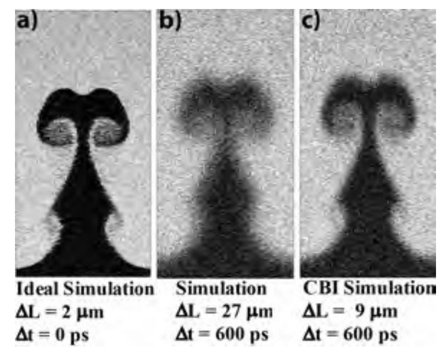
- **Fundamental research in High Energy Density physics**
  - **Radiative Heat Front experiments on Omega and Z**
- **Interactions with NNSA laboratory scientists**
- **CLA students and education**



Gas Cell on Z machine



Target Alignment at Omega



HYDRA simulations

CLA Project Goals

- Perform fundamental research in High Energy Density physics and closely related areas, united by the theme of relevance to the evolution of the Universe after its Dark Ages, during the period when galactic structure developed, soon after the first stars formed

- Continue a high level of scientific interactions with the NNSA laboratories

- Continue our long-term pipeline of junior scientists of interest to the NNSA laboratories, trained and educated in fundamental research of relevance to stockpile stewardship goals, thereby also increasing the visibility of DOE/NNSA scientific activities to the U.S. academic communities.

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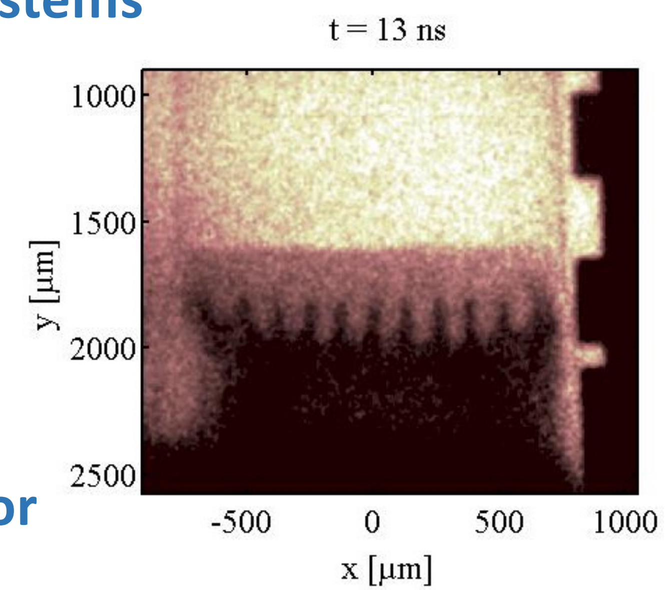
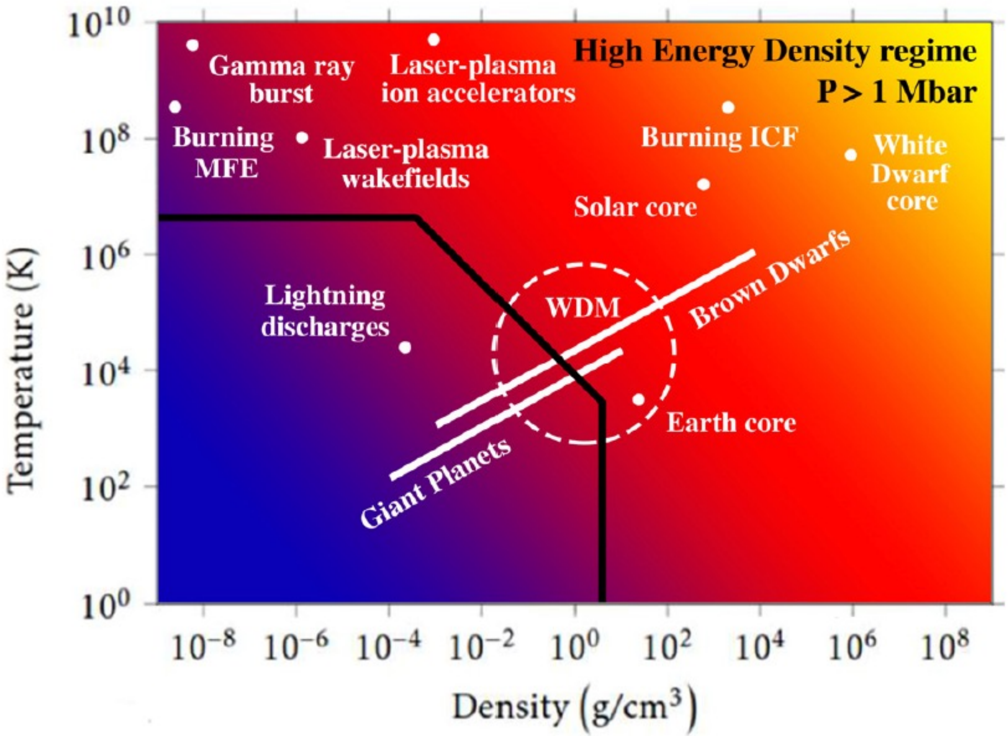
The Center Laboratory Astrophysics studies high-energy-density phenomena that are relevant to astrophysics

- We advance fundamental understanding of HED systems
  - Radiation transport and radiation hydrodynamics
  - Complex HED hydrodynamics
  - Magnetized flowing plasma
- While advancing the required infrastructure
  - Computer simulation
  - Target fabrication
- The ultimate goal of these activities is to train junior scientists
  - We have an HED-focused education
  - We conduct HED research at NNSA facilities
  - We have significant interactions with NNSA scientists



X-ray radiography of a RT experiment at the National Ignition Facility with high energy fluxes

High-energy-density (HED) physics has significant overlap with astrophysical systems



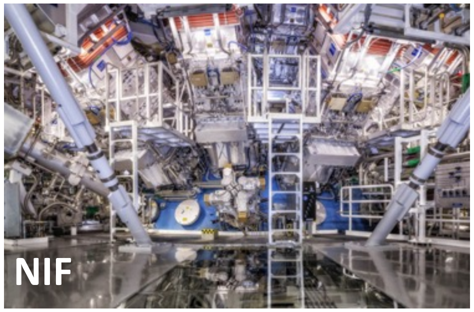
HED systems have pressures > 1 Mbar

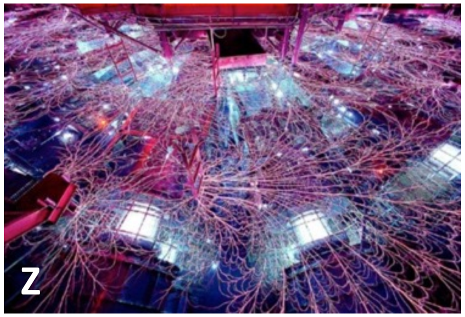
1 Mbar = 0.1 Tpascal
10^{12} dynes/cm^2
10^6 atm

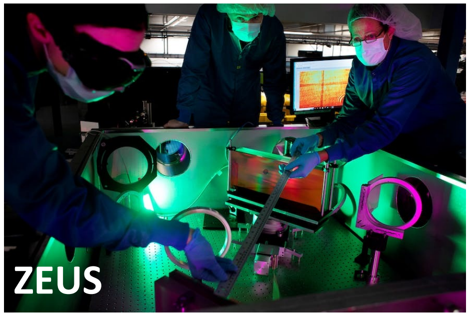
NASEM Report, Plasma Science: Enabling Technology, Sustainability, Security, and Exploration (2020)
NASEM HED Assessment Coming Soon!

