# Science with High-Power Lasers and Pulsed Power (#2), Research Opportunities and User Meeting

Report of a workshop, Santa Fe, August 4-6, 2010

**10/8/2010**

## Executive Summary

A workshop on "Science with High-Power Lasers and Pulsed Power (#2), Research Opportunities and User Meeting" was held in the Santa Fe Eldorado Hotel, August 4 through August 6, 2010. It was organized under the auspices of the Institute for High Energy Density Science (HEDS), a joint University of Texas (UTX) 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 and the University of Texas, 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 primary objectives of the 2 1/2 days workshop were first to discuss broad-interest, fundamental science experiments that can be performed using the pulsed power facilities and high-power lasers at Sandia National Laboratories (SNL) and the University of Texas (UTX), and second to facilitate a user meeting for current and prospective users of the same facilities. Of note is the intent to provide up to 15% of the shot time on Z at SNL for fundamental science; plans for a proposal call are in hand.

The experimental devices under consideration were, at SNL: The Z accelerator, the Z-Beamlet laser, and Z-Petawatt laser, and at UTX (Austin): The Texas Petawatt, THOR, THOR PW, and GHOST lasers. Information on facility capabilities, and how to access them, was provided as part of the User meeting.

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 UTX. This included discussing new ideas, new participants (especially new-to-High Energy Density and new-to-materials science academic participation), and the status of proposals from last year.

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 and new working groups to develop experimental plans and proposals, even do some science.

In the Research Directions part of the workshop four research areas were considered, determined by: current and past interest at both UTX and SNL, input from UTX and SNL scientists, and interest generated in the national HED community by the workshop. These four areas were: Radiative astrophysics, Planetary science, Magnetized high energy density science, and Particles and beams. Organizers for each of the four areas were chosen with input from SNL and UTX scientists; these organizers were then responsible for plenary presentations and individual breakout session, and a summary session in each of the four areas. Individual presentations will be found at the workshop web address:

http://www.ph.utexas.edu/~iheds/2010%20IHEDS%20Workshop.html

The plenary session provided overviews of ideas for new research at UTX and SNL. The breakout sessions further developed new research ideas. The summary session documented the breakout sessions' deliberations, with the intent of providing a list in each area of high impact concepts, involving national users, worthy of further pursuit.

In the User meeting part of the workshop, presentations by past and current users of the Texas and Sandia facilities described their results, and discussed opportunities for improving their experiences. Facility scientists described current and intended future capabilities, how access to the facilities was achieved, and the realities of performing experiments. The summary session and round table discussion included a presentation on student access to the facilities, and an opportunity for a discussion of how to improve user experiences.

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, particles and beams, magnetized high energy density science, planetary science). Table 1 summarizes the topics discussed, and includes some comments concerning personnel ('community'). Highlights from each area are now given:

<u>Radiative astrophysics</u>, organized by Don Winget and Jim Bailey. This session discussed white dwarf photospheres and related topics, laboratory x-ray spectroscopy for accretion-powered objects, and stellar opacities. Ideas to further the recently initiated white dwarf studies (on Z) include studying C and He atmospheres, and investigating the effect of magnetic fields. As part of the accretion powered objects, a team is forming to look at the x-ray radiation from black hole disk conditions (on Z). Utilizing post-docs located at SNL was emphasized.

<u>Planetary science</u>, organized by Thomas Mattsson. At the first workshop in 2009 this area was only lightly covered, whereas this year two topics emerged, with teams of mixed academic and laboratory scientists forming. These two new topics were a) Earth and super-earths, and b) Gas- and ice giants here and out there. The Earth and super-earth area proposes using Z to measure fundamental EOS up to 400 GPa and 5000 K in Fe and silicates, with implications for earth-now dynamo generation and for earth past moon formation. The Gas- and ice giants here and out there area proposes high-precision experiments, again on Z, to distinguish between the equation of state for H, $H_2O$ above 100 GPa, with implications for understanding how our planetary system formed.

| Science area | research topic | Ongoing research | New idea | Community |
|---|---|---|---|---|
| Radiative astrophysics | White dwarf photoshperes | Lab (Z) spectral properties in H | Study (in Z) He, C. Add B fields. Lower temperatures | Add: postdoc at Z, spectroscopist, line theorist |
| | Accretion-powered objects | Test spectral models used to infer driving radiation and absorption in active galactic nuclei | Test and improve spectral synthesis models associated with accretion disks around black holes | Need PI. Add: postdoc, student at Z; improve links to astro community |
| | Stellar opacities | Fe opacity in sun's convection zone | Mid-Z opacities | Add: postdoc a Z; additional theoretical effort |
| Particles and beams | Proton beams | Ddeflectometry diagnostic development | Distinguish roles of different electron acceleration models, including multi-pass through target | Add: more theoretical effort |
| | Electron beams | Wakefield acceleration | | |
| Magnetized high energy density science | Hydrodynamic, magnetized jets | At MAGPIE, GenASIS, x-pinch | Z -> highter dimensionless numbers (Reynolds), resolution, density (all for turbulence studies). X-pinches-> B -> pulsars? | Consider possibility of LANL National High Field Lab, others |
| | Boundary effects | x-pinch | Higher current at Z; two-fluid modeling | |
| | Cluster fusion | no B field | With 100 T (energy transport) | |
| | Kelvin-Helmholtz instability | | | |
| | Reconnection | | In non-ideal warm dense matter -> better diagnostics | |
| Planetray science | Earths and super-earths | | EOS up to 400 GPa and 5000 K in Fe and alloys with impurities-> a) Earth now, understanding dynamo generation, b) Earth then, understanding moon formation | Grow teams, embrace geographic diversity |
| | gas and ice giants here and out there | | High-precision EOS and density for H, H2O above 100 Gpa and 5000 K. Study mixtures and phase stability | |

Table 1. The topics discussed at breakout sessions

<u>Magnetized high energy density science,</u> organized by David Ampleford. Here many ideas were discussed, as noted in Table 1. The hydrodynamic jet experiments are already planned for Z (relevant for jet propagation), and extensions to magnetized jet experiments (relevant for jet initiation) were considered. Extending current university studies to Z (and ZBL for radiography) will allow higher, more relevant dimensionless parameters

| | radiative astrophysics | particles and beams | magnetized high energy density | planetary science |
|---|---|---|---|---|
| DIAGNOSTICS | | | | |
| optical Thomson scattering (n, T) | x | | x | |
| x-ray Thomson scattering (n, T) | x | | x | x |
| laser interferometer (n) | x | x | | |
| high sensitivity spectroscopy (emission spectra) | x | | | |
| proton beam deflectometry (B) | | x | x | |
| pyrometry | | | | x |
| proton radiography (n) | x | | | |
| high intensity backlighters | x | | | |
| spectrometer 0.5-1 keV | x | | | |
| improved single-shot laser characterization | | x | | |
| laser Compton scattering | | x | | |
| Stark shift (B) | | x | | |
| CAPABILITIES | | | | |
| filed gas cells on top of x-ray source (higher photoionization parameter) | x | | | |
| cells with hazardous gasses | x | | | |
| thinner windows on cells | x | | | |
| longer duration x-ray drives (for equilibrium conditions) | x | | | |
| x-pinch geometry | | | x | |

Table 2. Diagnostic and other capabilities requested

and higher spatial resolution, so that any turbulent flows internal to the jet should be uncovered. The possibility of configuring Z to operate as an x-pinch was discussed, and scaling suggested that magnetic fields up to MT could be produced. The relevance to rotating pulsar research was introduced. Other interesting ideas, with more details found in the breakout session section, included: studying reconnecting magnetic fields, simulating accretion disks, understanding boundary effects in magnetized HED situations, studying Kelvin – Helmholtz instabilities, and (in hand) studying magnetized cluster fusion. This latter topic included a discussion of the new physics issues that could be addressed, including energy transport.

Particles and beams (Proton acceleration) organized by Marius Schollmeier. This session concentrated on the detailed planning for experiments at the Texas and Sandia lasers to develop proton radiography based on laser-accelerated protons. This would provide the capability to measure electric and magnetic fields on Z for a number of the fundamental science proposals discussed in this document. In addition, detailed measurements of sheath parameters would allow us to distinguish between competing theoretical models for the underlying electron acceleration.

