Science with High-Power Lasers and Pulsed Power (#3), Research Opportunities and User Meeting

Report of a workshop, Santa Fe, July 28-30, 2011

9/8/11

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Executive Summary

A workshop on "Science with High-Power Lasers and Pulsed Power (#3), Research Opportunities and User Meeting" was held in the Santa Fe Eldorado Hotel, July 28 through July 30, 2011. It was organized under the auspices of the Institute for High Energy Density Science (HEDS), a joint University of Texas (UT) and Sandia National Laboratories (SNL) Institute. This institute was created in part to encourage and enable national access to the unique High Energy Density (HED) facilities at the Sandia National Laboratories (SNL) and the University of Texas (UT), and in so doing to enable the best user-involved science in the broadest national interest, and to grow the national HED user community.

The objectives of the 2 1/2 day workshop were first to discuss broad-interest, fundamental science experiments that are or could be performed using the pulsed power facilities and high-power lasers at Sandia National Laboratories (SNL) and the University of Texas (UT), and second to facilitate a user meeting for current and prospective users of these same facilities. Emphasis was placed on how to maximize the impact of the current fundamental science program, while being realistic in what can be achieved with the limited shot time available on these unique facilities (i.e. 'manage and maintain expectations'). Of note at SNL is the intent to provide up to 15% of the shot time on Z for fundamental science; a proposal call, peer review and selection of the first experiments to be performed is complete. Of note at UT is that the Texas Petawatt Laser is operating routinely in a 'collaborative user' mode. The experimental devices under consideration were, at SNL: The Z accelerator with its diagnostic suite (including the Z- Beamlet laser and Z-Petawatt laser), and at UT (Austin): The Texas Petawatt (TPW), THOR, and GHOST lasers. Information on facility capabilities, and how to access them, was provided as part of the User meeting. Note that neither of the two major facilities (Z, TPW) is a 'User Facility' in the usual Department of Energy sense. Rather they should be considered as 'Collaborative User Facilities': an outside (to the facility institution) principle investigator requires a co-principle investigator from within the facility institution.

The two main components of the workshop were:

1) Research Directions: To propose and discuss fundamental research worthy of pursuit on the pulsed power and laser facilities at SNL and UT, with emphasis on maximizing the impact of those experiments ongoing or about to start.

2) User meeting: To facilitate a user meeting, and present to users the various facility operational plans, capabilities and support infrastructure. This included obtaining user

recommendations for improvements, and to provide an opportunity for existing working groups to develop experimental plans and proposals, even do some science.

The User Meeting provided for presentations by current and soon-to-be users of the facilities under discussion (a plenary session), and descriptions by facility staff of facility access, capabilities and experimental platforms. The Research Directions part of the workshop consisted of three individual daylong breakout sessions in the areas of: Radiative astrophysics, Planetary science, and Magnetized high energy density science. Here discussions revolved around the topics of: How to maximize the impact of our current research, How to grow the community and where appropriate the teams, New ideas, and Infrastructure requests.

Individual presentations will be found at the workshop web address: http://www.ph.utexas.edu/~iheds/2011IHEDSWorkshop.html. A summary session documented the breakout sessions' deliberations. The main topics discussed and conclusions drawn are found in the individual breakout session sections of this report, as presented at the workshop summary session (Radiative astrophysics, Magnetized high energy density science, Planetary science). Table 1 summarizes the major topics discussed in the breakout sessions. This selection is a direct result of the deliberations of the two previous workshops in this series.

Laboratory Astrophysics	
	White dwarf photospheres
	Photo-ionized plasmas
	Resonant Auger Destruction / black hole accretion
	Stellar interior opacities
Magnetized High Energy Density	
	Scaled ionization experiments and plasma transport
	Magnetized plasma jets
	Cluster fusion
Planetary Science	
	Earths and super-earths (moon-forming events)
	Giant planet formation

Table 1: Major experimental areas discussed

While emphasis was placed on discussing how to best utilize the available existing capabilities, there was limited discussion of what additional diagnostics or other facility capabilities would be beneficial. Table 2 represents a summary; details are given in the individual breakout session reports found below. Other infrastructure additions that would help users are summarized in Table 3; again details are found in the individual breakout session reports.

Diagnostics	
Laboratory astrophysics	
Electron temperature in x-ray driven gas	Optical Thomson scattering
	Radiative recombination continuum
	Line ratios
High accuracy drive spectrum	XUV spectrometer
Electron density in x-ray driven gas	Interferometry
	Optical Thomson scattering
	Line ratio or absolute spectral intensities
Self emission from photoionized plasma	Spherical crystal spectrometer
High resolution XUV spectroscopy (15-100 Angstroms)	Variable line space grazing incidence spectrometer
Multiple simultaneous optical spectra	Multiple optical spectrometer systems at Z
Gas cell initial conditions	Pressure transducer, temperature gauge
Magnetized HED	
Plasma dynamics	optical shadowgraphy & interferometry
Magnetic fields	How?
Planetary science	
Temperature	optical pyrometry, X-ray scattering
Solid participates	Mie-scattering
Structure	X-ray diffraction
Chemical analysis	Raman spectroscopy
Facility capabilities	
Magnetic fields in 2x10 cm scale cells (1-10 T)	
Ability to field sealed gas cells filled with Silane or other Si bearing gas	

Table 2. Diagnostics discussed to improve capabilities

A written description of how we do business, i.e. a standing operating procedure
Handbook: capabilities, platforms, diagnostics, training, access requirements
Checklist to ensure visitor logistics run smoothly
Assistance with housing, establishing a community atmosphere for visitors/students
Office space, lab space; computer access
External web: description of ongoing projects; solicitation schedule for Z time
Closure after experiments: outbrief soon after experiment, annual report of collaborative experiments and research

Table 3: User-suggested infrastructure additions

Workshop Objectives and Deliverables

The workshop was both a Research Directions and a User meeting. The overarching objective was to help maximize the impact of the current fundamental science program, while remaining realistic concerning the available resources. With this in mind, the following deliverables were requested, in two prioritized categories:

Priority 1

1) A status report for each research project with allocated experimental time (astrophysics, planetary science, magnetized HED science)

2) A summary of how each individual research proposal will maximize the impact of the research while managing expectations (limited shots, diagnostics, etc.)

3) Specific ideas on how to grow our community and where appropriate the individual research teams

Priority 2:

4) New research directions for consideration. However we need our committed-to fundamental research to succeed, so this must have priority

5) Infrastructure suggestions (diagnostics, design tools, analysis tools, data access, lab space, etc.). However initial focus should be on utilizing existing infrastructure

Deliverable 1 (status reporting) is met by the individual presentations collected on the web page at http://www.ph.utexas.edu/~iheds/2011IHEDSWorkshop.html. Deliverable 2 (how to maximize impact utilizing existing resources), Deliverable 3 (community growth) and Deliverable 4, (new directions) are met by the content of the three breakout session out-briefs found following this section. Deliverable 5 is met by Tables 2 and 3.

Summary of the laboratory radiative astrophysics session

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Basic questions:

What is our definition of success?
    Near term impact: a peer-reviewed paper combined with a compelling story, in a presentation format suitable for non-experts
    Longer term: sustained track record of publication; attraction of new scientists to the field; altering the approach adopted by others
What is the ***minimum*** collection of measurements needed?
    Focus on minimum needed to ensure solid reliable results, then expand into new arenas
What might go wrong and how can we avoid it?

What capabilities are needed?

How should we communicate our results?
    AAS summer meeting typically includes special sessions
    IAU workshop
    HEAD
    AAS maintains a list of specialized meetings
    Distinguished lecturer series
    University colloquia and seminars

White Dwarf photosphere objectives, status, strategy:

Objectives:

Relative line shape measurements of Hβ, Hγ, Hδ at T_e=0.8 - 1.5 eV, $n_e=10^{16} – 10^{18}$

Direct comparison with new line-broadening models

Status, achievements:

Reached white dwarf photospheric conditions of T and ρ on the Z-platform

Produced a macroscopic plasma that is uniform (at some level)

Produced a plasma that is stable over long times (300—400 ns)

Demonstrated we can measure up to Hα, Hβ, and Hγ

Strategy for impact:

measure full set of lines, possibly including Hδ and Hε

characterize T and n_e independently, or semi-independently

- Improve modeling
- Introduce trace elements
- Implement something like Roberto's "charge state analysis"
- Dream of optical Thomson Scattering

Publish paper characterizing platform

Publish paper constraining/comparing line broadening theories

Analyze observed WD spectra with new line-broadening, empirically constrained, models

Photoionized plasma objectives, status, strategy :

Objectives:

Measure charge state distribution for two different photoionized elements and as a function of photoionization parameter

Strengthen the newly identified line ratio temperature diagnostic by extending it to another element and by comparing with radiative recombination temperature diagnostic (using fluorine)

Status, achievements:

Re-established the ability to do photoionized plasma experiments at Z

Measured photoionized neon charge state distribution as a function of gas density

Identified a new temperature diagnostic suitable for laboratory photoionized plasmas

The inferred temperature confirms production of photoionized plasmas

Strategy for impact:

Extend absorption measurements to sulfur

Perform simultaneous measurements with gas cells at different distances and different pressures to evaluate the approach to equilibirum

Resonant Auger Destruction / Black Hole Accrestion objectives, status, strategy :

Objectives:

Measure Kα satellite fluorescence from photoionized Si or S
Measure relative Kα satellite intensities as a function of column density

Status, achievements:

Photoionized Si data recently obtained by RCM group confirms the correct charge states can be produced on Z
Experiment definition is in progress

Strategy for impact:

In near term (CY11) use existing target possibilities: either Si_3N_4 (with CH tamping) or SF_6 filled gas cell
In CY12 consider feasibility of Silane or other Si-bearing gases
Measure charge state distribution with absorption spectroscopy
Measure self emission with XRS^3 (spherical crystal spectrometer)
Measure temperature with Radiative Recombination Continuum

Stellar Interior Opacity objectives, status, strategy :

Objectives:

Measure iron plasma transmission at conditions corresponding the base of the solar convection zone

Status, achievements:

The 2007 Z data reproduced iron charge states found at the base of the solar convection zone, but the density was an order of magnitude lower

The 2007 comparisons should inspire concern for calculations, but higher density/ temperature measurements are needed

Recent experiments demonstrated the we can reach the conditions found at the base of the solar convection zone

Strategy for impact:

Measure transmission in thick iron and thin iron samples using sample design that produces the CZ base conditions

Exploit the data to perform Beer's Law scaling tests

Infrastructure needs:

- Z is a “collaborative facility”, not a user facility. Need a written description of how we do business. Standing operating procedure
- Handbook: capabilities, platforms, diagnostics, training, access requirements
- Checklist to ensure visitor logistics run smoothly
- Assistance with housing, establishing a community atmosphere for visitors/students
- Office space, lab space; computer access
- External web: description of ongoing projects; solicitation schedule for Z time
- Need closure after experiments: outbrief soon after experiment, annual report of collaborative experiments and research

Physics measurement gaps and diagnostics needed to fill gaps:

- Electron temperature in x-ray driven gas
  - Optical Thomson scattering
  - Radiative recombination continuum
  - Line ratios
- High accuracy drive spectrum
  - XUV spectrometer
- Electron density in x-ray driven gas
  - Interferometry
  - Optical Thomson scattering
  - Line ratio or absolute spectral intensities
- Self emission from photoionized plasma
  - Spherical crystal spectrometer
- High resolution XUV spectroscopy (15-100 Angstroms)
  - Variable line space grazing incidence spectrometer
- Multiple simultaneous optical spectra
  - Multiple optical spectrometer systems at Z
- Gas cell initial conditions
  - Pressure transducer, temperature gauge

Capability needs:

Magnetic fields in 2x10 cm scale cells (1-10 T)

Ability to field sealed gas cells filled with Silane or other Si bearing gas

New ideas:

1. Magnetic fields have been identified in many White Dwarfs and the relatively simple structure makes it more feasible to quantify the impact on important phenomena, such as energy transport through the convection zone.
However, the field observations depend on interpreting photosphere spectra in the presence of both Stark broadening and Zeeman splitting.
This is a challenge for spectral synthesis models and motivates experimental benchmarks.