CLA uses a variety of HEDP "tools" to do our work – big and small

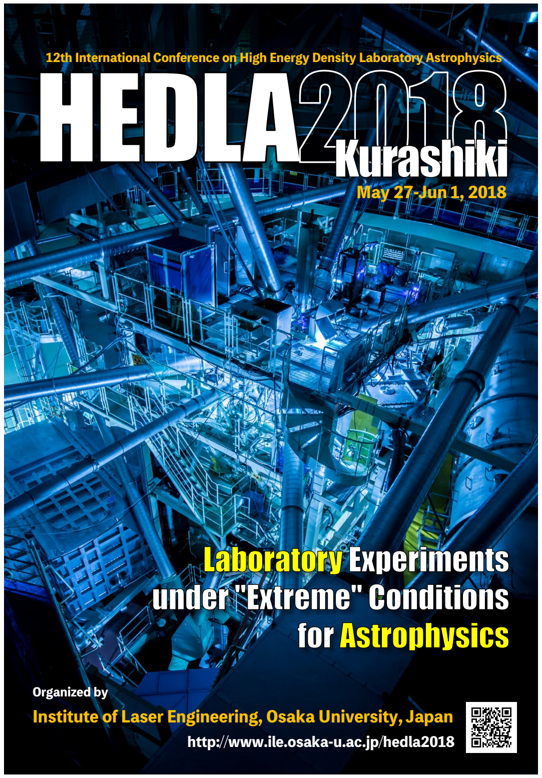
- Omega, Omega EP, MTW (LLE)
- National Ignition Facility, Jupiter Laser Facility (LLNL)
- MAIZE (University of Michigan)
- ZEUS (University of Michigan, coming soon!)
- BELLA (LBNL)
- Z machine (SNL)
- ORION Laser Facility (AWE)





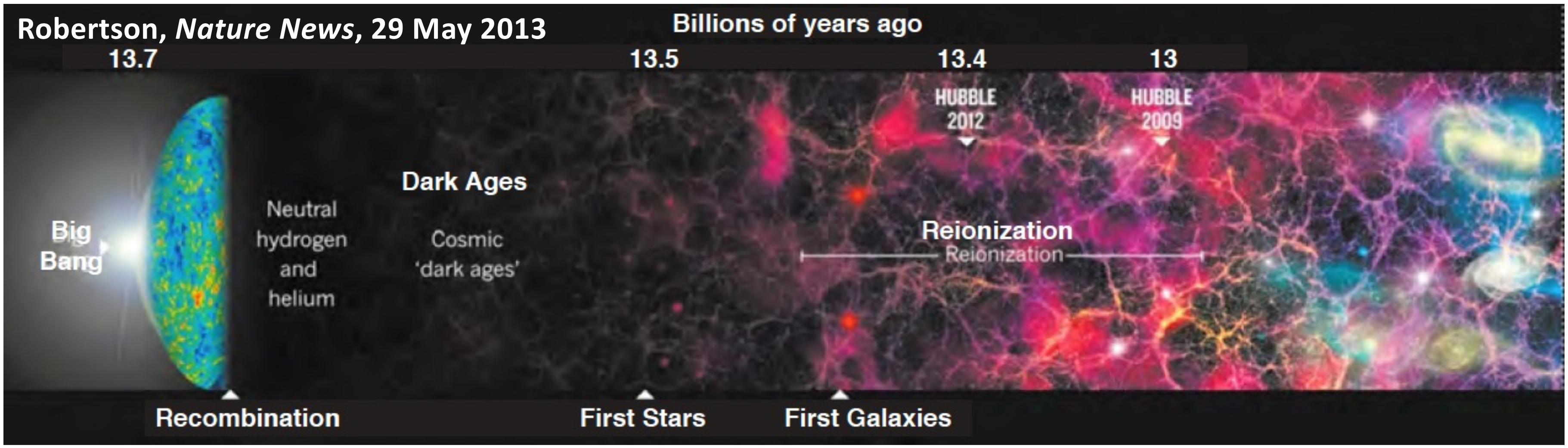


HED Laboratory Astrophysics is a young, but growing field



- HEDLA started in 1996 focused on hydrodynamics
- Now includes planetary interiors, equation of state, atomic processes, photoionization, stellar opacity, magnetic reconnection, particle acceleration, collisionless plasmas, turbulent dynamos, nuclear astrophysics, pair plasmas…
- Here I will focus on radiation hydrodynamics, specifically photoionization fronts

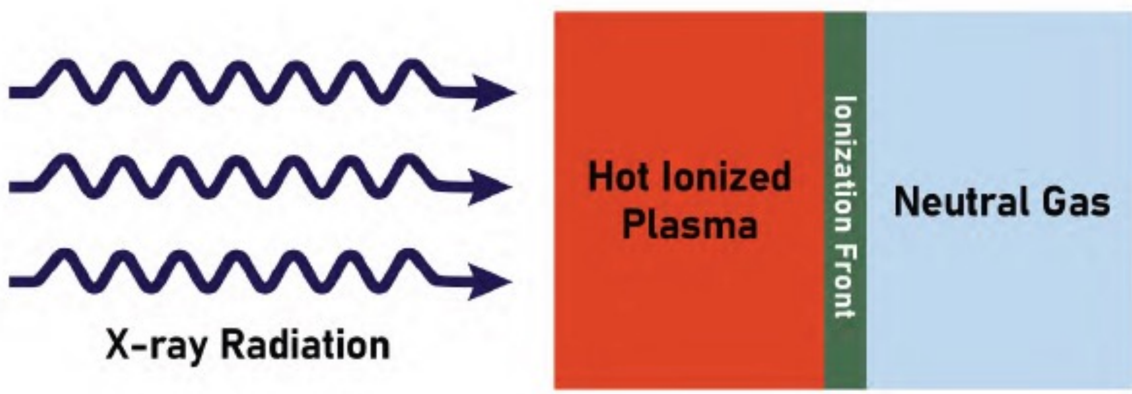
Photoionized plasmas exist throughout our Universe



How do we create and characterize photoionized (PI) fronts in the laboratory? How do PI fronts evolve? What is the origin of clumpy material?