The workshop included discussions of what additional diagnostics would be beneficial, and these are shown in Table 2 together with the experiments that require them. Clearly temperature and density measurements are a high priority. Other ways in which both institutions (UT, SNL) could improve user experience are shown below in Table 3:

| | |
|---|---|
| 1) | Providing better infrastructure for visitors (offices, network, computing, 'phone, project meeting rooms/collaborative environment) |
| 2) | Developing a well-defined process for machine-time application |
| 3) | List of diagnostics: past, present and future |
| 4) | A Calculator" for simulating existing diagnostics and predicting experiment outcomes – similar to what is available for space and ground based observatory instruments |
| 5) | A POC, but from a hardware perspective: – someone who knows all the hardware, what is available and where it is and who to talk to |

Table 3: User-requested infrastructure additions

## Workshop Objectives and Deliverables

The workshop was both a Research Directions and a User meeting. The two main objectives were:

1) <u>Research Directions:</u> To propose and discuss fundamental research worthy of pursuit on the pulsed power and laser facilities at SNL and UTX. This included discussing new ideas, new participants (especially new-to-High Energy Density and new-to-materials science academic participation), and the status of proposals from last year.

2) <u>User meeting</u>: 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 and new working groups to develop experimental plans and proposals, even do some science.

In objective 1 above, worthy of pursuit was defined as an experiment meeting most of the following criteria:

a) Be performed using the UTX or SNL (or both) high power lasers or pulsed power (or both)
b) Involve the national or international scientific community
c) Grow the community
d) Facilitate a proposal to a specific funding agency (e.g. DoE, NSF, NIH, etc.)
e) Produce great science in the broadest national interest
f) Produce results publishable in high-impact journals
g) Produce results in either a short term (~3 year) or longer term (~5 year) timeframe
h) Be in either basic or applied science areas

i) Cover low-hanging fruit through grand challenges

Deliverables expected from the meeting were

1) As suitable, grow existing research and research-proposal teams (grow the community by further involving academia, including students)
2) Develop teams for those concepts highlighted in 2009 but not yet further developed. If possible, these teams should have an academic PI, with student participation, and a facility co-PI. Initial proposal writing should start in the breakout sessions
3) Propose new fundamental research opportunities that can be developed into proposals (session 1 and breakout sessions)
4) Initiate new teams, new proposals (breakout session)
5) A list of user-requested infrastructure additions

Tables 1, 2 and 3 provide the deliverables.

## Workshop Organization

This second workshop was a follow up to the first, with the added component of a user meeting. The four scientific areas (laboratory radiative astrophysics, beams and particles, magnetized high energy density science, and planetary science, were chosen through a process based on: current and past interest at both UTX and SNL, input from UTX and SNL scientists; and interest generated in the national HED community by both the first, and this second, workshop.

The user component of the meeting included presentations by past and present users, and by facility staff on current and future facility capabilities, and how to access the facilities. The breakout sessions were intended to:

1) Discuss new ideas for research, including those presented in the plenary session (session 1). Develop new proposals, and initiating new teams, keeping in mind the opportunity to grow the community.

2) Discuss current work (from the user meeting, session 2). Work on extending existing projects, and growing research teams.

3) Discuss facility capabilities and access, and suggest improvements

Participants were asked to report back to the full workshop on their discussions.

## The Institute for High Energy Density Science

The workshop was held under the auspices of the Institute for High Energy Density Science (IHEDS), a joint institute between the Sandia National Laboratories and the University of Texas. The vision is: *To enable of science in the broadest national interest at NNSA-funded facilities, in particular the HED programs of SNL and UTX, and in so doing grow the national HED user community.*

The mission is:

1. To provide an intellectual center and support for the exploration of fundamental and applied science and technology using the high intensity lasers and pinches at the Sandia National Laboratories and the University of Texas
2. To enhance access to the unique facilities at the Sandia National Laboratories and the University of Texas, to both University and Laboratory researchers, <u>and to the larger scientific community</u>
3. To contribute to science education, strengthen existing programs, and develop new initiatives

## Summary of the laboratory radiative astrophysics session

(two presentations)

# Laboratory x-ray spectroscopy for accretion powered objects

Ongoing research topic: active galactic nuclei
Spectral models are used to infer the driving radiation and the structure of the warm absorber region. Are they accurate? Can laboratory research lead to new diagnostic methods for astrophysical objects?

New topic: High mass x-ray binaries and accretion disk spectroscopy
Astrophysicists are already using X-ray spectra from atoms with L-shell vacancies to infer the characteristics of high mass x-ray binaries and accretion disks around black holes. This acitivity will increase with the launch of Astro H and IXO.
Our goal is to test and improve the spectral synthesis models, with initial emphasis on wavelength accuracy, evaluation of how complete an atomic model is needed for realistic interpretations, and resonant abosrption effects on radiation transport.

Research community: We reccomend adding one postdoc and one student stationed at SNL to fully exploit the opportunities. Strengthening the connection with the astro communitiy is imperative; possibilities include groups at U. Pennsyvania, Columbia, Nasa Goddard, and Imperial College.

# Laboratory x-ray spectroscopy for accretion powered objects

Diagnostic improvements:
High sensitivity spectrometer for emission spectra (XRS3; spherical option for PODD)
Electron temperature diagnostic (optical Thomson scattering)
Electron density diagnostic (optical Thomson scattering; interfrerometry)

Source and target improvements:
Ability to field gas cell on top of x-ray source to reach higher photoionization parameter
Ability to fill gas cells with hazardous gases
Thinner input windows for gas cells
Longer duration x-ray drive (to improve liklihood of equilibrium conditions)

Organizational issues:
What is the right balance of scientists stationed at SNL and scientists who visit to conduct experimetns?
For students stationed at SNL for a majority of the time, will SNL scientists be available to provide adequate guidance?

Some research topics share many of the same needs, but each encompass a large scope of work. What is the optimum way to combine and/or separate topics to ensure healthy growth of the community and strong impact on the science?

# Stellar Opacities

Ongoing research topic: iron at the solar convection zone boundary
How accurate are the opacities used as inputs for stellar models? Is opacity the origin of the solar puzzle?

New topic: How does the opacity change for mid-Z atoms that are minor constituents of a mostly hydrogen plasma?

Research community: Adding one postdoc stationed at SNL would enable better exploitation of the opportunities. The existing level of effort at Ohio State may be adequate to refine the atomic physics, but it may not be sufficient to build new opacity tables needed to fully understand the impact of opacity refinements on stars.

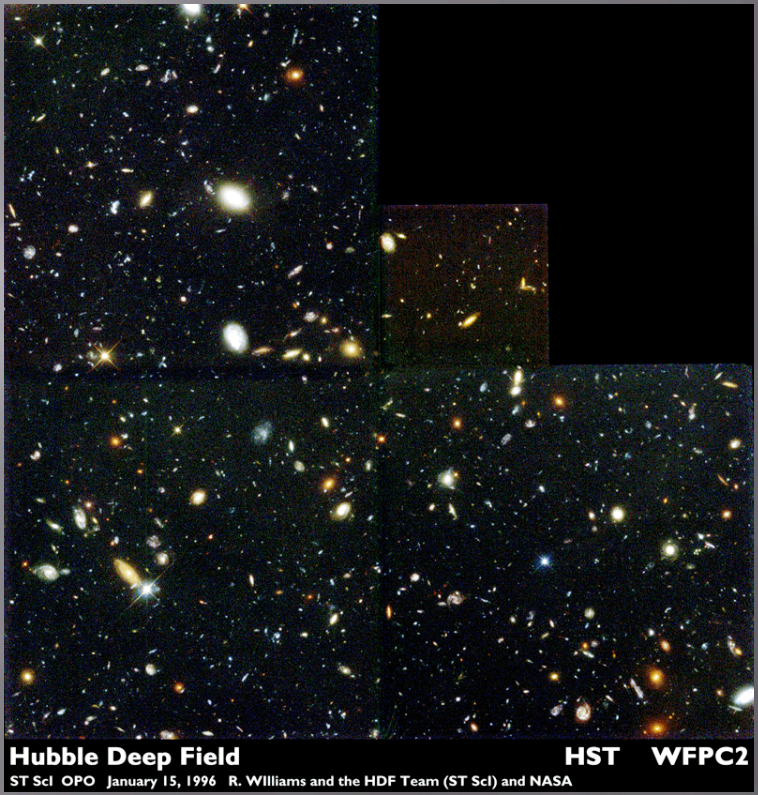
# Stellar Opacities

Diagnostic improvements:
spectrometer capable of high quality measurements at 500-1000 eV photon energies
(improved crystals; spherical spectrometer; grating spectrometer)

Electron density diagnostic (x-rayThomson scattering; radiography)

Source and target improvements:
Higher brightness backlighter

Organizational issues:
How to best structure Z proposals for topics that can be combined to exploit a single Z shot?
If they are combined, how to ensure progress for topics that compete for prime real estate
(e.g., the highest radiation flux position at the top of the source) or unique diagnostics?




# RADIATIVE ASTROPHYSICS

Working Session Report II: White Dwarf Photospheres and related topics

# White Dwarfs and Related Physics
## *New Ideas:*

- After H (ongoing project), then He and C line profiles and “pseudo continuum”

- Add B-fields (10KG-10MG) to the above

- Test opacities in the coolest (oldest) WDs: He, CIA in H, mixtures with He

- Do we understand the EOS and Opacities at the base of the convection zone in H, He, and C WDs?