2. Chandra spectra contain unidentified lines in the 20-50 Angstrom range that may arise from photoionized argon.
This motivates XUV studies of photoionized argon plasmas.

3. Resonant enhancement of Auger electron production from high Z nanospheres may lead to new possibilities for cancer treatment. However, the realization of this goal depends on efficient monochromatic x-ray sources and a thorough understanding of Auger production.

Summary of the magnetized high energy density science session

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Magnetized HED breakout session outbrief

Daniel Sinars
Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Topics discussed

- Discussion of new ideas and how to grow the community
- Experimental possibilities for scaled ionization expts
- Measuring magnetic fields in HED expts on Z
- Cluster fusion & related laser expts
- Magnetized plasmas and jets
- Infrastructure & Diagnostic needs

Discussions on how to grow the community

- A major challenge of magnetized HED experiments is that almost by definition they are not “ride-along” or “beamline” experiments—they are driven by the facility itself
- Community sees value in “scaling” experiments up to Z
  - University-scale pulsed power is generally 1 MA, up to 2 MA
  - Big step to go from ~1 MA to ~25 MA (>600x increase in pressure!)
  - SATURN would seem to be ideal (5-6 MA) as intermediate facility, but
    - …SATURN is on standby unless a paying customer exists
    - …cost of doing SATURN shots is high for universities
    - …almost no permanent diagnostics & diagnostic access is poor
  - Alternate option could be “low-current Z” to take advantage of existing diagnostic infrastructure, but has not been demonstrated
- Professors see value in sending students to the lab for extended times
  - Local technical mentors essential, builds interest from students in labs
- Mark Koepke discussed “Distinguished Lecturer” program (as a potential “missionary” effort)
- Interest in having a “MagLIF workshop” to look for opportunities for both fundamental and applied science within the community

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Discussion of new ideas focused on the output of the ReNeW report for the magnetized HED area

- **What is the maximum magnetic pressure we can achieve in the laboratory?**
- **For sufficiently strong magnetic fields, can we study new frontiers of atomic physics?**
- **Can we understand how magnetic fields affect laser absorption and plasma transport processes?**

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What is the maximum magnetic field we can achieve?

Pulsars have fields ~ 10^{12} G and Magnetars have fields > 10^{14}G (P~ 4*10^{20}Bar)!

Above ~ 10^{9} G the magnetic field is large enough to significantly change atomic structure

What can we reach? By applying a large current at small radius:

$$B_\theta(G) \sim \frac{I(\mathrm{A})}{5R(\mathrm{cm})}$$

25 MA at 100 μm -> 500 Megagauss!

We can also do flux compression in cylindrical geometry by doing an implosion

$$B_f \sim B_0\left(\frac{R_0}{R_f}\right)^2$$

For B_0=500kG (50T) at CR ~45 with little loss leads to B_f= 1 Gigagauss

These conditions are well beyond the state of the art, but could provide a long term challenge

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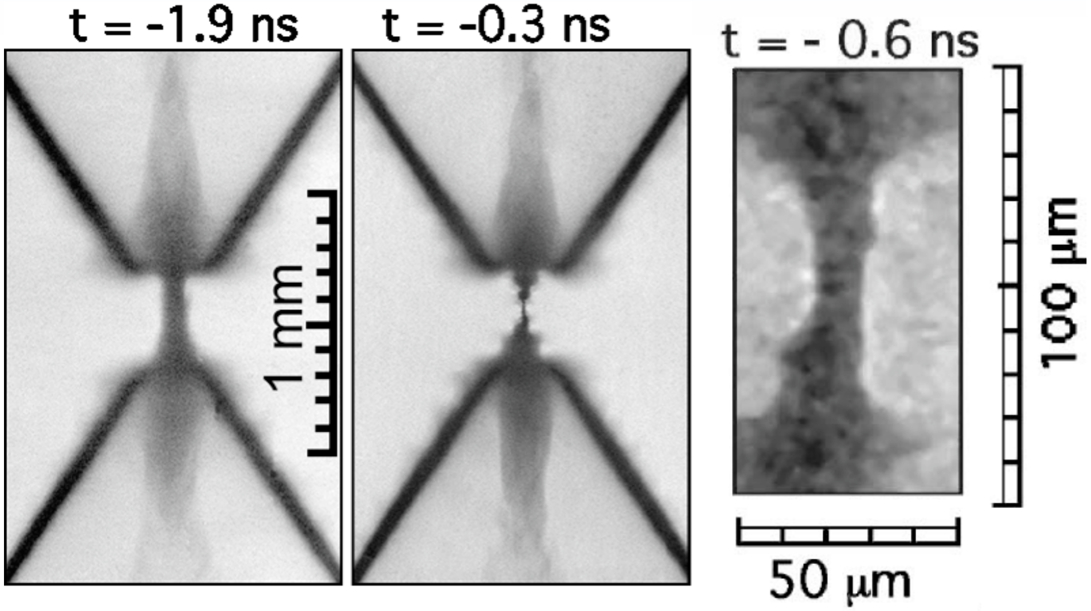
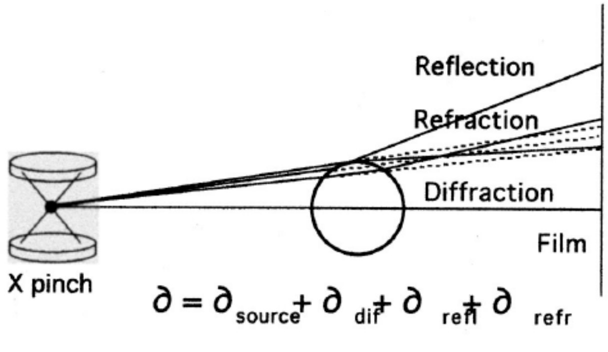
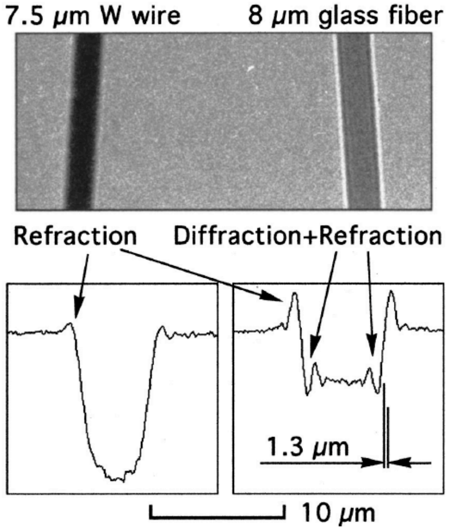
X pinches driven by 200 kA currents are an extreme example of current reaching small radius

- **Diameter: 1.2±0.5 μm**
- **Duration: 10-100 ps**
- **T_e: ~1 keV (Ti, Mo)**
- **n_i: ≥0.1 * Solid density**
- **Matter pressure at ~1 g/cc and 1 keV is ~1 Gbar**
- **200 kA at 1 micron radius has magnetic pressure ~ few Gbar!**







How much current gets to 1 μm?
Why does it stop at 1 μm?

T.A. Shelkovenko *et al.*, RSI 72, 667 (2001).

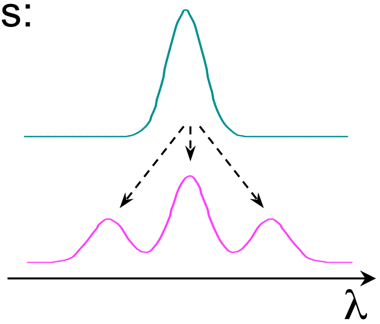
Very large magnetic fields can significantly affect atomic orbits

Magnetic effects are determined by the relative contributions of Coulomb, spin-orbit, and magnetic field interactions to the Hamiltonian:

$E^C \sim Z^2/n^2$ Ry $\quad E^{SO} \sim \alpha^2 Z^4/n^3$ Ry $\quad E^B \sim B/B_0$ Ry $+ O(B^2)$

Ry =13.6 eV, $B_0 = 2.35\text{x}10^9$ G

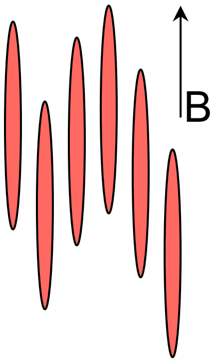
For near-neutrals (Z~1), magnetic fields can give the following effects:



$E^C >> E^{SO} >> E^B$ → Zeeman splitting for B ~ 10^4 Gauss (1T)

$E^C >> E^B >> E^{SO}$ → Paschen-Back effects for B ~ 10^6 Gauss

$E^B >> E^C >> E^{SO}$ → Landau effects for B ~ 10^9 Gauss:



- electrons are confined in Landau orbits $\perp$ to B, compressing atoms to one-dimensional “needles” aligned with B in the high-field limit

$$B/4B_0 >> Z^3$$

- binding energies increase from $\sim Z^2/n^2$ to $\sim Z(B/2nB_0)^{1/2}$; highly charged negative ions with 4/3 Z bound electrons might exist in the high-field limit

High fields in HED plasmas enables investigations of Zeeman & Paschen-Back effects for Z>>1. Accessing the more exotic effects requires fields that scale as ~ B_0Z^3 and challenges us to limit ionization in or near the extreme environments that can generate B ~ B_0.