See Posters by Kwyntero Kelso and Michael Springstead

We can use high-energy-density facilities to explore PI fronts evolution



Omega and Z can create a sufficient x-ray source to drive a photoionization front

CLA Theory and Design papers on PI Fronts:

Drake et al., *Astrophysical Journal* (2016)
Gray et al. , *Astrophysical Journal* (2018)
Gray at al. , *Physics of Plasmas* (2019)
LeFevre et al., *Physics of Plasmas* (2021)
LeFevre et al*, Physics of Plasmas* (2022)

H. J. LeFevre thesis: “Radiation Hydrodynamics Experiments on Large High-Energy-Density-Physics Facilities that are Relevant to Astrophysics,” (2021)

Dr. Heath LeFevre, NSF Postdoctoral Fellow

For a PI front to form we require

1) photoionization to dominate recombination

$$\alpha = \frac{\text{recombination}}{\text{photoionization}}$$

2) recombination to dominate electron collisional ionization

$$\beta = 1 + \frac{\text{electron collisional ionization}}{\text{recombination}}$$

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

We need photoionization to dominate recombination and recombination to dominate electron collisional ionization

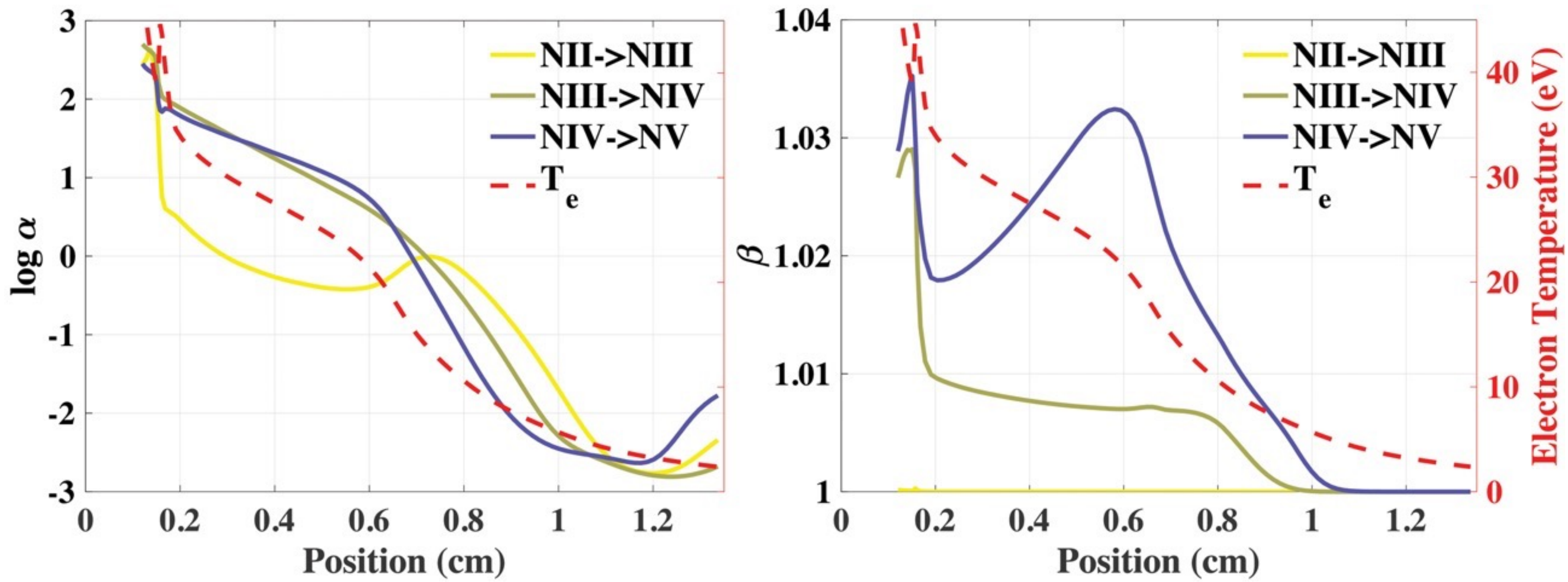
$$\alpha = \frac{n_{i+1}}{n_i}\frac{R_{i+1,i}n_e}{\Gamma_{i,i+1}},$$

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

For a PI front to form $\alpha \ll 1$ 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})

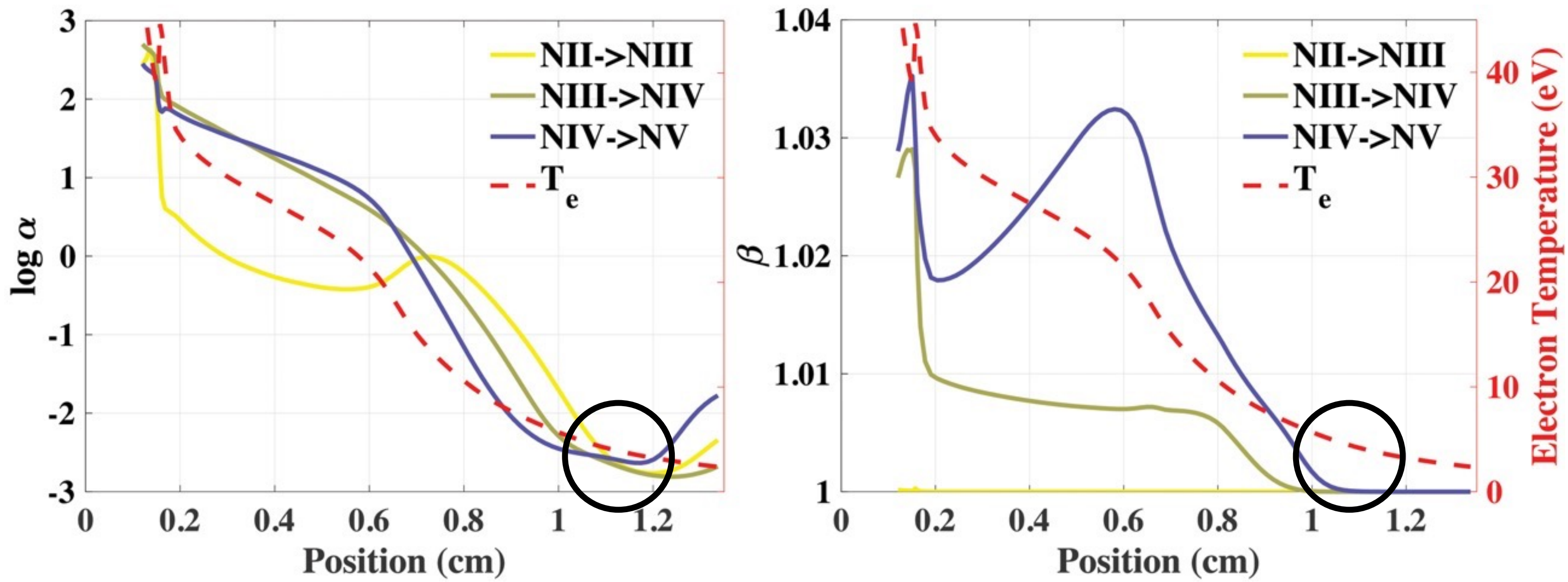
We use HELIO-CR to estimate key PI front parameters