# Research Community

- Add white dwarf line-profile theorists from the astrophysical academic community: Currently we have secured active interest (commitment to collaboration) from Adam Burrows (Princeton), Pier-Emmanuel Tremblay and Pierre Bergeron (U. Montreal) and space mission specialists Martin Barstow (U. Leicester) and Jay Holberg (U. Arizona) along with Piotr Kowalski and Detlev Koester (Germany)
- Add expert white dwarf spectroscopist S.O. Kepler (UFRGS, Brazil)
- Identify other interested parties in the astrophysical community in the universities and national laboratories
- Add a postdoc at SNL

# Priorities for New Diagnostics:

## We need to develop independent measurements of density and Temperature. Need to evaluate, but current assessment is …

- Optical Thompson Scattering – highest priority, edge for determining temperature
- Laser Interferometry – this has the edge for density determinations

# Improving the User Experience:

- List of diagnostics: past, present and future
- “Calculator” for simulating existing diagnostics and predicting experiment outcomes – similar to what is available for space and ground based observatory instruments
- A POC, but from a hardware perspective: analogy with David Doss at McDonald Observatory – someone who knows all the hardware, what is available and where it is and who to talk to.

# Summary of the magnetized high energy density science session

10/8/10

# Magnetized HED breakout session

Organized by Dave Ampleford (SNL) & Simon Bott (UCSD)

- Hydrodynamic and magnetized jet experiments on Z
- Simon Bott (UCSD)

- Edge effects in HED plasmas
- Matthew Martin (SNL, in collaboration with Cornell)

- Cluster Fusion
- Roger Bengston (UT)

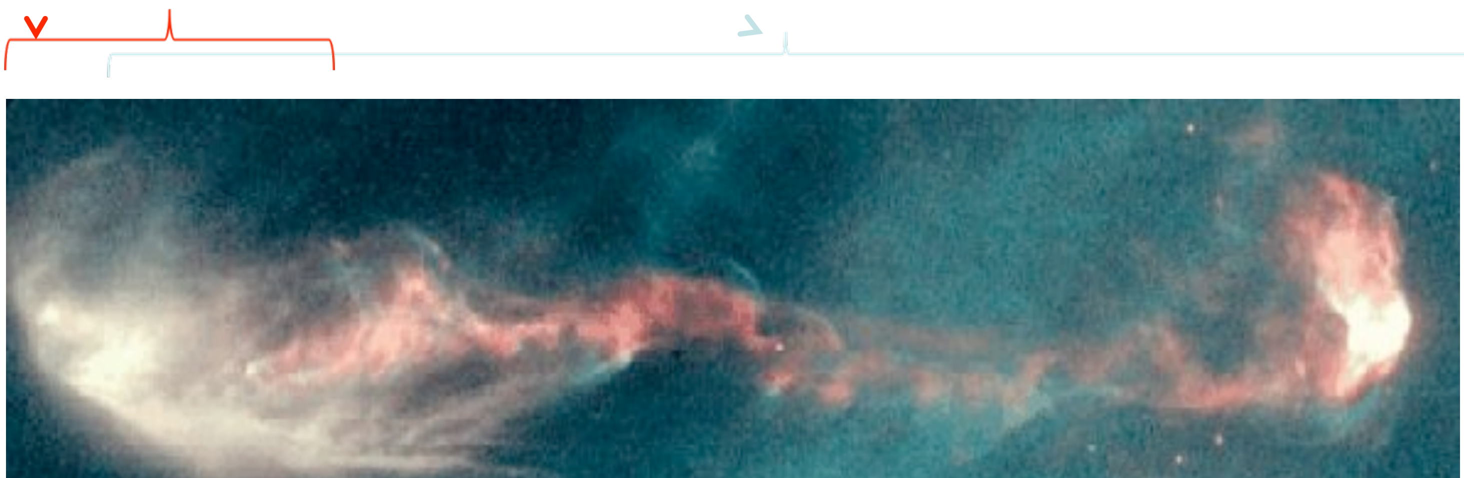
- Kelvin-Helmholtz experiments using pulsed power
- Eric Harding (SNL, in collaboration with U. Michigan)

- Accretion disk experiments
- Dmitry Ryutov (LLNL)

S.C. Bott

# Experimental Approach

- **Break jets into 2 regions:**
  - **Formation – dynamically significant B-field, strong collimation, source of knots**
  - **Propagation – mainly hydrodynamic, high Mach number flow with low divergence**

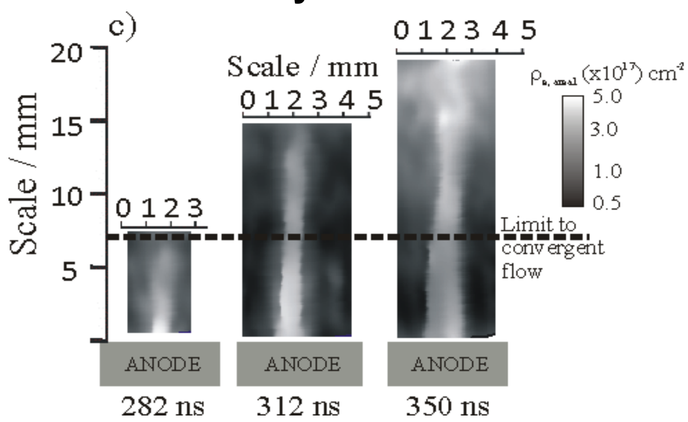


HH-47 (Credit: NASA, HST, WFPC 2, J. Morse)

S.C. Bott

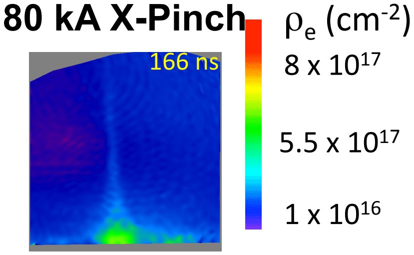
# Comparison of Experimental and Astro-jets

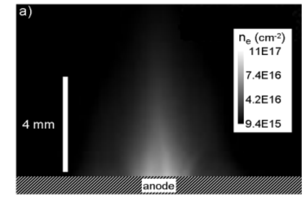
**200 kA Conical Array**

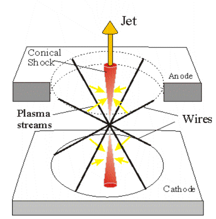


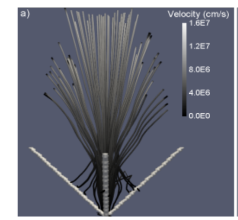

S. C. Bott *et al, IEEE Trans. Plasma Sci*, **38**, 567 (2010)

**80 kA X-Pinch**




D. M. Haas *et al, (Submitted to Astro Space Sci)*

| | | MAGPIE | GenASIS | X-Pinch | YSO Jet |
|---|---|---|---|---|---|
| **Flow Parameters** | Length (cm) | 2 | 2 | 1 | $3 \times 10^{17}$ |
| | Width (cm) | 0.1 | 0.1 | 0.1 | $2 \times 10^{16}$ |
| | Dynamical time Scale | 100ns | 100ns | 50ns | $10^3$ yrs |
| | $T_e$ (eV) | 10 | ~15 | ~15 | 1 |
| | Jet tip velocity (km/s) | ~200 | ~200 | ~40 | ~100 |
| | Jet density, (g/cm$^3$) | $10^{-5}$ | $10^{-7}$ | $10^{-9}$ | $10^{-22}$ |
| **Fluid description** | Localisation | $10^{-4}$ | $10^{-4}$ | $10^{-3}$ | $10^{-6}$ |
| | Reynolds Number ($R_e$) | $10^5 - 10^6$ | $10^4$ | $10^1$ | $>10^8$ |
| | Peclet number ($P_e$) | >10 | >10 | >10 | $\sim 10^7$ |
| **Jet scaling** | Mach number, M | > 20 | >10 | ~6 | >10 |
| | Density Contrast, | >>1/ ~ 1 | >>1 | >>1 | ~1-2 |
| | Cooling Parameter, | 0.1 – 1 | 0.1 – 1 | 0.1 – 1 | 0.1-10 |

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# Planning for Z shots

- **Topic for initial Z shot series is hydrodynamic jets**
  - **Better characterized at low MA**
  - **Scaling and simulation work simpler**

- ***Generate higher $R_e$ jets***
  Final set-up $R_e$ may be 100 times at full current (analytical scaling argument)

- ***Higher density jet for interactions:***
  Easier target design (jets ~100 mg/cc)
  More choices , inc. under/matched/overdense, inclusions (c.f. Douglass work)