Garstang, Rep. Prog. Phys. 40, 105 (1977)

Lieb et al. Comm. on Pure and Applied Mathematics XLVII, 513 (1994)

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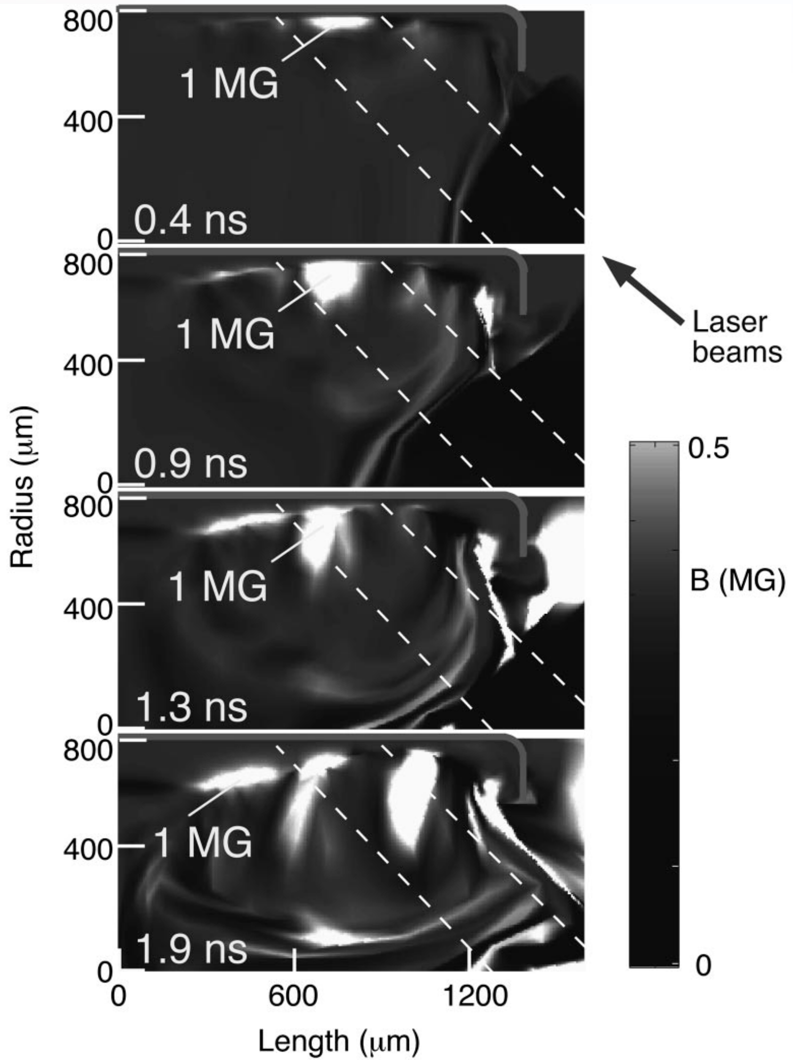
Magnetic Fields can be spontaneously generated from plasma gradients in HED plasmas



Magnetic field generation is ubiquitous in HED plasmas:

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{\nabla T_e \times \nabla n_e}{e\, n_e}$$

These fields do not affect the plasma motion ($\beta \sim P/B^2 >> 1$)

The fields can significantly change electron heat transport since $\Omega\tau > 1$. This in turn can lead to changes in deposition.

Simulations suggest this field can have 10-20% effects on the electron temperature in laser hot spots

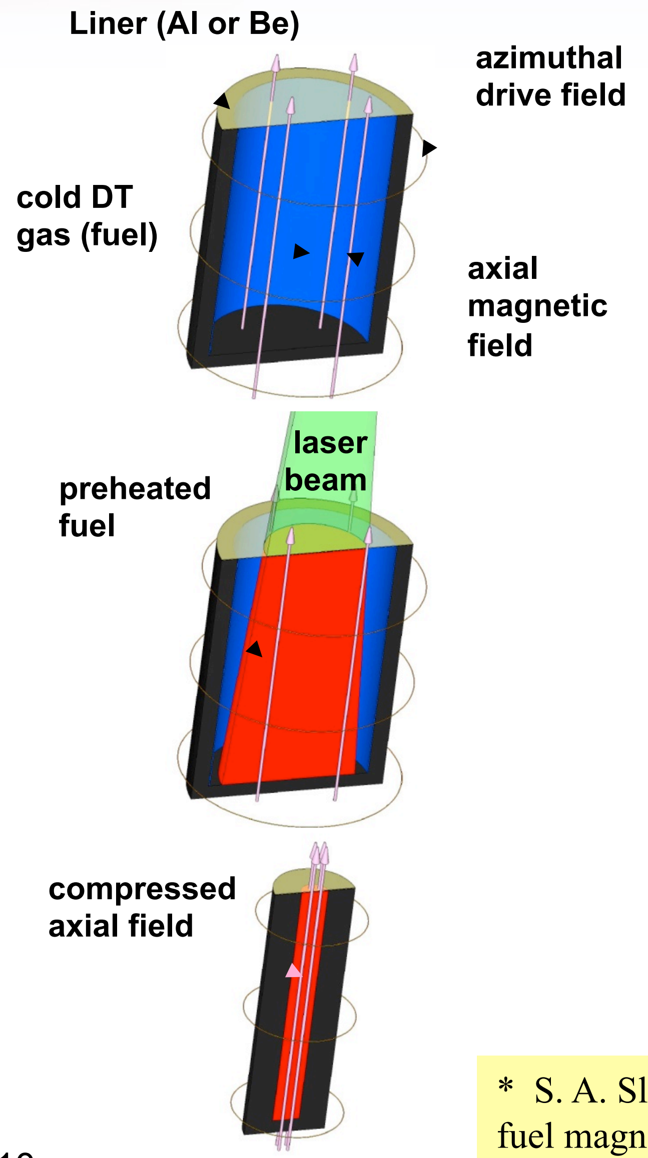
This will need to be validated to have a complete understanding of hohlraums

R. P. J. Town, UCRL PRES-216240

Experimental possibilities for scaled ionization experiments

- Discussed the MagLIF platform and whether similar or scaled conditions can be achieved in university laboratory experiments that are relevant to MagLIF
- Important to find "fundamental" physics items for study that while they may be motivated by applications, still stand on their own right as scientifically interesting
- An example could be plasma/energy transport in the presence of a strong magnetic field

The ICF program on Z is working toward an evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



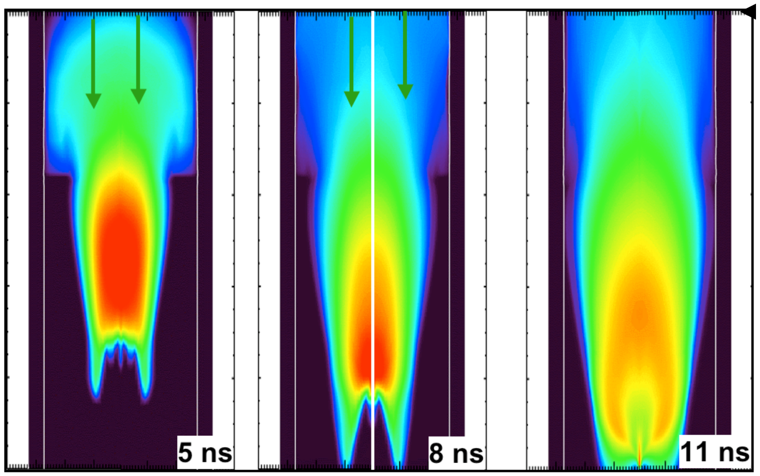
- **Idea: Directly drive solid liner containing fusion fuel**
- **An initial ~10 T axial magnetic field is applied**
  - **Inhibits thermal conduction losses**
  - **Enhances alpha particle energy deposition**
  - **May help stabilize implosion at late times**
- **During implosion, the fuel is heated using the Z-Beamlet laser (<10 kJ needed)**
  - **Preheating reduces the compression needed to obtain ignition temperatures to 20-30 on Z**
  - **Preheating reduces the implosion velocity needed to "only" 100 km/s (slow for ICF)**
- **Simulations suggest scientific breakeven may be possible on Z (fusion yield = energy into fusion fuel); something not yet been achieved in any laboratory**

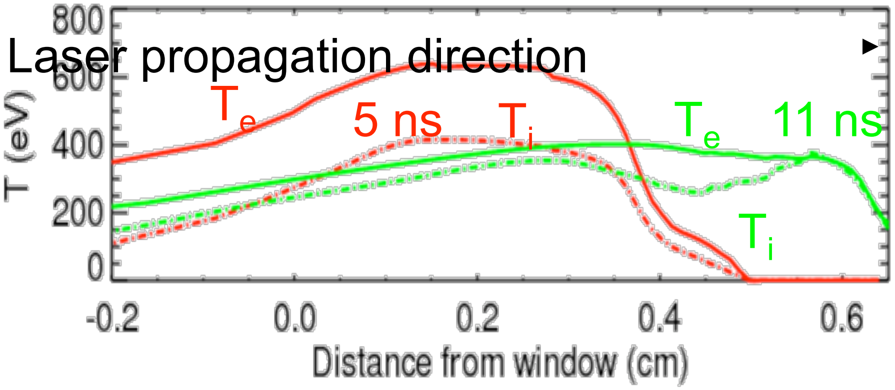
* S. A. Slutz *et al*., "Pulsed-power-driven cylindrical liner implosions of laser preheated fuel magnetized with an axial field," Physics of Plasmas 17, 056303 (2010).

Simulations indicate the Z-Backlighter Laser could preheat fuel for experiments on Z

0.8 TW, 10 ns pulse, 1 mm spot radius, 2.5×10^{13} W/cm^2

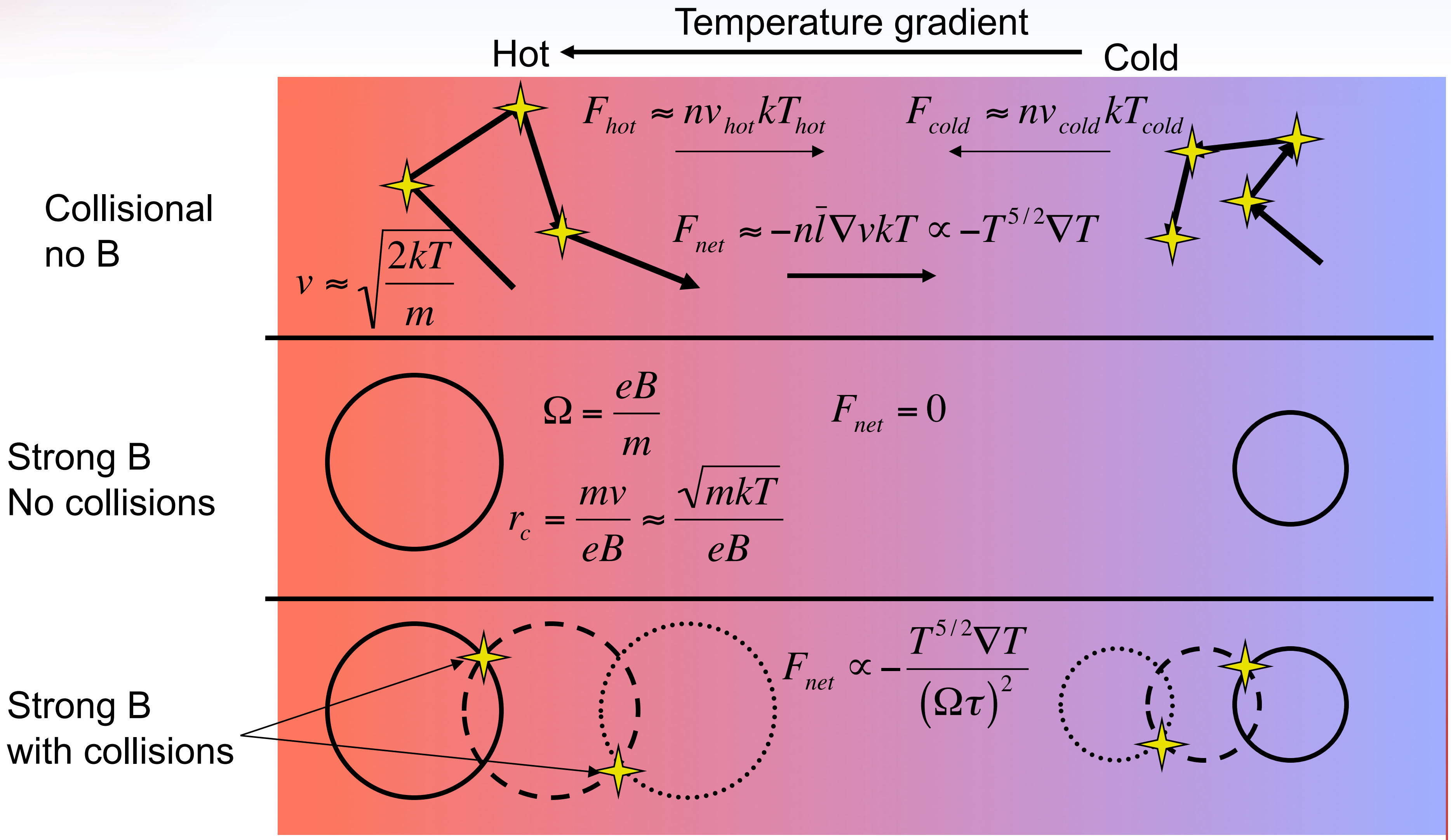
Electron Temperature contours (r,z)