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

See LeFevre, *Physics of Plasmas*, 2021

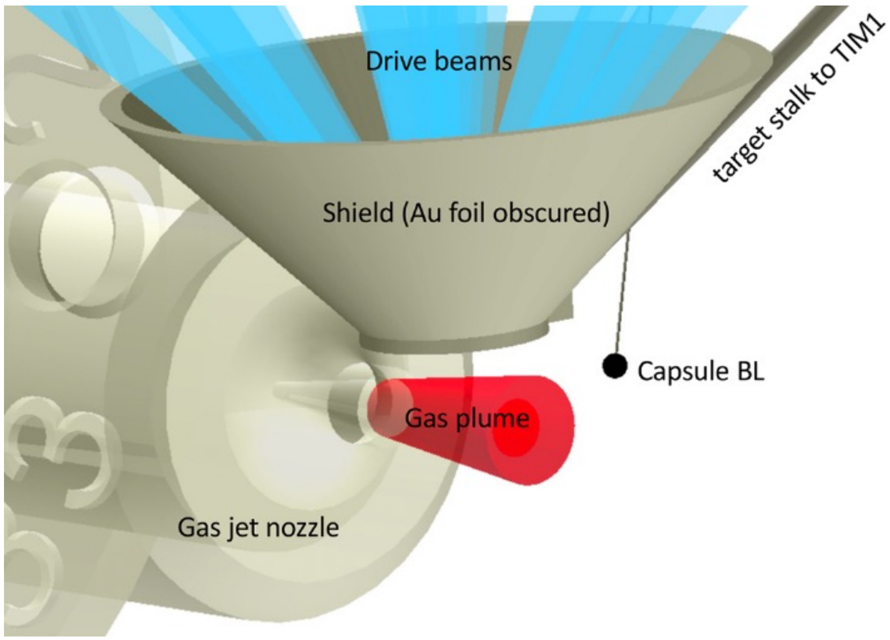
We use HELIO-CR to estimate key PI front parameters



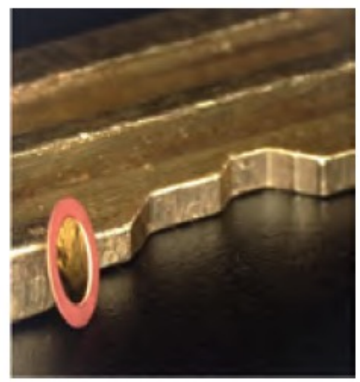
For a PI front to form α << 1 and β ≈ 1

See LeFevre, *Physics of Plasmas*, 2021

On Omega we use x-ray absorption spectroscopy to measure temperature, density, and ionization state populations



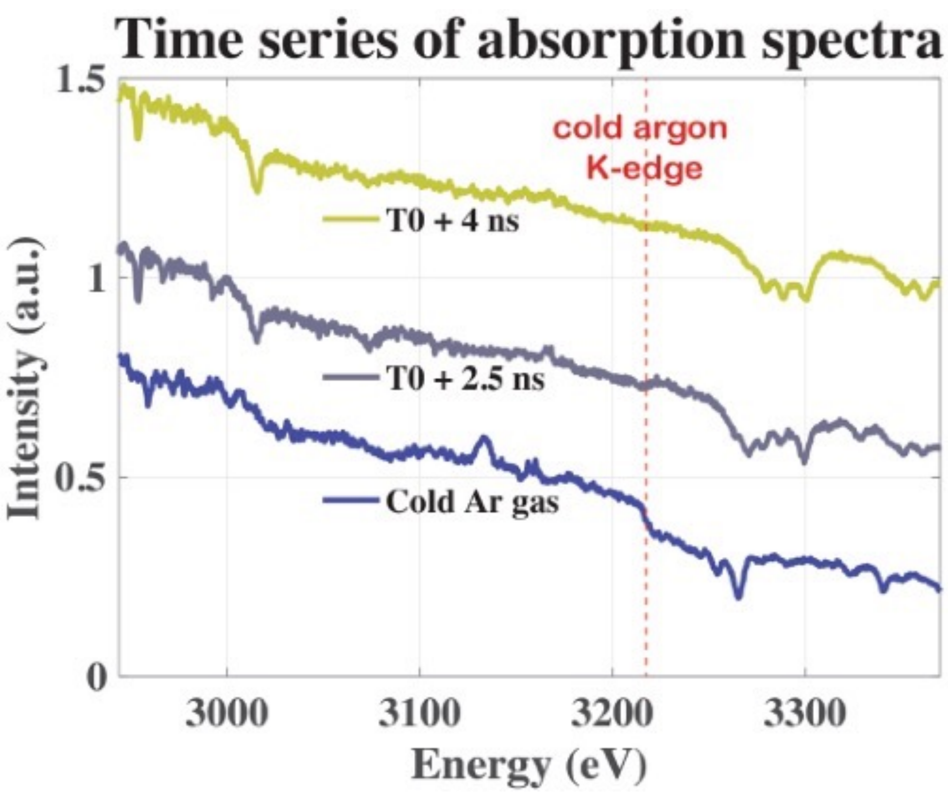
I ~ 10^{14} W/cm^2 on Au foil creates an ~ 80 eV source for several ns
X-rays are incident on an Argon gas plume
A CH capsule creates a 2-4 keV continuum x-ray source for diagnostic



500 nm Au foil next to a key for scale

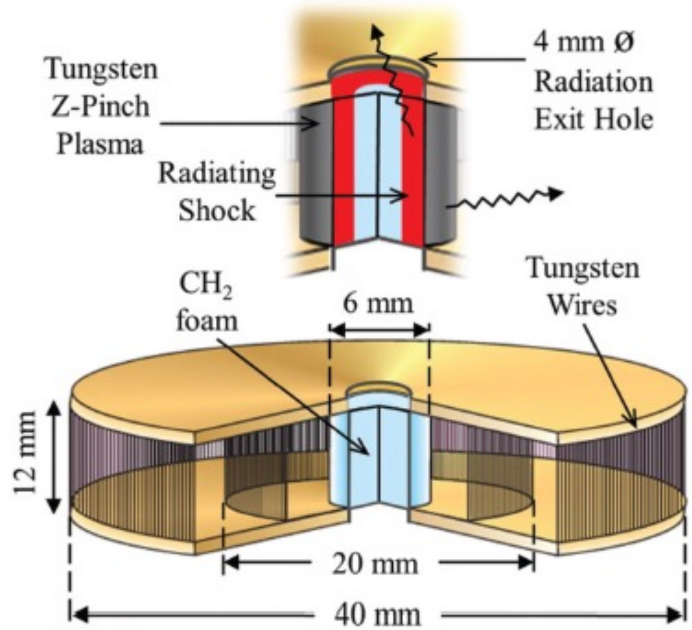
See Davis et al., *Review of Scientific Instruments (*2016) and Davis et al. *Physics of Plasmas* (2018) for source characterization