- ***High spatial resolution of ZBL:***
  Jet of ~1mm diameter is 50 'cells' across
  High resolution compared to all previous expts and sims
  Should be able to diagnose turbulent flow internal to jet and in interactions

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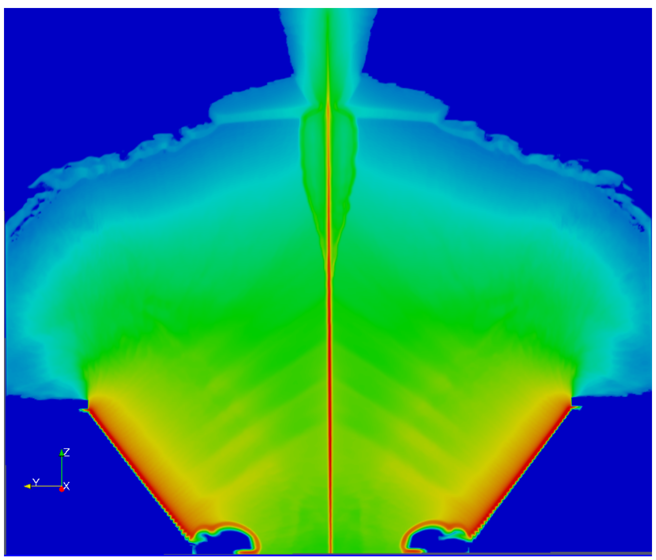
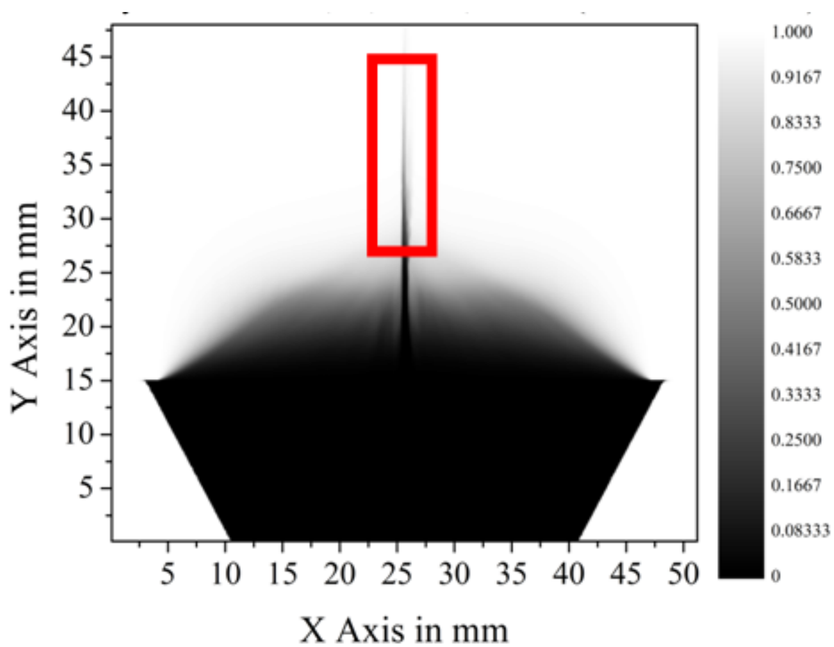
# Simulations for Z

- 3D GORGON simulation with 100um cell size
- Simulated of jets and synthetic radiograph
- Very little B-field on axis at jet formation
- Density of jet at 30mm height ~100 kg/m$^3$, with $T_e$ ~10eV ($R_e > 10^8$, $P_e > 10^4$)



*Density slice through breaking 150 wire 50um W array on long-pulse Z (20 MA in 300ns)*




*Ideal case simulated ZBL radiograph 390ns*

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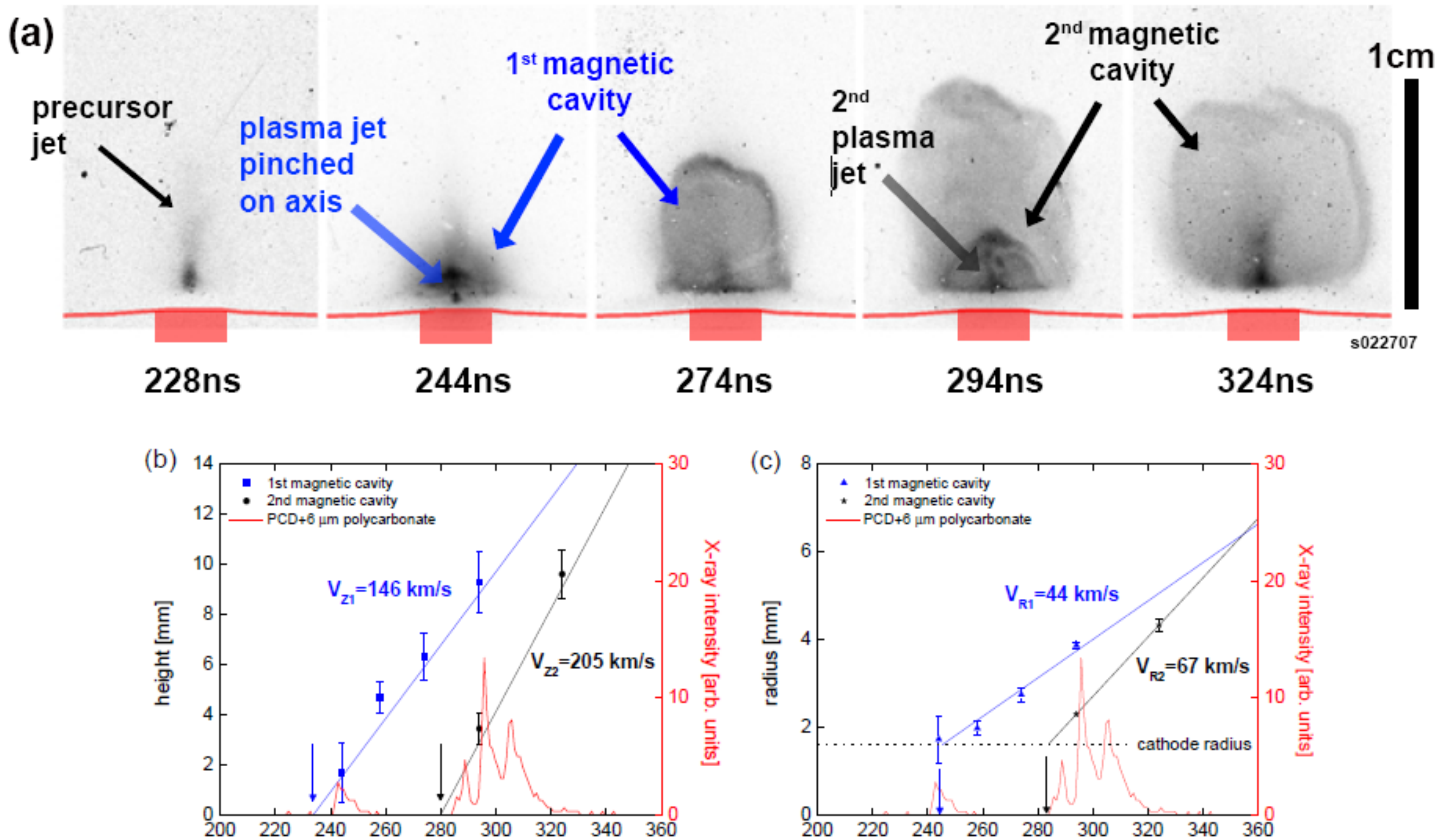
# Experimental Dynamics of Episodic Jets



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# Dense Plasmas in intense B-fields: X-Pinches

- X-Pinches are sources of intense x-rays from a highly localised transient plasma
- HEDP conditions occur in the central region compressed by the applied B-field
- In inferred B-fields at pinch time are very large. Assuming 10mm source size (diameter) B-fields for previous work are of order:

| Current (MA) | Density | Temperature (keV) | Spot Size ($\mu$m) | B-field (T) |
|---|---|---|---|---|
| 0.08 | ? | ~0.9 | ~5 | 6,000 |
| 0.27 | ~solid | ~1 | <1-few | 20,000-100,000 |
| 0.45 | ~solid | >2 | <1-few | 30,000 -160,000 |
| 1.00 | ~solid | ~1 | 3-40 | 10,000 – 130,000 |

- Scaling is challenging, but innovation is still providing excellent performance