- •The gas can be held in place by a 1 μ plastic foil
- •The critical density for green light is 4-7 x initial fuel density absorption by inverse bremsstrahlung
- •The total laser energy needed <10 kJ
- •analytic solution shows that the laser must bleach through the fuel

The presence of a magnetic field can strongly affect transport properties, e.g. heat conduction



Temperature gradient

Hot ← Cold

Collisional
no B

$$F_{hot} \approx n v_{hot} k T_{hot}$$

$$F_{cold} \approx n v_{cold} k T_{cold}$$

$$F_{net} \approx -n\bar{l}\nabla v k T \propto -T^{5/2}\nabla T$$

$$v \approx \sqrt{\frac{2kT}{m}}$$

Strong B
No collisions

$$\Omega = \frac{eB}{m}$$

$$F_{net} = 0$$

$$r_c = \frac{mv}{eB} \approx \frac{\sqrt{mkT}}{eB}$$

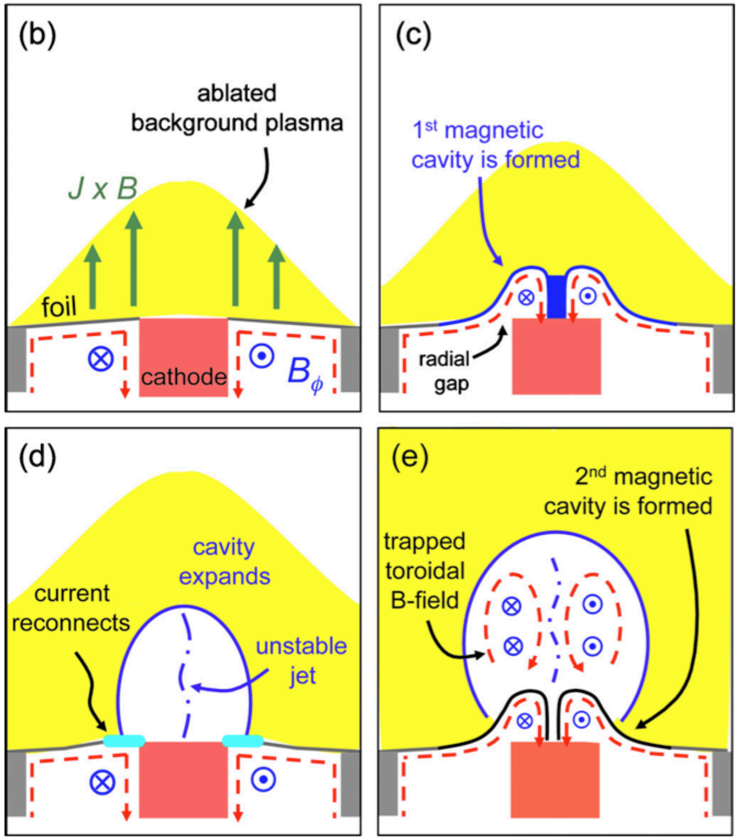
Strong B
with collisions

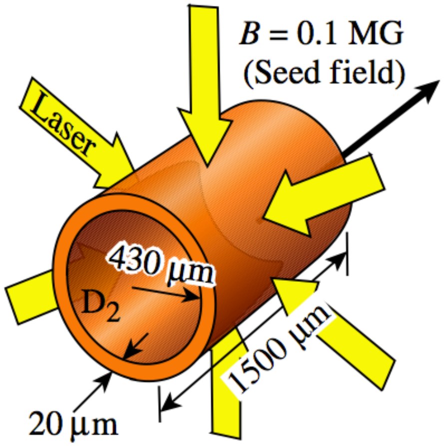
$$F_{net} \propto -\frac{T^{5/2}\nabla T}{(\Omega\tau)^2}$$

Energetic particles can also be strongly affected by magnetic fields

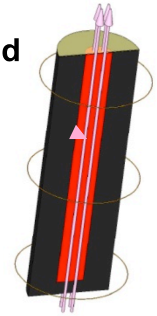
Measuring magnetic fields in HED expts on Z

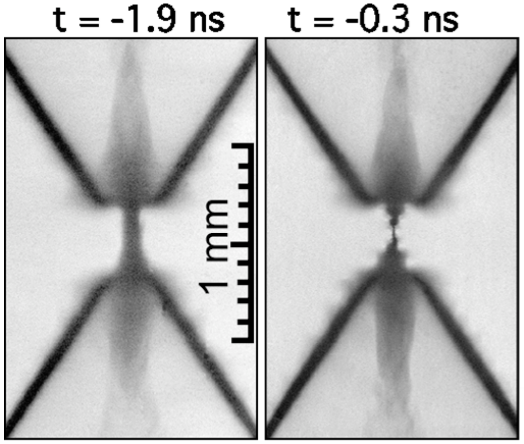
- **Measuring magnetic fields in compressed, magnetized plasmas, is a major challenge common to all magnetized HED systems**
- **Challenges in spatial scale, time scale, densities, & velocities**

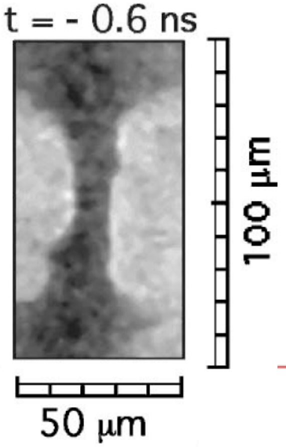




compressed axial field

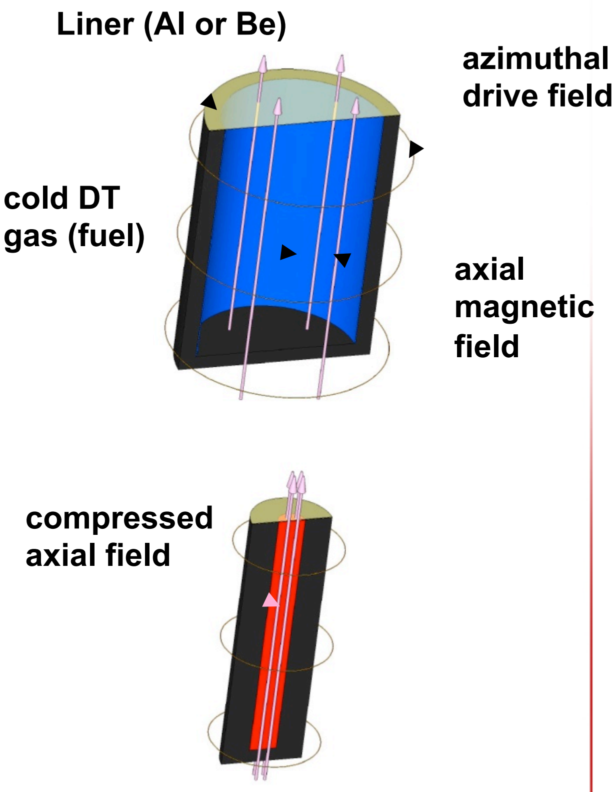






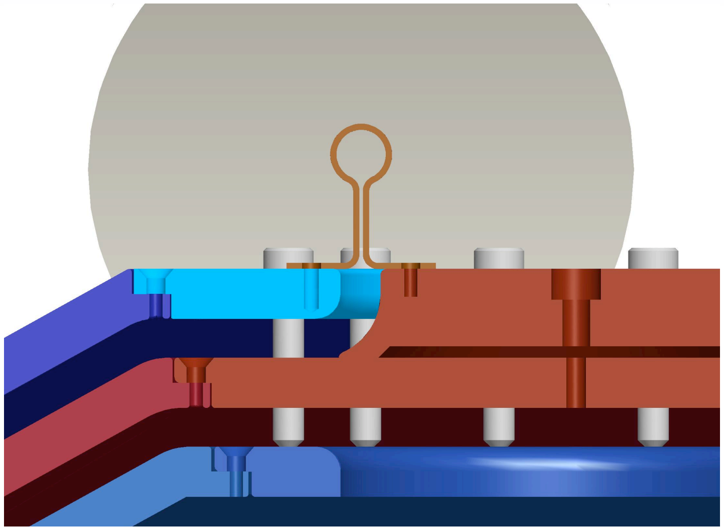
Many measurement techniques don't scale well to Z conditions—MagLIF example

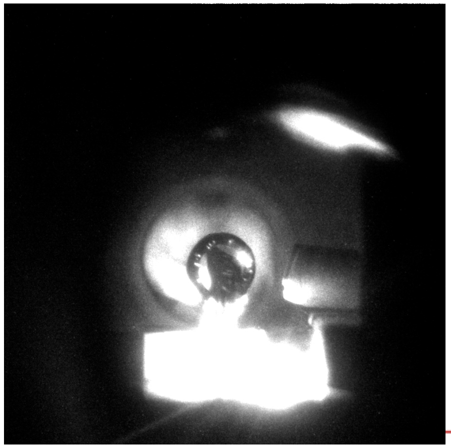
- Spent a great deal of time discussing MagLIF conditions as an example:
  - Bdot probes would require a very small loop area, only work well in non-plasma situations
  - Proton deflectometry (used very well on Omega) difficult due to higher Bfield and larger spatial scale of Z experiments
  - Zeeman splitting complicated by high opacity of plasma (need multi-keV photons), high velocities (Doppler broadening), high densities (Stark broadening), and small magnitude of Zeeman
  - May be possible to use Faraday rotation with fibers on axis of liner, but only under non-plasma conditions?
- I owe Alan a list of conditions in MagLIF for further contemplation by others…



Magnetized cluster fusion experiments on Texas Petawatt are making progress

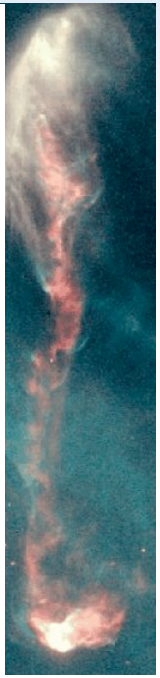
- Motivated by trying to achieve higher fusion neutron yields from clusters by using magnetic confinement
- Sandia-designed coils arrived at UT, being assembled
- System tested to 400 kA, 50 T fields
- Issues being worked on:
    - Paschen breakdown
    - Enough clusters in high-field region?
    - Design of the coil mount
    - Coil debris
    - Funding
- Expect shots in Summer 2012 on Texas Petawatt