Preliminary data indicates we have a heat wave

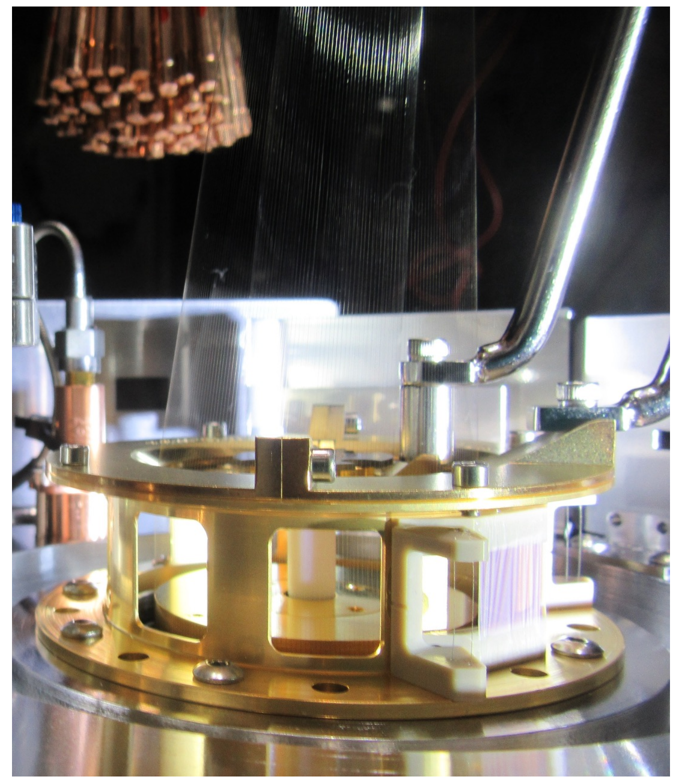


- Ionization of gas is changing with time and space, likely due to a heat wave moving through the gas cell
- Working to estimate α and β and if the heat wave is dominated by photoionization
- Next shot day in May

We are also using the Z pinch dynamic hohlraum (ZPDH) to study PI fronts

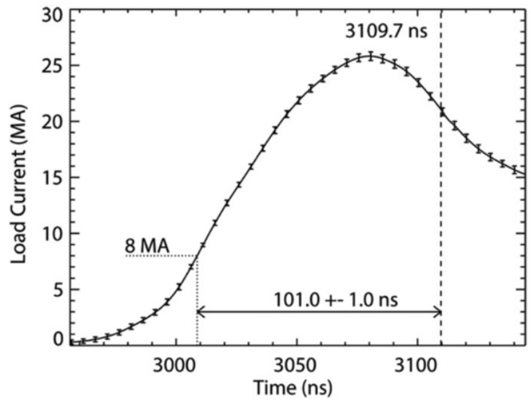


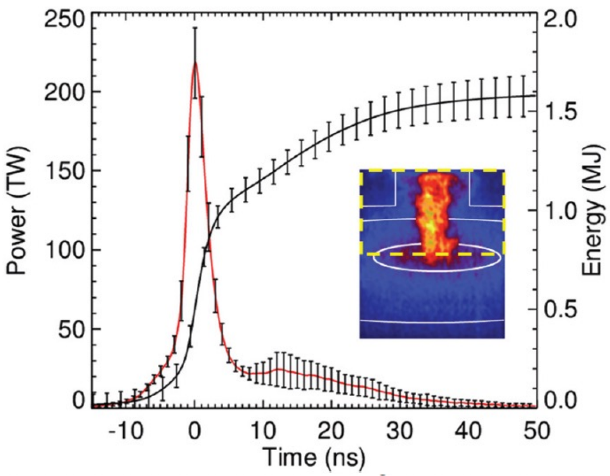
G. Rochau et al., *Physics of Plasmas* 2014