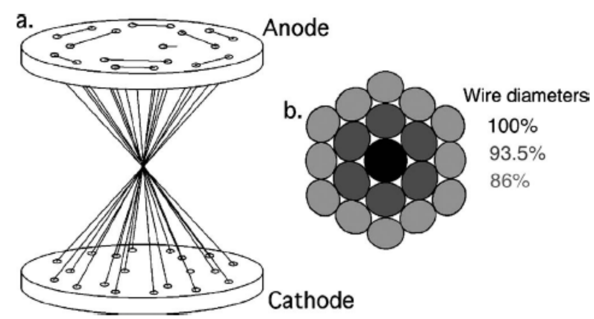
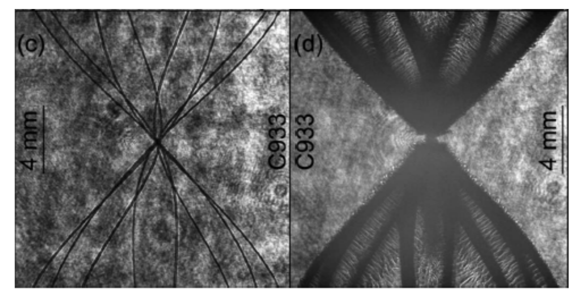
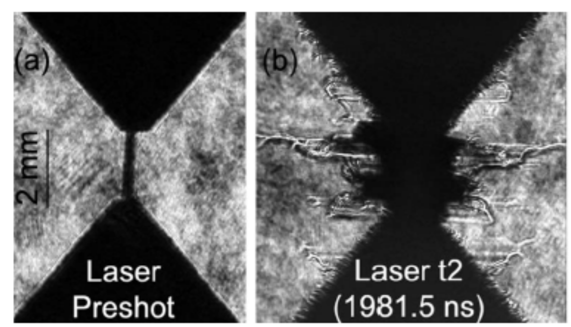



FIG. 1. (a) Simplified nested multilayer X pinch configuration. (b) The wire crossing region of a three-layer nested X pinch.

Source sizes as small as 3um at 1MA
T.A. Shelkovenko, Phys Plasmas, 16, 050702 (2009)




D.B.Sinars, Phys Plasmas 15, 092703 (2008)
T.A. Shelkovenko, IEEE Trans Plasma Sci, 34, 2336 (2006)

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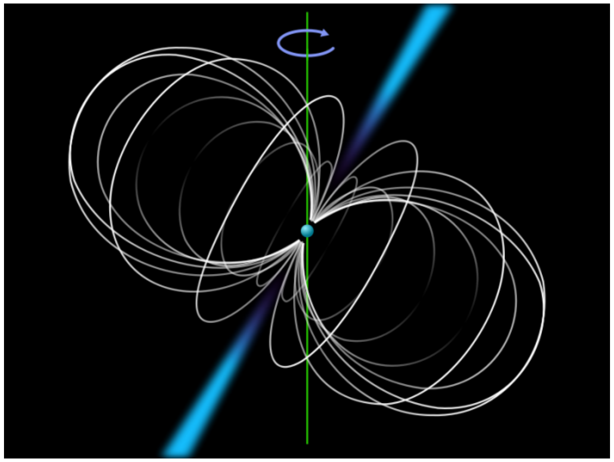
# Scaling of X-pinches to very high current

- Assuming experiments can produce 5-40um hotspots from very high current x-pinches, very high field strengths are possible:

Saturn at 6MA = 60,000 – 450,000T
Z at 20MA = 190,000 – 1,500,000T = 15 GGauss

- Field strengths here are in the range for rapidly rotating pulsars
- compression using large fields may allow generation of degenerate matter in the laboratory
- Change in emission spectrum in extreme B-fields



- What are the maximum densities and B-fields obtainable using x-pinches?
- How can we take advantage of these conditions – small spatial scale (1000$\mu m^3$) and highly transient (10ps)
- Diagnostics required?

# Summary – what does the use of Z gain you?

- ***Hydro Jets:***
  - Significantly larger Re and Pe values (Nov 2010)
  - Ability to design and diagnose jet-target interactions at high Re (Fall 2011)

- ***Magnetized Jets:***
  - Rm?
  - Evolution of B-field in episodic magnetized jets (diagnostics?)

  - ***X-Pinches:***
  - Extreme B-fields confining solid density plasma at few keV
  - Pulsar/neutron star studies?

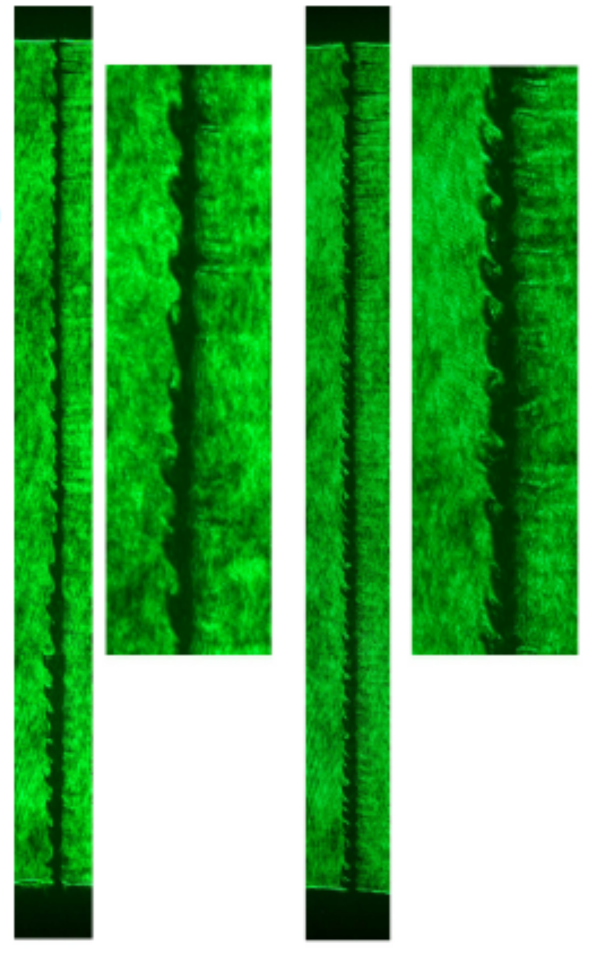
S.C. Bott

# Boundary Conditions Matter

I. Magnetized HED plasmas are formed through complicated processes with regions where MHD fails

II. Our modeling capability and physical understanding of HED systems depend describing their formation

III. Two-fluid model provides next incremental step in describing non-ideal forces



*P.F. Knapp et. al, DPP 2009

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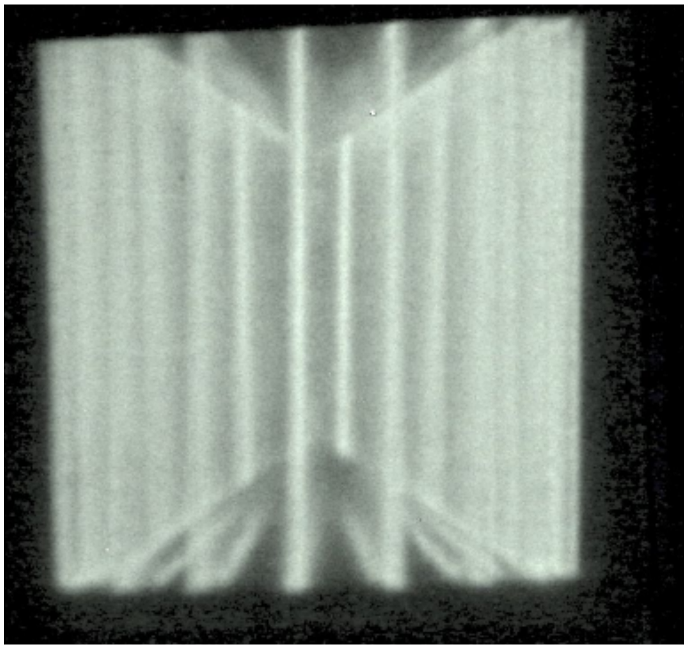
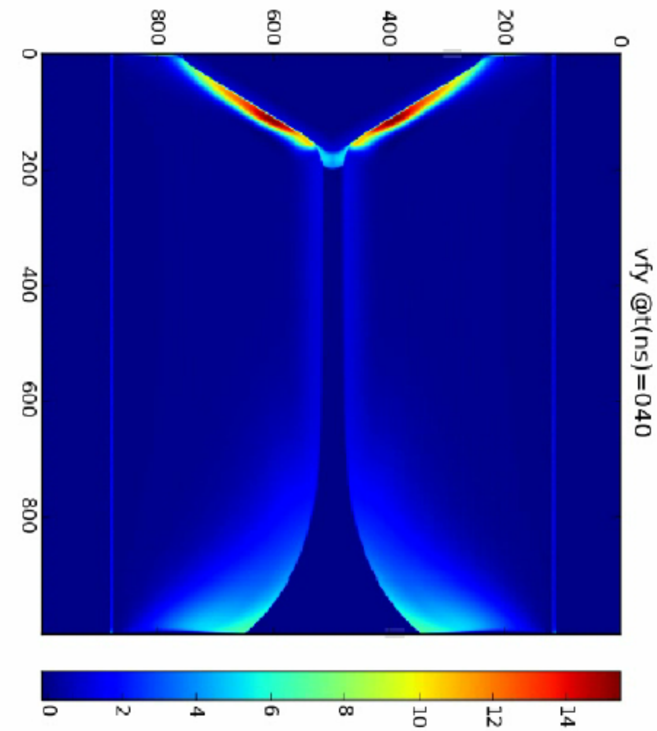
# A-K Flow of ablation plasma observed experimentally at 1 MA can be explained by Hall effect