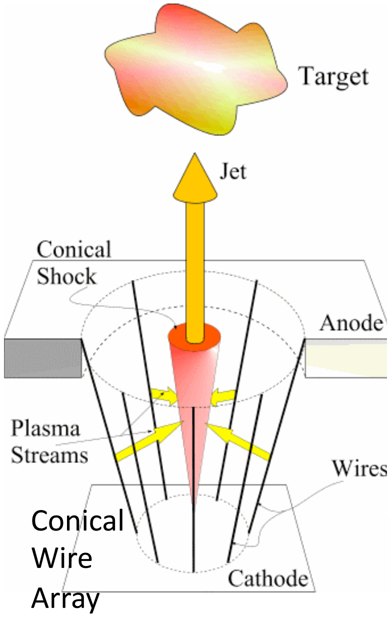


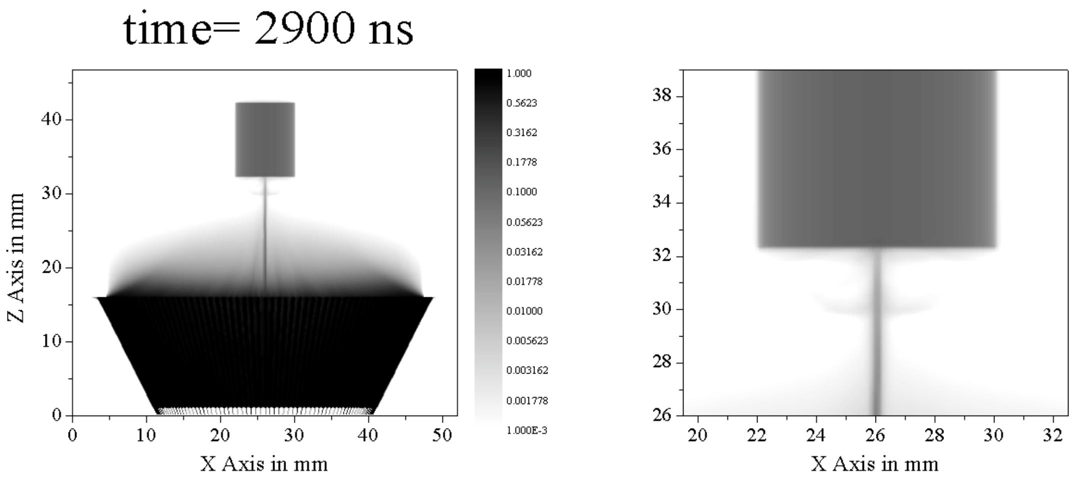
Magnetized plasma jet discussion

- **Simulations of turbulent jets are limited by numerical Reynolds Number**
  - **Experiments can test validity of simulations in similar regime**
  - **To be good test of simulations, experiments should have**
    - **High Reynolds number (to allow turbulence)**
    - **High radiative cooling (properly capture energy loss across shocks)**
    - **High mach number flows**



HH-47 (Credit: NASA, HST, WFPC 2, J. Morse)





3 experiments in Jan. 2011 showed jets could be made, but returned little quantitative data
2 experiments in Oct. 2011 will study jet interaction with a foam using 6.151 keV backlighting

Infrastructure & Diagnostic needs

- Interest in optical shadowgraphy & interferometry
  - Can observe plasma dynamics “easily and cheaply” on most shots
  - Sensitive to low-density plasmas that radiography can’t see

- Again long discussions on how to measure magnetic fields
  - (Can ultra-high harmonic sources be used?)

- May be some interest in using the 10-30 T axial B-field coils in future fundamental science experiments
  - Magnetized plasma jets
  - Opacity measurements in presence of strong fields

Extra slides

Actual Agenda

8:30-9:30	Discussion of new ideas
9:30-10:15	Experimental possibilities for scaled ionization expts
10:15-10:45	Measuring magnetic fields in HED expts on Z
10:45-11:45	Cluster fusion & related laser expts
1:30-2:30	Magnetized plasmas and jets
2:30-3:00	Infrastructure & Diagnostic needs

What are Magnetized High Energy Density Plasmas and what is interesting about them?

A working definition of Magnetized High Energy Density Plasmas :

HED Plasmas with fields magnetic fields > 5 Megagauss (Magnetic Pressure > 1 MB)

and/or

HED Plasmas whose transport processes are significantly affected by the presence of a magnetic field

If strong enough Magnetic Fields fundamentally alter the behavior of HED plasmas:

- **Magnetic fields and currents can push on plasmas in unique ways**

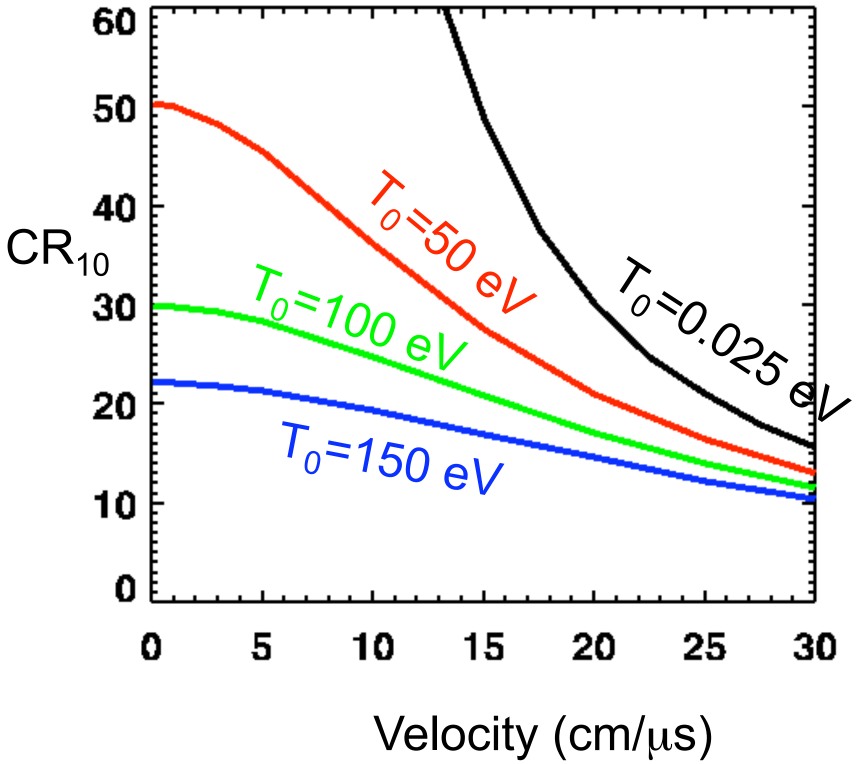
- **Magnetic fields can be spontaneously generated and amplified**

- **Magnetic fields change the way particles and energy are transported in a plasma**

Preheat is necessary for liner implosions, which are slow

CR_{10} = Convergence Ratio (R_0/R_f) needed to obtain 10 keV (ignition) with no radiation losses or conductivity

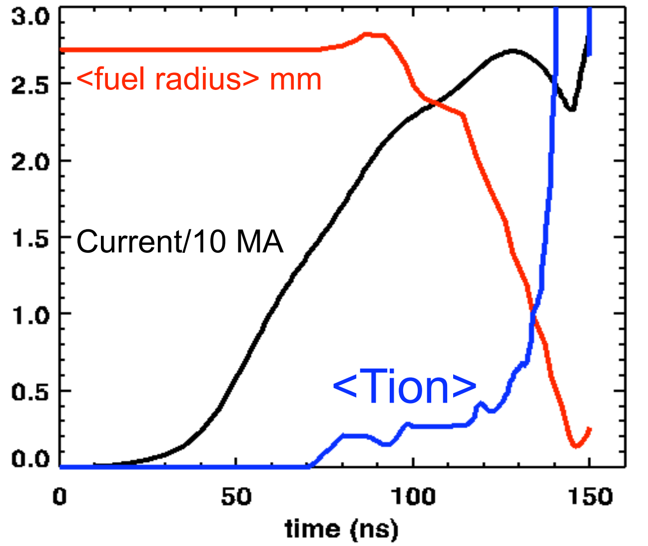
Lasnex simulation with constant velocity

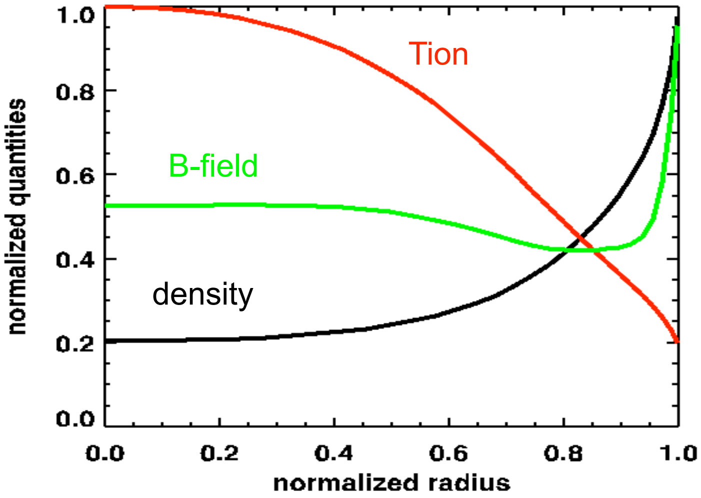


Fuel can be heated to ignition temperature with modest Convergence Ratio when the initial adiabat is large

- adiabat set by implosion velocity (shock) or
- alternatively by fuel preheat plus shock

We are working toward a MagLIF point design for Z





We are using Lasnex to simulate MagLIF

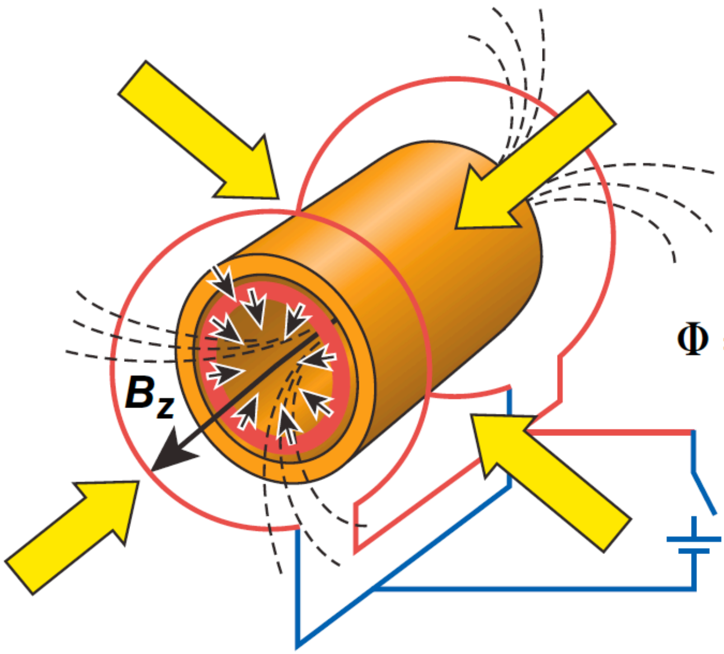
- Well benchmarked
- Radiation hydrodynamics
- Includes the effect of B on alphas