ZAPP shots January 2023

The ZPDH is a well characterized platform



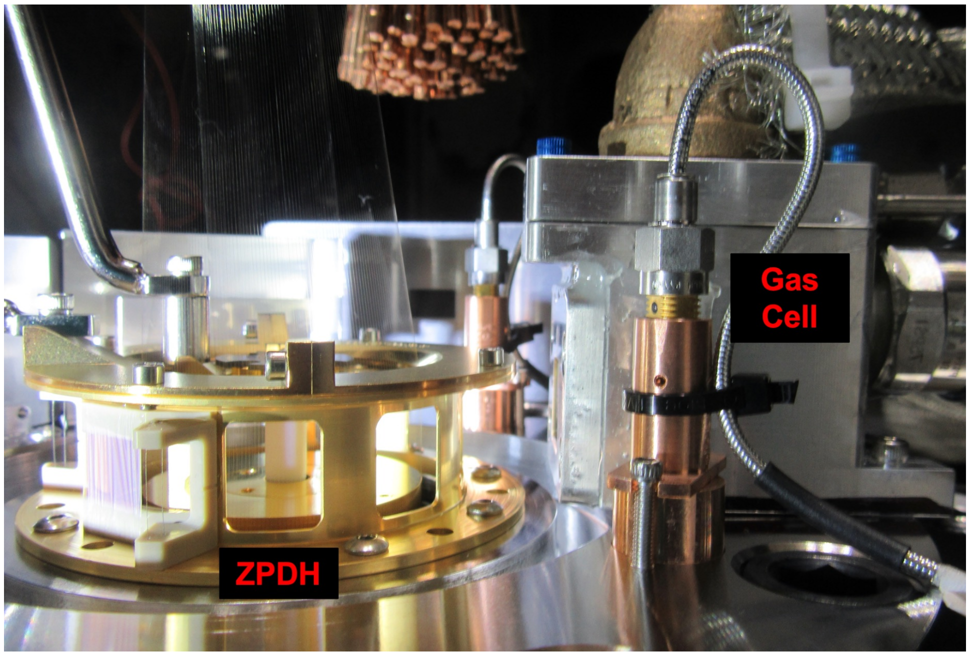


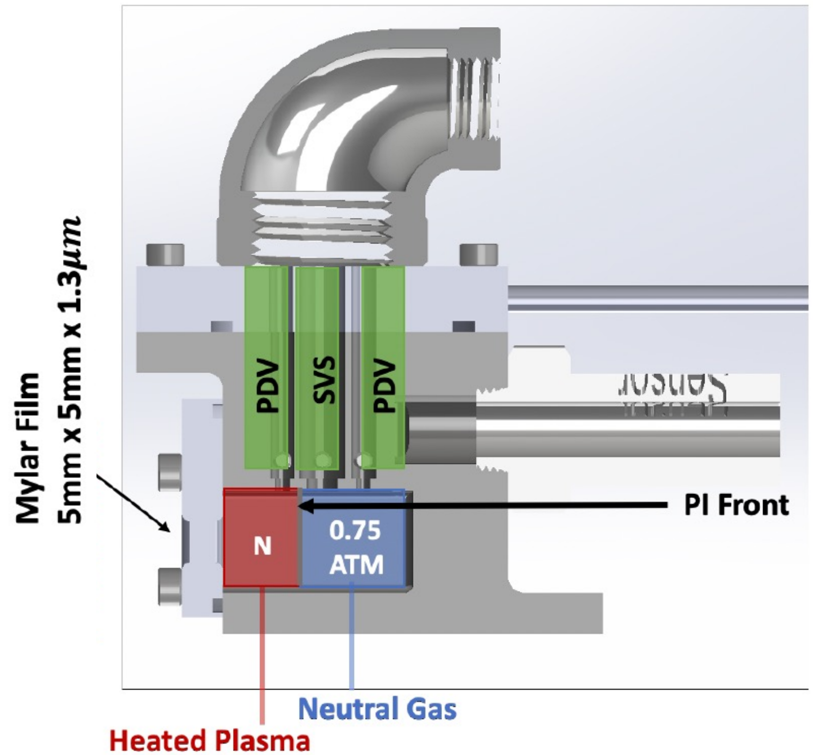
G. Rochau et al., *Physics of Plasmas* 2014

Recent papers using the ZAPP platform:

P.B. Cho et al., *Astrophysical Journal* (2022)
H.J. LeFevre et al., *Physics of Plasmas* (2021)
D.C. Mayes et al., *Physical Review E* (2021)
M.-A. Schaeuble et al., *Physics of Plasmas* (2021)
D.E. Winget et al., *High Energy Density Physics* (2020)

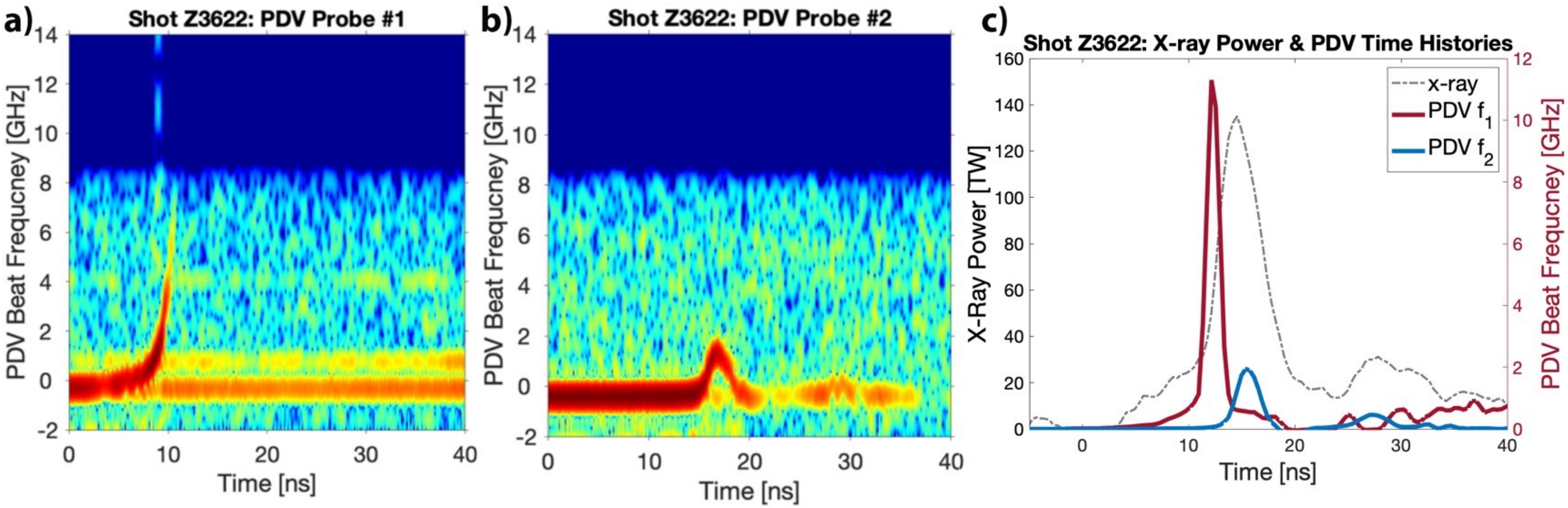
We use Photon Doppler Velocimetry (PDV) and Streaked Visible Spectroscopy (SVS) to measure plasma parameters





PDV has 2 probes and can measure wave velocity and electron density
SVS can measure temporally resolved density, temperature and ionization state

Again, we likely have created a heat wave, but need to determine if it is a PI front



Ionization of gas is changing in time and space, likely due to a heat wave moving through the gas cell, but need additional information to determine if it is dominated by photoionization.

Next experiments in November

Summary of fundamental research in HED radiation hydrodynamics and radiation transport

- We designed and fielded experiments on the Omega Laser Facility and the Z machine to create and characterize photoionization fronts
- Preliminary data on both platforms suggest we have an ionizing radiation wave, but we need more information to determine if photoionization is dominant
- We have additional experiments in May on Omega and in November on Z
- For our future work we will change the gas species and the density of the gas and determine how that affect the formation and evolution of the front.

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- Continue our long-term pipeline of junior scientists of interest to the NNSA laboratories, trained and educated in fundamental research of relevance to stockpile stewardship goals, thereby also increasing the visibility of DOE/NNSA scientific activities to the U.S. academic communities.

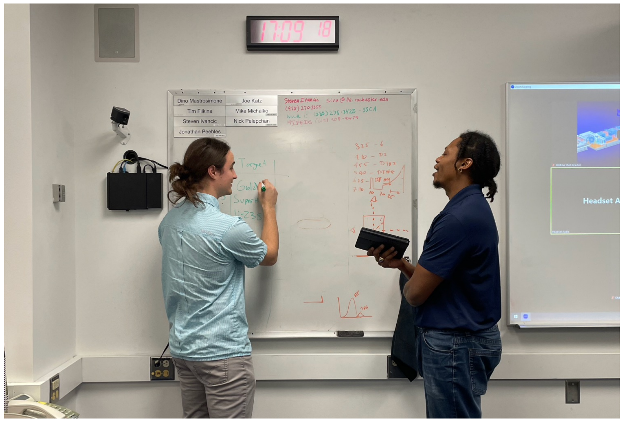
Each scientific thrust area has NNSA collaborators

- Radiation transport and radiation hydrodynamics
  - Heather Johns, LANL
  - Stephanie Hansen, SNL
  - Chris Fryer, LANL
  - Todd Urbatsch, LANL
  - Paul Keiter, LANL
  - Guillaume Loisel, SNL
  - Jim Bailey, SNL
  - Peter Porazik, LLNL
  - Patrick Poole, LLNL
- Magnetized plasmas
  - Joseph Levesque, LANL
  - Kirk Flippo, LANL
  - Kathy Chandler, SNL
  - Kumar Raman, LLNL
  - Chris Jennings, SNL
- Complex HED hydrodynamics
  - Sabrina Nagel, LLNL
  - Channing Huntington, LLNL
  - Liz Merritt, LANL
  - Forrest Doss, LANL
  - Carlos Di Stefano, LANL
  - Mike MacDonald, LLNL