Anode



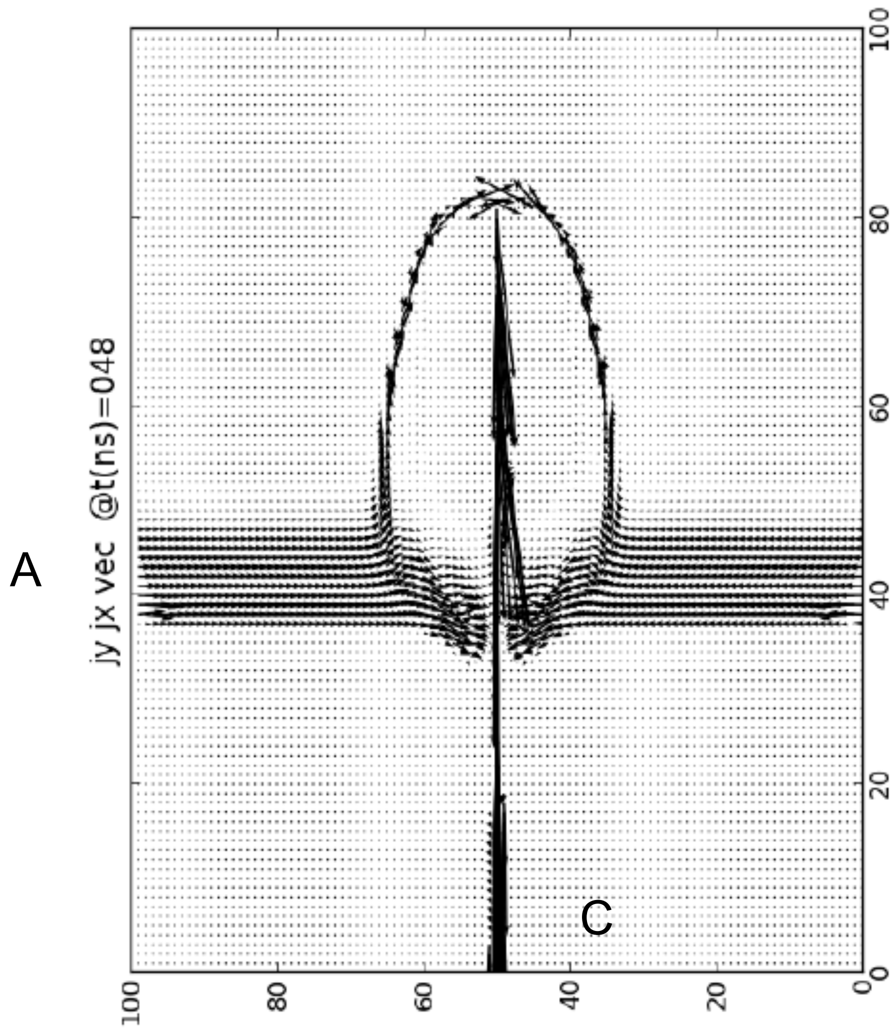



Cathode

Hall induced drift effects could be experimentally tested with higher mass ablation rate (I > 1 MA) precursor column formation

M.R. Martin, J. Greenly

# Radial foil bubble expansion




M.R. Martin

# Concluding Remarks

- **Limited set of experiments have directly explored highly magnetized collisionless plasma regions in HED sources**
- **How well do we understand the propagation of a current carrying plasma front in to vacuum?**
- **Is MHD with a resistive modification adequate for sources with reverse current or diode regions?**
- **How is instability development in highly magnetized HED plasma sources modified by two-fluid/kinetic physics?**

M.R. Martin



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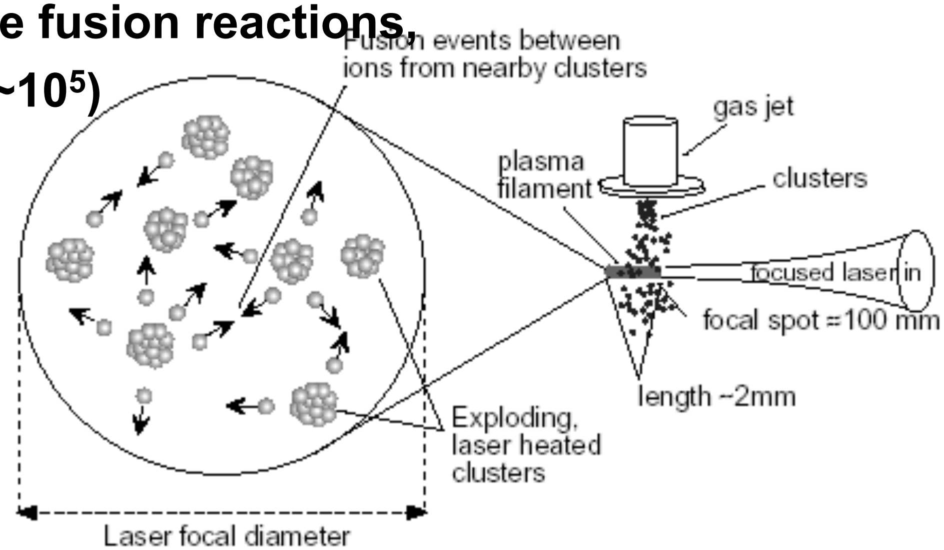
## Experimental motivation`

- **Expanding supersonic deuterium jets produce clusters, that are liquid-density droplets a few nanometers in radius.**
- **The laser field quickly converts clusters into dense fully ionized nanoplasmas.**
- **The resulting explosions produce fusion reactions, with a noticeable neutron yield (~$10^5$) measured experimentally.**




T. Ditmire et al., Nature **398**, 489 (1999)



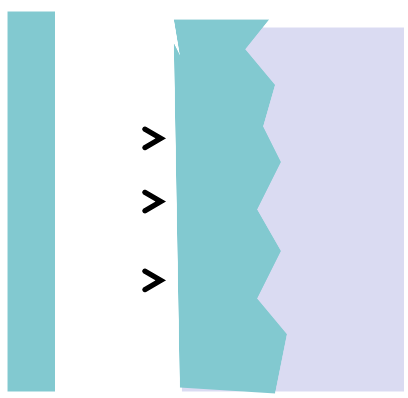
R. Bengstone

# New physics questions

- Where do the 10 keV ions needed for neutron production come from?
- Do fusion neutrons come from single cluster or multiple cluster interactions?
- Transport of energy in a high density, high temperature, high magnetic field plasma?

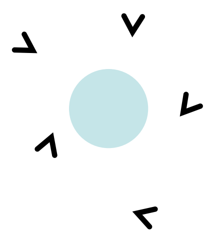
# Experiments to drive RT/RM/KH

- **Experiments can be designed to use Z's fields to drive flyer into foam and then drive hydro instability growth in seeded target**



E. Harding

# Accretion disks can be modeled in the lab with lasers



- **Can drive on standard lasers**
- **Axial field (into screen) makes experiment interesting**
- **~5T field will give $R_m$ ~ 1000**

D.D. Ryutov

# Reconnection in non-ideal plasmas (e.g. WDM) is a major area of interest

- **Edge wires with central foil**
- **Setup opposing fields on either side of foil and let diffuse through**

D.D. Ryutov

# Overview of potential new projects

- **X-pinches at 20-25MA**
  - Expand on Sinars et al. Saturn data
  - Extreme states of matter only possible on Z; densities >solid, Te ~few keV, B~ few GGauss
  - Possible platform for testing proton deflectometry (need to think about geometry)
  - Mature platform at lower currents, Z can add significant value
- **End effects in pulsed power driven sources**
  - Many interesting simulations and experimental observations
  - Modifications to observations at higher densities (currents) would provide proof of origin of observations
  - Exploring basic physics of two fluid plasma effects
- **Reconnection in WDM**
  - Ideas ready for exploration on smaller generators
  - In future likely well suited for development on Z proposal
  - Z would allow higher fields, better diagnosis
- **Cluster fusion**
  - Experiments planned/on-going
- **K-H instability growth**
  - LDRD proposal planned by E. Harding
- **Absorption spectroscopy of Z-pinches**
  - Currently being performed at 1MA
  - Unclear value added at >1MA at present
- **Flux compression on Z**
  - Possibility to reach extreme fields
  - Needs further consideration/collaboration and determination of applications
  - Los Alamos – National High Field Laboratory could add expertise