Preliminary point design parameters

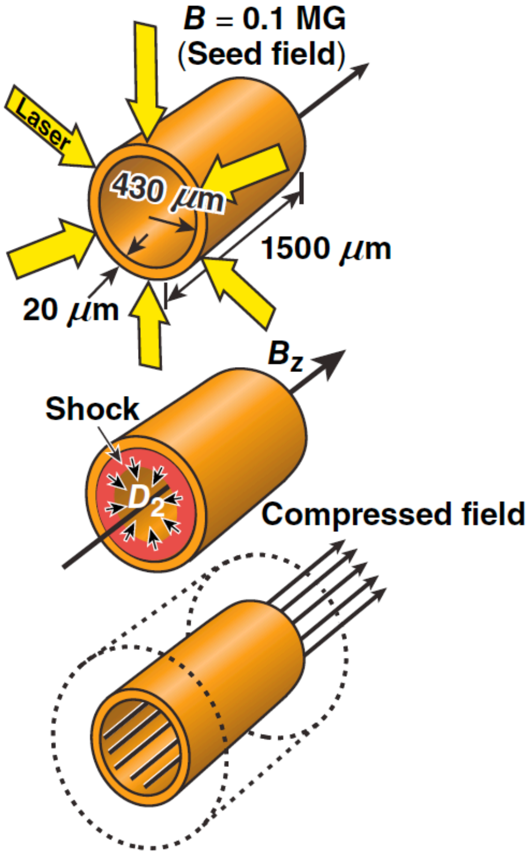
•Beryllium liner R_0	2.7	mm
•Liner length	5.0	mm
•Aspect Ratio $R_0/\Delta R$	6	
•Initial fuel density	0.003	g/cc
•Final fuel density <on axis>	0.5	g/cc
•Preheat temperature	250	eV
•Peak central averaged Tion	8	keV
•Initial B-field	30	Tesla
•Final peak B-field	13500	Tesla
•Peak current	27	MA
•1D Yield	500	kJ
•Convergence Ratio	23	
•Peak Pressure	3	Gbars
•EFUEL	120	KJ

The UR/LLE approach uses lasers to directly drive a cylinder with a preimposed magnetic field

- **In a cylindrical target, an axial field can be generated using two Helmholtz-like coils; the target is imploded by a laser to amplify the field**



$$\Phi = \pi B_z R^2 \approx \text{const}$$



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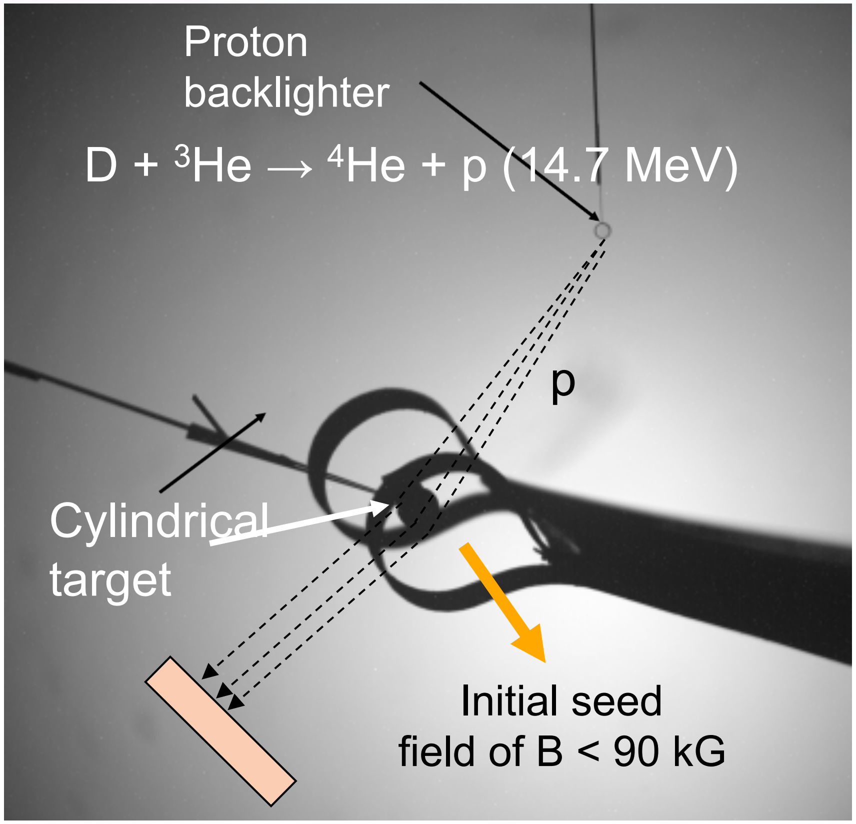
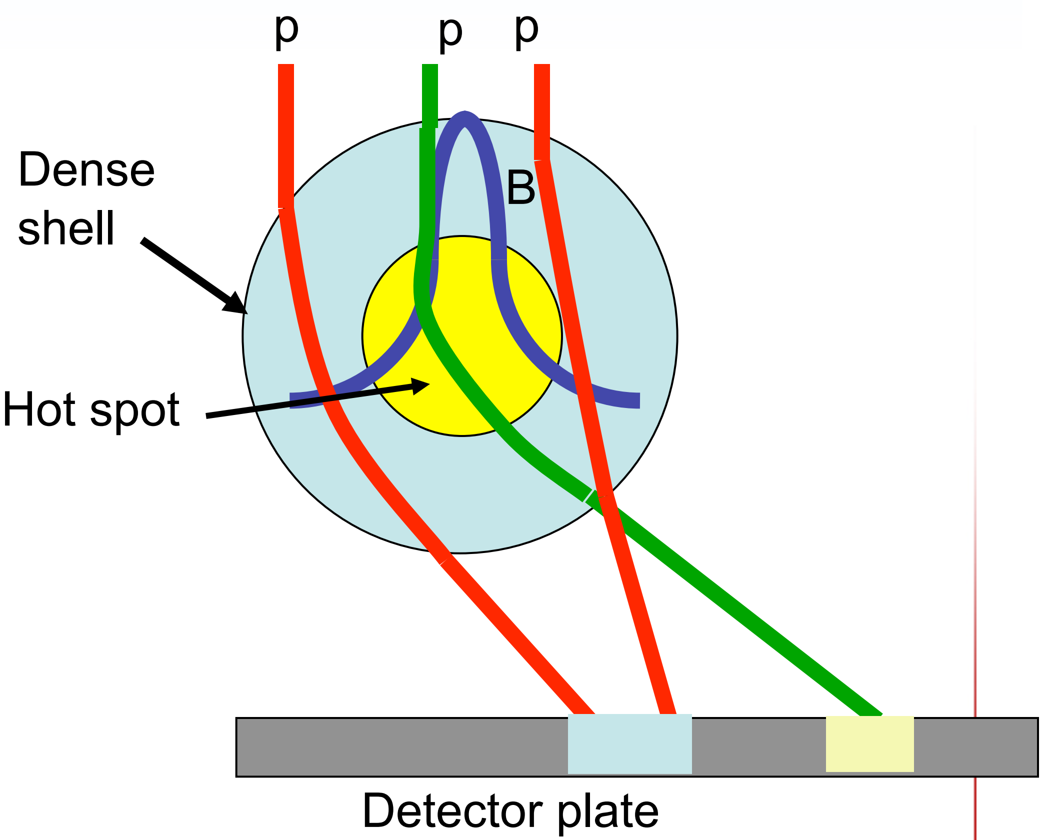
*O. V. Gotchev *et al.*, to be published in Phys. Rev. Lett.

Proton deflectometry is used to measure the magnetic field in the compressed core





<R*Bmax> ~ 0.052 MG-cm with 14.7 MeV protons
(30 MG hot-spot field, hot-spot radius ~17 microns)

vs. MagLIF: Seed field 30 T = 0.3 MG
Final field 13500 T = 135 MG
“Hot spot radius” ~ 125 microns

Summary of the planetary science session

Sandia National Laboratories

Date 07/30/2011

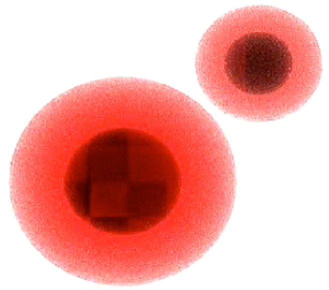
IHEDS Planetary break-out 2011

Ao, Davis, Hamel, Jacobsen, Kraus, Mattsson,
Nettelmann, Remo, Saumon, Shulenburger

Sandia National Laboratories

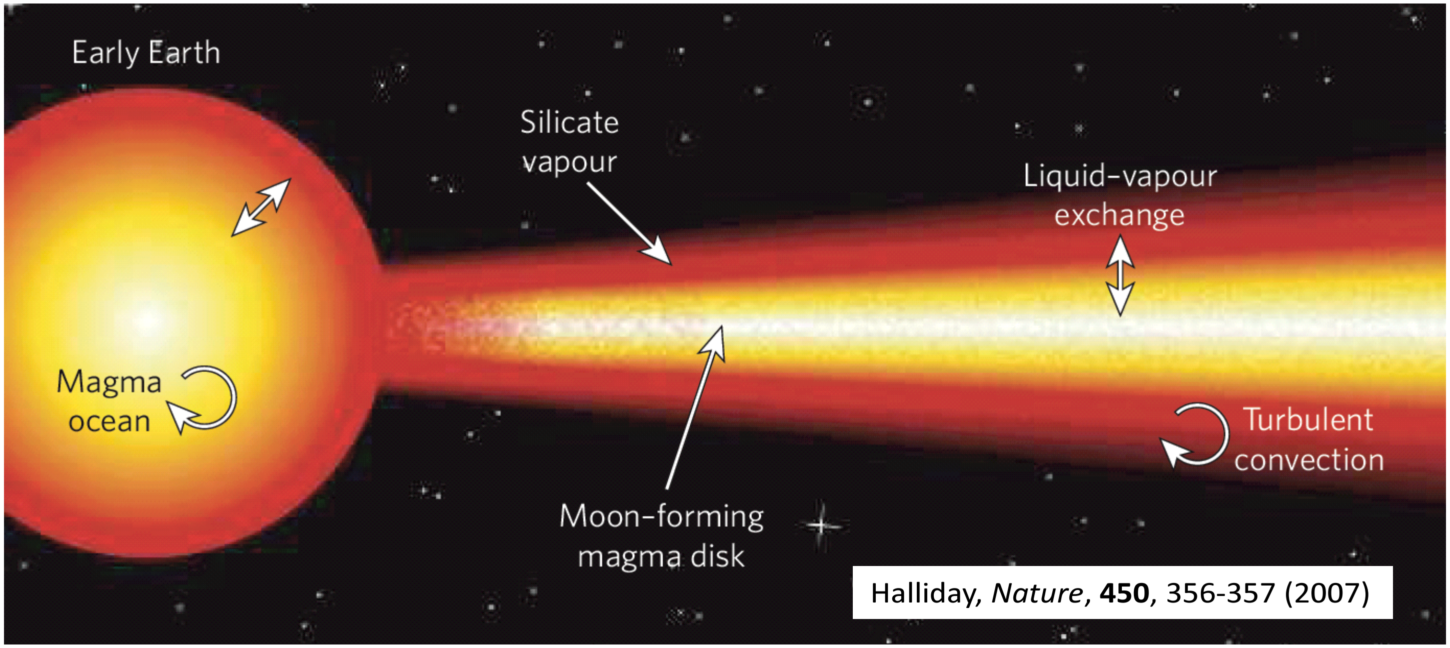
Intriguing physics of earth and super-earth materials and events, laboratory work crucial to gain understanding