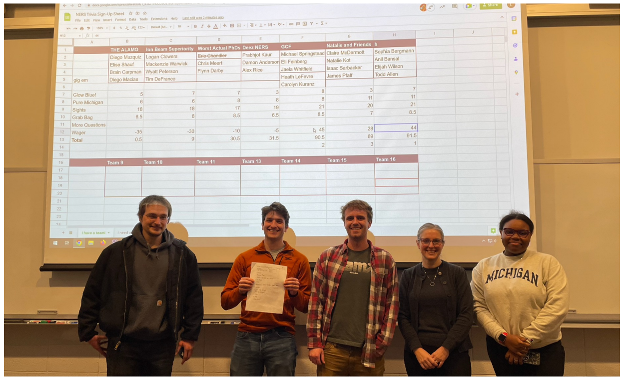
Names in blue serve on student PhD thesis committees

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)
- Nuclear Engineering is #1 in the country
- UM is #3 public, UM COE is #9 overall



Students at Omega Laser Facility



CLA at Trivia Night!

CLA has place many students at NNSA laboratories

Recent Graduates at NNSA labs:

- Jeff Fein (2017, SNL)
- Willow Wan (2017, LANL, LLNL)
- Alex Rasmus (2019, LANL)
- Laura Elgin (2019, SNL)
- Joseph Levesque (2020, LANL)
- Robert Vandervort (2022, LANL)

Shane Coffing and Adrianna Angulo defended in January 2023. Shane has accepted a position at LANL.

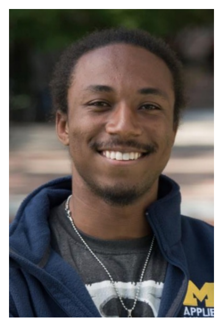
Current Grad Students and Postdoc:

- Dr. Heath LeFevre
- Raul Melean
- Kwyntero Kelso
- Khalil Bryant
- Michael Springstead
- Eli Feinberg
- Shailaja Humane
- Julian Kinney
- Jaela Whitfield

CLA Students and Postdocs at SSAP

Dr. Heath LeFevre
Kwyntero Kelso
Michael Springstead
Khalil Bryant
Eli Feinberg
Shailaja Humane
Julian Kinney




HEDP Education at University of Michigan

- Students take a variety of plasma physics classes
  - 15 classes offered involving theory, diagnostics, laboratory
  - 7 TT faculty, 4 research faculty, 3 emeritus faculty
- We offer a High Energy Density Physics course
- We offer a biennial summer school
  - Next is summer 2024
- We also have a strong undergraduate program

HEDSS Lectures by Kuranz, Thomas, Willingale, McBride, Johnsen, Baalrud, and Krushelnick

Undergraduate working in target fabrication lab

UM faculty in HED or related fields

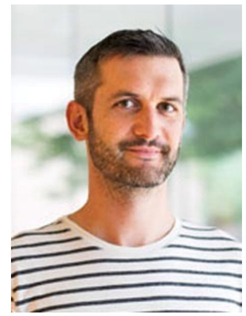
TT faculty

Eric Johnson
(ME)

Ryan McBride
(NERS)

Scott Baalrud
(NERS)

Karl Krushelnick
(NERS)



Alec Thomas
(NERS)

Louise Willingale
(ECE)

Carolyn Kuranz
(NERS)

Emeritus faculty

YY Lau
(NERS)

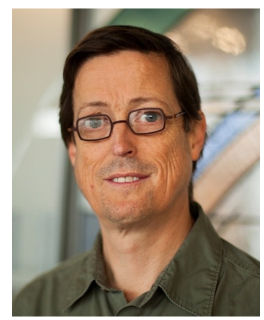
Ron Gilgenbach
(NERS)

Paul Drake
(CLASP)

Research faculty

Nick Jordan
(NERS)

Anatoly
Maksimchuk
(ECE)



John Nees
(ECE)

Gennady Fiksel
(NERS)

nature physics

Article https://doi.org/10.1038/s41567-022-01839-x

Non-thermal electron acceleration from magnetically driven reconnection in a laboratory plasma

Received: 11 June 2021
Accepted: 14 October 2022
Published online: 16 January 2023
Check for updates

Abraham Chien[1], Lan Gao[2], Shu Zhang[1], Hantao Ji[1,2], Eric G. Blackman[3,4], William Daughton[5], Adam Stanier[5], Ari Le[5], Fan Guo[5], Russ Follett[4], Hui Chen[6], Gennady Fiksel[7], Gabriel Bleotu[8,9,10], Robert C. Cauble[6], Sophia N. Chen[8], Alice Fazzini[10], Kirk Flippo[5], Omar French[2,11], Dustin H. Froula[4], Julien Fuchs[10], Shinsuke Fujioka[12], Kenneth Hill[2], Sallee Klein[7], Carolyn Kuranz[7], Philip Nilson[4], Alexander Rasmus[5] & Ryunosuke Takizawa[12]

Matter and Radiation at Extremes RESEARCH ARTICLE scitation.org/journal/mre

On the study of hydrodynamic instabilities in the presence of background magnetic fields in high-energy-density plasmas

Cite as: Matter Radiat. Extremes 6, 026904 (2021); doi: 10.1063/5.0025374
Submitted: 19 August 2020 • Accepted: 26 January 2021 •
Published Online: 5 March 2021

View Online Export Citation CrossMark

M. J.-E. Manuel,[1,a)] B. Khiar,[2] G. Rigon,[3] B. Albertazzi,[3] S. R. Klein,[4] F. Kroll,[5] F. -E. Brack,[5,6] T. Michel,[3] P. Mabey,[3] S. Pikuz,[7] J. C. Williams,[1] M. Koenig,[3] A. Casner,[8] and C. C. Kuranz[4]

Physics of Plasmas ARTICLE scitation.org/journal/php

Vortex-sheet modeling of hydrodynamic instabilities produced by an oblique shock interacting with a perturbed interface in the HED regime

Cite as: Phys. Plasmas **28**, 022303 (2021); doi: 10.1063/5.0029247
Submitted: 10 September 2020 · Accepted: 8 January 2021 ·
Published Online: 2 February 2021

View Online Export Citation CrossMark

S. Pellone,[1,a)] C. A. Di Stefano,[2] A. M. Rasmus,[2] C. C. Kuranz,[1] and E. Johnsen[1]

Physics of Plasmas ARTICLE scitation.org/journal/php

The design of a photoionization front experiment using the Z-Machine as a driving source and estimated measurements

Cite as: Phys. Plasmas **28**, 093304 (2021); doi: 10.1063/5.0049527
Submitted: 5 March 2021 · Accepted: 6 September 2021 ·
Published Online: 27 September 2021