# New people to get involved

- Los Alamos – National High Field Laboratory could add expertise
- Russian groups may be interested and have good ideas to scale
    - Angara
    - Kurchatov
    - P.N. Lebedev
- Nuclear Physics community
- Send workshop invitation and proposal solicitation to HEDLA mailing list
- Generally wider distribution of workshop info and solicitation would be helpful

# Useful capabilities and user interfaces

- Proton Deflectometry (happening)
- Thompson Scattering
  - X-ray (happening)
  - Optical (going to happen)
- Clarity on how ZBL/ZPW can be coupled to Z
  - On axis?
  - If not possible – would add to utility if it was
  - Should encourage use of ZBL/ZPW as expt driver not simply diagnostic
- Easier access to SNL (or UT for TPW etc) expertise would aid in new ideas
  - Formal connecting method would help (e.g. between workshops)
  - Possibly mailing list of ask for advice/practicalities to ensure resource fully used
- Pre-proposals outside normal cycle may aid in developing ideas
  - Could even be used as ‘Abstracts’ for ideas to discuss at workshop
  - Could be used to engineer development meetings at workshop
    - Help tune working groups for really new ideas

# Other comments

- Community should be encouraged to publish astro-relevant data in ApJ and MNRAS etc in addition to lab journals
  - Same with conferences – AAS etc as well as APS/ICOPS
- Proposal selection should consider need for unique capabilities on Z and maturity of ideas
  - Some problems can be covered by smaller (cheaper) facilities
  - Other ideas can be matured on smaller machines
    - E.g. Zebra at Reno (talk to Joe/Aaron)
- Are fusion related proposals part of the open call for proposals
- Unclear what maturity of idea is currently needed to be successful at proposal stage

## Summary of the beams and particles session

# Breakout 4: Proton radiography on Z
# - a summary -

New diagnostic capability: Proton radiography on Z to measure
- fringe fields on current return can
- measure a capsule in a hohlraum
- compressed magnetic fields
- plasma jets

with a charged particle beam

If successful, it would answer questions 1 and 2 of the User Meeting:
- ability to measure EM-fields with spatiotemporal resolution would improve user experience on Z
- it would offer the opportunity to grow research capability on Z

# Charged Particle Beam Radiography

Charged Particles: Protons as proposed in LDRD, or Electrons?

• new idea: 300 MeV electrons from wakefield acceleration in gas jet or preplasma

• particle number may be an issue

• detectors are difficult to build and characterize, electron signal hard so resolve

• no time resolution, electrons are all close to c

→ Better to use protons

# Proton beam enhancement

- includes energy, flux, emittance. Therefore we need to better understand the fundamental processes taking place:
    - pre-plasma characterization
    - electron heating, what is relevant for TNSA?
    - measure electron spectra inside target
    - better TNSA modeling
    - scalings over many orders of magnitude, and not only two as usual?
    - learn how to design better targets

- Knowledge/control of laser parameters:
    - prepulse
    - polarization, influence of tight focusing on polarization

- plasma mirrors -> experiment on its own
- diagnostic development
- theory
- this naturally leads to experiment/theory proposals

# Proton Energy

- Goal: Highest energies possible
  - enhance intensity (…)
  - necessary to understand hot electron generation first
  - What is role of pre-pulse/pre-plasma for SNL laser?
    - characterize pre-plasma, this includes pre-plasma generation in a controlled way
    - measure electrons + protons simultaneously with pre-plasma
    - Use simulations to get insight into electron dynamics, and find experiments which will distinguish theories
    - What is the main effect of the pre-plasma on the main pulse
      - self-focusing, how strong?
      - pre-pulse suppression?
    - Correlation of e-,p+, pre-plasma measurements will lead to detailed insights of physical processes, which so far has not been done for ZPW/TPW parameters

# Plasma Mirror design and characterization

- Design and manufacture ellipsoidal plasma mirrors
- Characterize PMs:
  - laser focal spot behind mirror
  - transmission
  - pulse contrast

- Does additional focusing with ellipsoidal PM overcompensate energy loss, does it really improve the performance for a given energy? (First published experiments not conclusive)

- Scaling of p+ with pulse energy, intensity, pulse width, and compare to measurements w/out PM

- low-hanging fruit, high-quality publication
- can be performed both at UT/SNL

# Electron spectra inside target

- Which part of electron distribution is relevant for proton acceleration ?
  - 10 MeV – 100 MeV
  - requires theoretical modeling

- How to measure?
  - x-ray spectroscopy (Bremsstrahlung)
  - alloyed Targets with changing alloy, measure K-alpha -> EDF inside target

- Questions to be answered:
  - angular dependence?
  - absolute electron numbers/MeV
  - measure e-/p+ and change pre-pulse in controlled way
  - set into relation with proton spectrum → is only TNSA going on?

- Time-resolved measurements (not feasible < 1 ps)
- Spatial resolution? → Needs more thinking

# Target Design

• Simple, but high-payoff targets to test various theories
• Obviously correlation between target geometry and proton energy

• Target which confines electron transport (repeat VULCAN expts, but measure e- and p+ spectrum)
• Rear-side coated targets (CH, ErbH) or doped targets
• D-doped targets, measure energy gain of fusion protons in sheath to determine sheath potential

• More sophisticated targets:
  • Flat-Top Cones
  • small Hemis/Apollos
  • nm targets once high contrast is reached: RPA regime

• We need better laser characterization for a single shot to learn about individual target performance

• Always scan targets for angle of incidence, and polarization (s/p)

# Theory

• optimum pre-plasma parameters to optimize electron gain for SNL/UT parameters

• examine multi-pass electron heating

• better TNSA models: scalings that do not need codes to compare with expts.

• investigate hydrodynamic instabilities for accelerated protons

• can we optimize proton acceleration with existing laser constraints/ parameter space?

• participate in target design

• get more SNL theorists involved in our work
• establish a dialogue with SNL and UT theorists!

# Experiments (low-hanging fruits)

- PM calibration, and measure e-/p+ simultaneously
- Characterize SNL pre-plasma and measure e-/p+ simultaneously
- Use a high contrast laser in conjunction with a pre-pulse to scan effect of pre-plasma on proton energy/flux/efficiency for $I > 10^{20}$ W/cm$^2$
- angularly resolved Bremsstrahlung yield measurements to map electron spectrum (collaborate w/ LLNL?)
- Target which confines electron transport (repeat VULCAN expts, but measure e-/p+ spectrum)
- Sheath p+ radiography

# Experiments: Electron and sheath diagnostics + $p^+$ spectrum

- CTR: Relevance to TNSA doubtful from LANL expts.
- Stark shift measurements of sheath fields
- Laser Compton scattering off the expanding plasma electrons in sheath
- Polarized x-rays to measure TV sheath fields
- Proton radiography of charged target before TNSA
    - Deflectometry with pencil beams
- Frequency-Domain Interferometry of sheath electron density
- Nuclear transitions as diagnostics
- Radiochemistry from target from electrons?
- Neutron diagnostics?  Prompt p,n measurements?

- And correlate that to electron and p+ measurements
- Knowledge of sheath parameters and resulting proton spectrum will lead to distinguish validity of theoretical models (TNSA: isothermal expansion, adiabatic expansion, two-phase models, …)

# Summary

• Many experiments have been done world-wide, but transfer of results from one laser system to another is highly questionable. Well-characterized experiments (laser, plasma, electrons + protons) can change this.