- **Moon Forming Event**
  - **Moon would most easily be formed by the impactor**
  - **Earth and moon has virtually identical isotope composition**
  - ***Significant problem***
  - ***Critical point of silicates***
    - **Amount of rock vapor during MFE**



Metals (black) silicates (red)
(Stein Jacobsen)

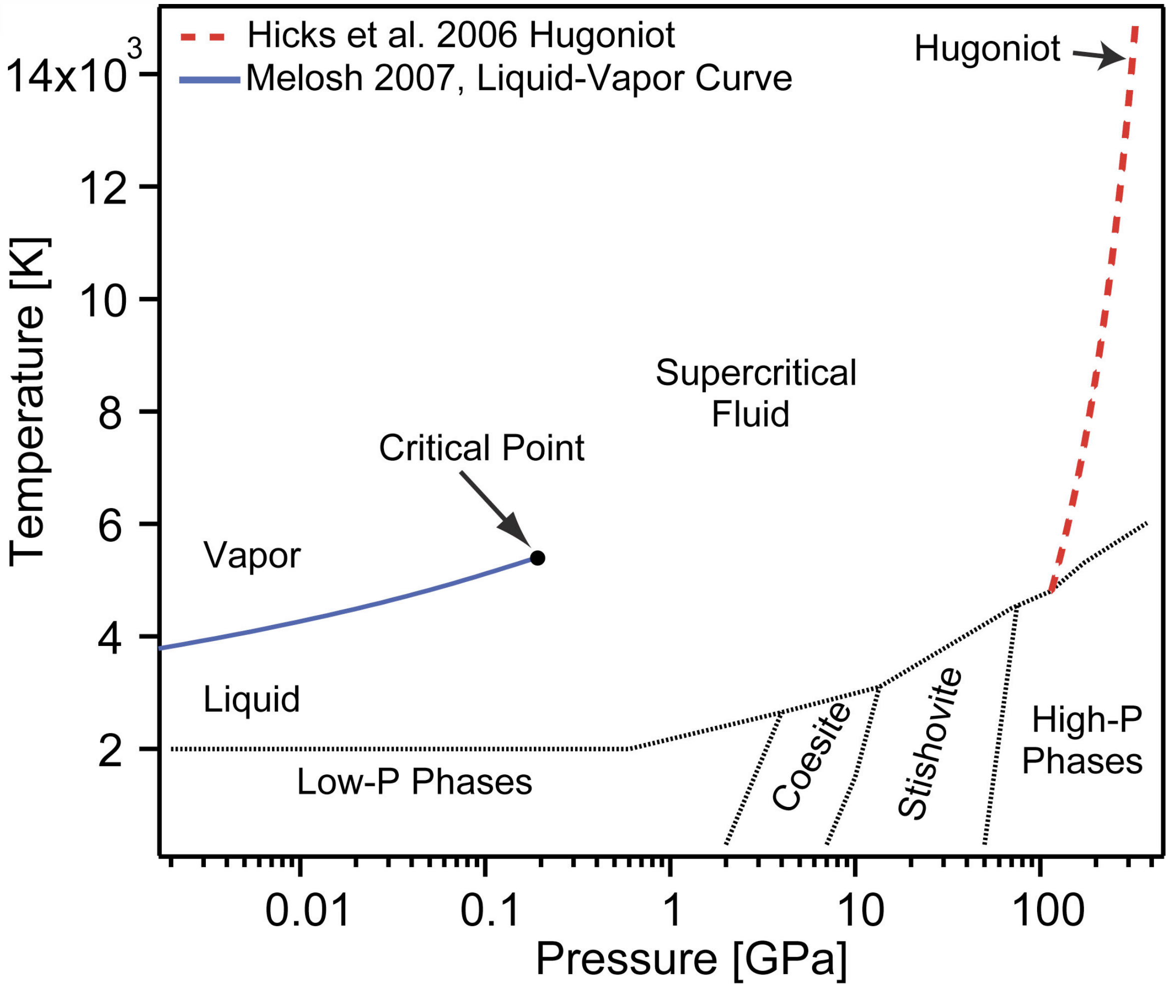
An extended vapor-liquid coexistence after MFE can explain the isotope equilibration between earth and moon



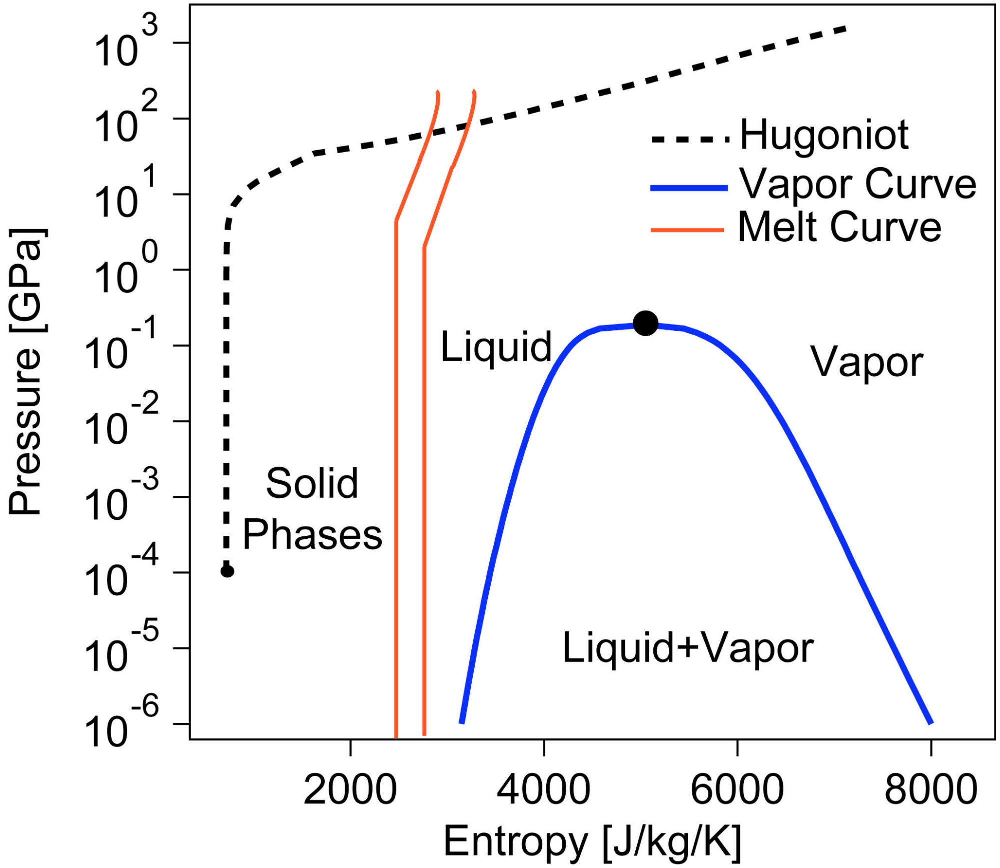
Halliday, *Nature*, **450**, 356-357 (2007)

Pahlevan & Stevenson (2007) proposed a model of ***isotopic equilibration of a magma disk derived from the Earth's impactor and the Earth*** through turbulent exchange in a relatively long-lived (for ~100-1000 years) silicate atmosphere enveloping both the Earth and the magma disk after the giant impact .

Accurate modeling relies upon knowing the vapor-liquid critical point of silicates



Entropy-temperature offers a more useful view of phase space for this purpose



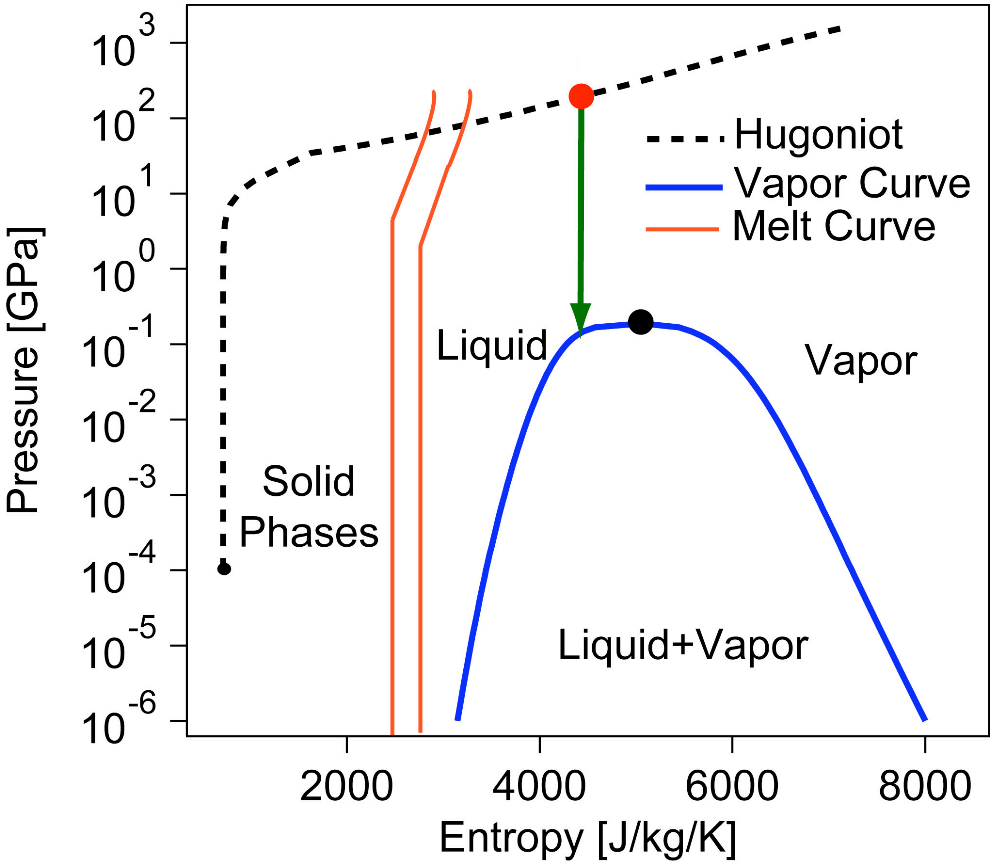
Melosh (2007) model Hugoniot and vapor curve

We will shock along the Hugoniot and release (isentropic) into, or above, the vapor dome

MgO experiments on Z

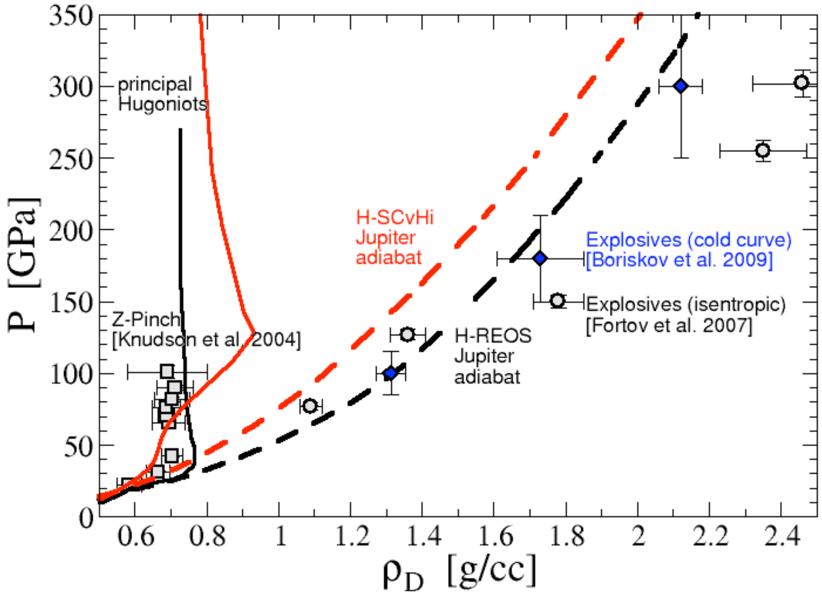
We have done initial MgO shock experiments on Z