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H. J. LeFevre,[1,a)] M. Springstead,[1] K. Kelso,[1] R. C. Mancini,[2] G. P. Loisel,[3] P. A. Keiter,[4] R. P. Drake,[5] and C. C. Kuranz[6]

Jinst

Published by IOP Publishing for Sissa Medialab

Received: *December 1, 2021*
Accepted: *January 19, 2022*
Published: *February 15, 2022*

Design of a high-resolution Rayleigh-Taylor experiment with the Crystal Backlighter Imager on the National Ignition Facility

A.M. Angulo,[a,*] S.R. Nagel,[b] C.M. Huntington,[b] C. Weber,[b] H.F. Robey,[c] G.N. Hall,[b] L. Pickworth[d] and C.C. Kuranz[a]

Physics of Plasmas ARTICLE scitation.org/journal/php

Experimental observations of detached bow shock formation in the interaction of a laser-produced plasma with a magnetized obstacle

Cite as: Phys. Plasmas **29**, 012106 (2022); doi: 10.1063/5.0062254
Submitted: 3 July 2021 · Accepted: 11 December 2021 ·
Published Online: 10 January 2022

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Joseph M. Levesque,[1,2,3,a)] Andy S. Liao,[4,5] Patrick Hartigan,[4] Rachel P. Young,[2,3] Matthew Trantham,[2,3] Sallee Klein,[2,3] William Gray,[2] Mario Manuel,[2,6] Gennady Fiksel,[3] Joseph Katz,[7] Chikang Li,[8] Andrew Birkel,[8] Petros Tzeferacos,[7,9,10] Edward C. Hansen,[9,10] Benjamin Khiar,[9] John M. Foster,[11] and Carolyn C. Kuranz[2,3]

Physics of Plasmas BRIEF COMMUNICATION scitati

The evolution of curvature in planar, photoionization-driven heat fronts

Cite as: Phys. Plasmas **29**, 084501 (2022); doi: 10.1063/5.0088624
Submitted: 18 February 2022 · Accepted: 6 July 2022 ·
Published Online: 3 August 2022

View On

H. J. LeFevre,[1,a)] R. P. Drake,[2] and C. C. Kuranz[1]

2021 Conference on Lasers and Electro-Optics, CLEO 2021 - Proceedings • May 2021 • 2021 Conference on Lasers and Electro-Optics, CLEO 2021 • Virtual, Online • 9 May 2021through 14 May 2021 • Code 173264

Zettawatt Equivalent Ultrashort pulse laser System: An NSF mid-scale facility for laser-driven science in the QED regime

Nees, John; Maksimchuk, Anatoly; Kalinchenko, Galina; Hou, Bixue; Ma, Yong; Campbell, Paul; McKelvey, Andrew; Willingale, Louise; Jovanovic, Igor; Kuranz, Carolyn; Thomas, Alexander; Krushelnick, Karl

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Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Check for updates

ptimization of the electron beam dump for a GeV-class laser electron ccelerator

Shi[a], D. Sun[a], I. Jovanovic[a,b,*], G. Kalinchenko[b,c], K. Krushelnick[a,b], C.C. Kuranz[a,b], Maksimchuk[b,c], J. Nees[b,c], A.G.R. Thomas[a,b], L. Willingale[b,c]

›partment of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109, United States
›rard Mourou Center for Ultrafast Optical Science, University of Michigan, Ann Arbor, MI 48109, United States
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Recent CLA Publications

Angulo, A. M., Nagel, S. R., Huntington, C. M., Weber, C., Robey, H. F., Hall, G. N., . . . Kuranz, C. C. (2022). Design of a high-resolution rayleigh-taylor experiment with the crystal backlighter imager on the national ignition facility. Journal of Instrumentation, 17(2) doi:10.1088/1748-0221/17/02/P02025

Chien, A., Gao, L., Zhang, S., Ji, H., Blackman, E. G., Daughton, W., . . . Takizawa, R. (2023). Non-thermal electron acceleration from magnetically driven reconnection in a laboratory plasma. Nature Physics, doi:10.1038/s41567-022-01839-x

Lefevre, H. J., Drake, R. P., & Kuranz, C. C. (2022). The evolution of curvature in planar, photoionization-driven heat fronts. Physics of Plasmas, 29(8) doi:10.1063/5.0088624

Lefevre, H. J., Springstead, M., Kelso, K., Mancini, R. C., Loisel, G. P., Keiter, P. A., . . . Kuranz, C. C. (2021). The design of a photoionization front experiment using the Z-machine as a driving source and estimated measurements. Physics of Plasmas, 28(9) doi:10.1063/5.0049527

Levesque, J. M., Liao, A. S., Hartigan, P., Young, R. P., Trantham, M., Klein, S., . . . Kuranz, C. C. (2022). Experimental observations of detached bow shock formation in the interaction of a laser-produced plasma with a magnetized obstacle. Physics of Plasmas, 29(1) doi:10.1063/5.0062254

Manuel, M. J. -., Khiar, B., Rigon, G., Albertazzi, B., Klein, S. R., Kroll, F., . . . Kuranz, C. C. (2021). On the study of hydrodynamic instabilities in the presence of background magnetic fields in high-energy-density plasmas. Matter and Radiation at Extremes, 6(2) doi:10.1063/5.0025374

Nees, J., Maksimchuk, A., Kalinchenko, G., Hou, B., Ma, Y., Campbell, P., . . . Krushelnick, K. (2021). Zettawatt equivalent ultrashort pulse laser system: An NSF mid-scale facility for laser-driven science in the QED regime. Paper presented at the 2021 Conference on Lasers and Electro-Optics, CLEO 2021 - Proceedings

Nees, J., Maksimchuk, A., Kalinchenko, G., Hou, B., Ma, Y., Campbell, P., . . . Krushelnick, K. (2021). Zettawatt equivalent ultrashort pulse laser system: An NSF mid-scale facility for laser-driven science in the QED regime. Paper presented at the Optics InfoBase Conference Papers

Pellone, S., Di Stefano, C. A., Rasmus, A. M., Kuranz, C. C., & Johnsen, E. (2021). Vortex-sheet modeling of hydrodynamic instabilities produced by an oblique shock interacting with a perturbed interface in the HED regime. Physics of Plasmas, 28(2) doi:10.1063/5.0029247

Shi, T., Sun, D., Jovanovic, I., Kalinchenko, G., Krushelnick, K., Kuranz, C. C., . . . Willingale, L. (2021). Optimization of the electron beam dump for a GeV-class laser electron accelerator. Applied Radiation and Isotopes, 176 doi:10.1016/j.apradiso.2021.109853

Conclusions

- Laboratory experiments can garner information about specific processes in astrophysical systems
- We have created heat waves on Omega and Z, but need further work to determine the dominant mechanisms for ionization
- We will use upcoming shot days to characterize the PI fronts and vary parameters that affect their evolution
- We will continue our interactions with NNSA scientists, placing students in positions at NNSA laboratories, and publish fundamental HED research