We defined preparatory (ride-along) experiments and required diagnostics: **Temperature** (SOP)



The accuracy of the equation of state of hydrogen is of key importance for modeling giant planets

- Hydrogen EOS targeting conditions at gas- and ice giants
  - High-precision experiments to distinguish between EOS for H, at 100 GPa along Jupiter isentrope
  - *Our aim is to decidedly shrink the error bars on Hugoniot and multiple-shock data to validate EOS models*

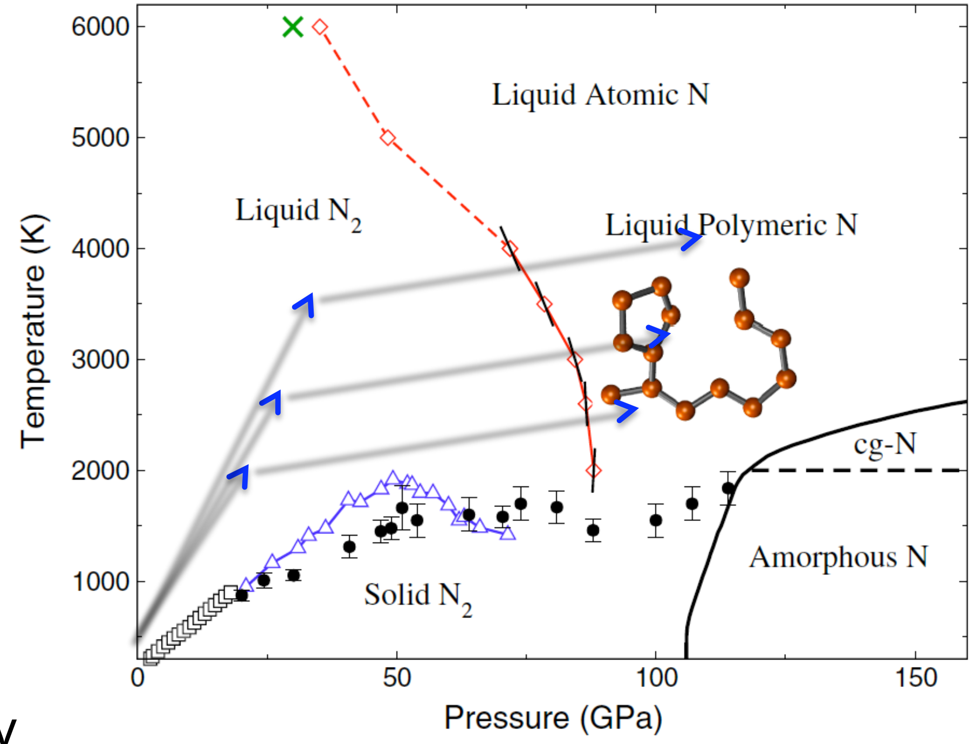


Jupiter adiabat using two different EOS (Nadine Nettelman)

Investigating the fundamental behavior of molecular liquids under pressure

- Complex phase-diagram of nitrogen has similarities to that of hydrogen

- Confirm the existence of a liquid-liquid critical point
  - Shock-ramp technique to cross the phase boundary
  - 14% predicted volume change across the boundary



Phase diagram of nitrogen (Boates and Bonev 2009)

New ideas and extensions on existing plans in the two projects

- **Earth/ super earth**
  - Silicon isotope fractionation between phases: melt/solid
  - Viscosity of the vapor/liquid
  - Surface tension, timescales for homogenous nucleation
  - Pure Si, pure O_2, for O and Si core composition in iron alloys

- **Giant planets**
  - Core conditions
  - Rock/ice mix
  - Superionic water phase – detect!
  - Target multi-component aspect of the giant planets: H2O/CH4 mixture, clathrate initial state final state dense plasma

Summary of discussions on the general topics

- **Grow team and the community**
  - Involvement of graduate students and postdocs*: obtain grants/ funding (NSF/DOE) and employ SNL sponsoring of students*
  - Participate at conferences and workshops to present work
  - The time-scale is a challenge: the fundamental science program can span 30-48 months before publication *a very long time from the perspective of a postdoc*

- **Diagnostics**
  - ***Temperature measurements by optical pyrometry***

  - Mie-scattering for detection of solid precipitates

  - X-ray Thomson scattering for temperature
  - X-ray diffraction for structure
  - Raman spectroscopy for chemical analysis

2011 workshop summary from a planetary perspective

- **Discussed CY12-13 project plans in detail**
  - Key diagnostics
  - Key supporting first-principles simulations
  - Timeline
  - Samples

- **Directions for future work**
  - Additional experiments
  - Grants
  - Simulations

- **Integration of project teams and solidifying common goals, directions, and expectations**

Appendix 1: Attendees

2011 IHEDS Workshop Attendees

Maria Aguirre	University of Texas at Austin
Kramer Akli	Ohio State University
David Ampleford	Sandia National Laboratories
Tommy Ao	Sandia National Laboratories
Alexey Arefiev	University of Texas at Austin
Briggs Atherton	Sandia National Laboratories
James Bailey	Sandia National Laboratories
Farhat Beg	University of California, San Diego
Keaton Bell	University of Texas at Austin
Roger Bengtson	University of Texas at Austin
Aaron Bernstein	University of Texas at Austin
Aaron Covington	University of Nevada, Reno
David Crandall	Department of Energy
Arati Dasgupta	Naval Research Laboratory
Jean Paul Davis	Sandia National Laboratories
Todd Ditmire	University of Texas at Austin
Michael Donovan	University of Texas at Austin
Gilliss Dyer	University of Texas at Austin
Jennifer Ellis	University of Texas at Austin
Ross Falcon	University of Texas at Austin
Sean Finnegan	DOE - Fusion Energy Sciences
Cari Gerlock	Sandia National Laboratories
Sebastian Hamel	Lawrence Livermore National Laboratory
Grant Heffelfinger	Sandia National Laboratories
Mark Herrmann	Sandia National Laboratories
Stein Jacobsen	Harvard University
John Keto	University of Texas at Austin
Mark Koepke	DOE - Fusion Energy Sciences
Richard Kraus	Harvard University
Ramon Leeper	Sandia National Laboratories
Edison Liang	Rice University
Duane Liedahl	Lawrence Livermore National Laboratory
Thomas Lockard	Sandia National Laboratories
Roberto Mancini	University of Nevada, Reno
Thomas Mattsson	Sandia National Laboratories
Mike Montgomery	University of Texas at Austin
Nadine Nettelmann	University of Rostock
Anil Pradhan	Ohio State University
John Remo	Harvard University
Gregory Rochau	Sandia National Laboratories

Didier Saumon	Los Alamos National Laboratory
Marius Schollmeier	Sandia National Laboratories
Luke Shulenburger	Sandia National Laboratories
Daniel Sinars	Sandia National Laboratories
Charles Starett	Los Alamos National Laboratory
Michael Storm	Ohio State University
Kenneth Struve	Sandia National Laboratories
Mary Ann Sweeney	Sandia National Laboratories
Maria Pia Vadivia Leiva	University of California, San Diego
Ethan Vishniac	Mcmasters, Hamilton
Xiaoming Wang	University of Texas at Austin
Don Winget	University of Texas at Austin
Alan Wootton	University of Texas at Austin

Appendix 2: Agenda

2011 Workshop and User Meeting on Fundamental Science using Pulsed Power and High Power Lasers

July 28 – July 30 (half day)
Eldorado Hotel & Spa

Wednesday July 27th

Eldorado Court

6:00 – 8:00 pm Reception and Registration

Thursday July 28th

Sunset Room

7:30 – 8:30 am Breakfast and Registration

8:30 - 9:00 am Introduction, proposal review process – Alan Wootton (UTX)

9:00 – 12:35 pm Session 1a: User experiments: status at Z. Chaired by Alan Wootton (UTX)
9:00 – 9:30 am White dwarf work status: Don Winget (UTX)
9:30 – 9:55 am Opacities work status: Anil Pradhan (Ohio St)
9:55 – 10:20 am Solar opacity work status: Jim Bailey (SNL)

10:20 – 10:35 am Break

10:35 – 11:05 am Photo-ionized plasma work status: Roberto Mancini (UNR)
11:05 – 11:35 am Black hole accretion disk status: Duane Liedahl (SNL)
11:35 – 12:05 pm Giant Planets: far out, close in, and deep inside: Nadine Nettelmann (U. Rostock)
12:05 – 12:35 pm Earth core work status: Stein Jacobsen (Harvard)

12:35 – 2:00 pm Lunch

2:00 – 5:00 pm Session 1b: User experiments: status at UT. Chaired by Mike Donovan (UTX)
2:00 – 2:30 pm Solid Target Experiments on the Texas Petawatt and GHOST Laser Facilities: Michael Storm & Kramer Akli (Ohio St)
2:30 – 3:00 pm Cluster fusion work status: Gilliss Dyer (UTX)
3:00 – 3:30 pm Wakefield acceleration work status: Xiaoming Wang (UTX)
3:30 – 4:00 pm Antimatter work status: Edison Liang (Rice)

4:00 – 4:15 pm Break

4:15 – 5:30 pm Session 2: Facility access, facility status. Chaired by Briggs Atherton (SNL)
4:15 – 5:00 pm Z diagnostics & Z plasma platforms: Greg Rochau (SNL)
5:00 – 5:30 pm The Texas Petawatt Laser User Program: Mike Donovan (UTX)

Friday, July 29th

Breakout rooms

7:30 – 8:30 am Breakfast (Sunset Room)

8:30 – 6:00 pm <u>Session 3: Breakout sessions</u>:

10:30 – 10:45 am Break

12:00 – 1:30 pm Lunch

3:30 – 3:45 pm Break

3.1) Magnetized HED, chaired by Dan Sinars (SNL) – Pinon Room, 2nd FL
  Magnetized liner fusion: scaled ionization experimental possibilities
  Cluster fusion
3.2) Planetary Science, chaired by Thomas Mattsson (SNL) – Chaparral Room, 3rd FL
  Earth core – working group prepares for experiments
  Jupiter – working group prepares for experiments
3.3) Astrophysics, chaired by Don Winget (UTX) and Jim Bailey (SNL) – Sunset Room
  White dwarf (including magnetic field effects)
  Stellar opacities
  Photoionized plasmas
  Black hole accretion disks and RAD
3.4) Additional HED topics – Turquoise Room – 4th FL

Saturday, July 30th

Sunset Room

8:00 – 9:00 Breakfast

Out-brief from panel chairs
9:00 – 9:20 am Magnetized HED breakout session report (Dan Sinars)
9:20 – 9:40 am Planetary Science breakout session report (Thomas Mattsson)
9:40 – 10:00 am Astrophysics breakout session report (Jim Bailey)
10:00 – 11:00 am Discussion