• Most of work really needs to be done! It will not lead to “great science in the broadest national interest”, but it will give our community more credibility and it will lead to a detailed understanding of the physics

• High-quality measurements, coupled with theoretical modeling, can be published in high-impact journals

Work to be done:

• Filter all these ideas, set up a game plan for the next 3-5 years

• Select experiments which will lead into formal proposals for SNL/UT

• Many experiments can be performed by grad students, and will lead to high-quality publications

• Organize and set up workgroups

• Grow research team: get more SNL theoreticians involved, start to communicate

## Summary of the planetary science session

10/8/10

Sandia National Laboratories

Date 08/06/2010

# Planetary break-out session

Jacobsen, Redmer, Hamel, Desjarlais, Nettelman, Davis, Ao, Schulenburger, Bernstein, Porter, Remo, Rose, Koepke, Mattsson

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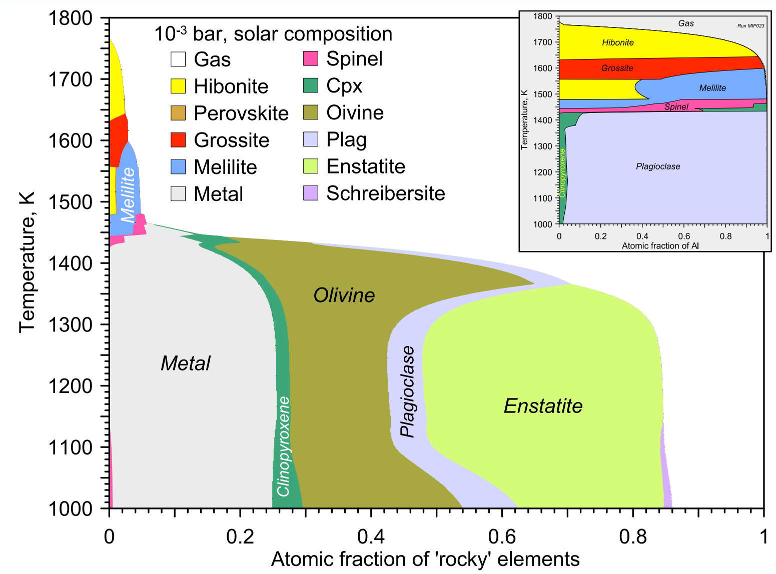
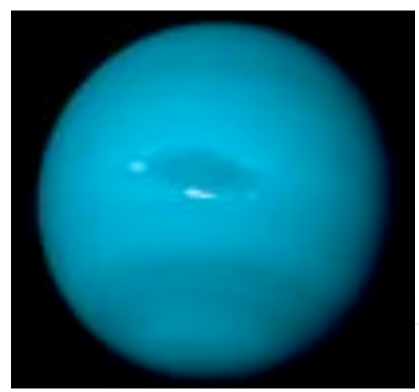
# New ideas and developing concepts

- **Earth and super-earths**
  - **Earth under pressure**
  - **Fundamental EOS up to 400 GPa and 5000 K**
  - **Materials**
    - **Iron**
    - **Silicates**
- **Gas- and ice giants here and out there**
  - **H, He, H2O, NH3, CH4**
  - **Improved EOS**
    - **High-precision experiments to distinguish between EOS for H, H2O**
  - **Mixtures: all of the above**



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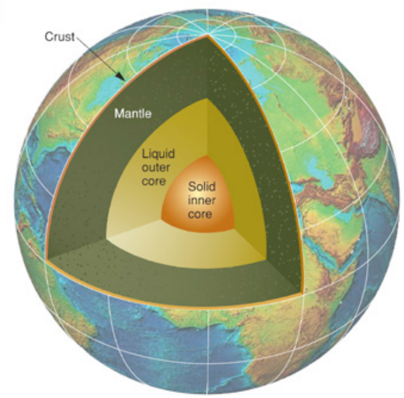
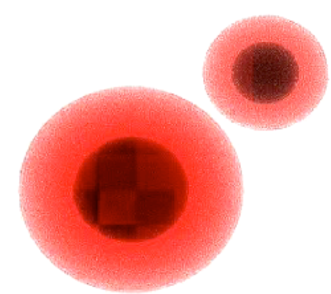
# Proposal one – earth and super-earth materials

- Earth and super-earths
  - Earth under pressure
  - Fundamental EOS up to 400 GPa and 5000 K
  - Materials
    - *Iron and iron alloys + impurities (C,S,K,O)*
      - Melt line
      - Solid-solid transitions
      - Pre-heat
- Earth now
  - *Melt line under pressure for Fe/Ni*
    - Staggering spread in melt estimations
  - Dynamo generation (conductivity)
- Earth then
  - MFE (Moon Forming Event)
  - *Critical point of silicates*
    - Amount of rock vapor during MFE

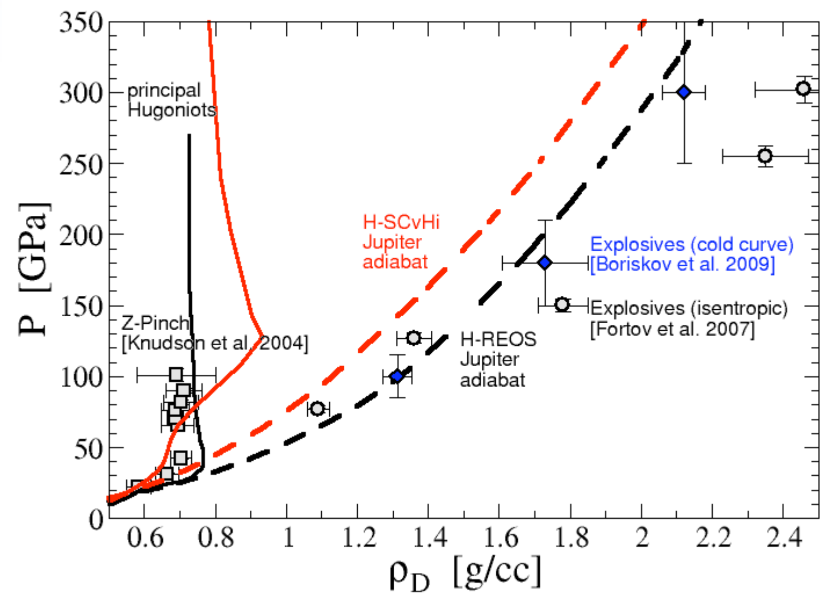


Metals (black) silicates (red)
(Stein Jacobsen)

# Proposal two – gas- and ice giants, plus exo ones

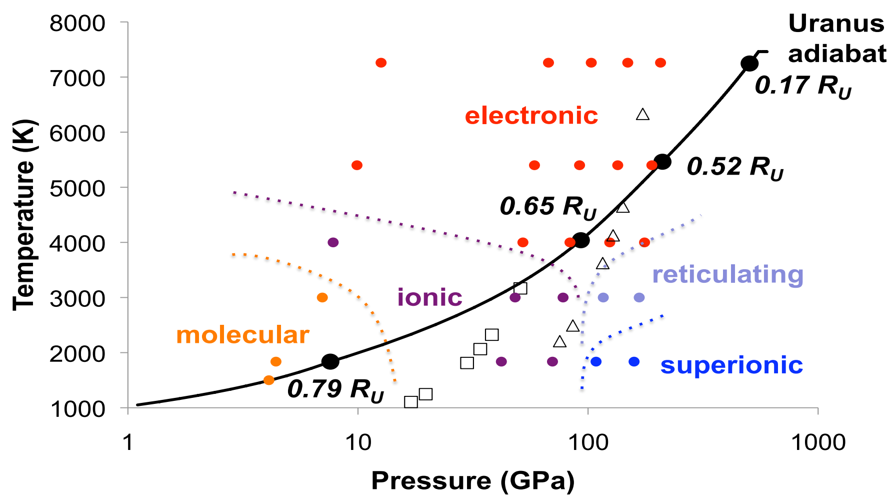
- Gas- and ice giants here and out out there
  - EOS
    - High-precision experiments to distinguish between EOS for H, H2O above 100 GPa
    - "density to 1 %" for hydrogen at 100 GPa and 5000 K. Sensitive region of EOS when combining w gravity data
    - *Meet this challenge!*
  - Diagnostics
    - Existing plus X-ray Thomson scattering, pyrometry/ optical reflectivity




Jupiter adiabat using two different EOS (Nadine Nettelman)

# Proposal two – gas- and ice giants, plus exo ones

- **Gas- and ice giants here and out out there**
  - **$H_2O$, $NH_3$, $CH_4$, $CO_2$**
  - **Mixtures: all of the above**
  - **Phase separation and non-traditional phase transitions**
    - **Liquid-liquid**
    - ***Investigate N***
  - **Stability of superionic phase**
    - ***Observe changes/ confirm* the superionic phase?**
  - **Very rich field of opportunities in mixtures and phase stability.**




Phase-diagram of water with methane/ ammonia mix (Sebastien Hamel)

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# Develop and grow research team(s)

- Nucleate and develop team (s)
  - Deep, broad, and constructive discussions yesterday
  - Identified strengths/core expertise
- Grow team and community
  - Identified lacking expertise and will contact scientist complementing the teams
  - Be open to work being done at additional facilities/universities as a way to engage a broader community. Primary supporting thus being directly involved at work on sites as well. Will lead to greater geographic diversity.

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# Improve the user experience

- **Infrastructure for visitors**
  - **Office**
  - **Network, computing, phone**
  - **Project meeting rooms/ collaborative environment**
  - ***How do we make visitors look forward to returning?***

- **Process for applying for laser exp**
  - **Acknowledge that it will take time, the "30 minutes" meeting is rarely, if ever, 30 mins. Hwo about "site visit, presentation, and coordination" 30 mins to full day depending on maturity of collaboration/project.**

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## Appendix 1: Organizing committee

### General Organization:

Briggs Atherton, Aaron Bernstein, Roger Bengtson, Todd Ditmire, Gillis Dyer, Mark Herrmann, Ramon Leeper, Gordon Leifeste, John Porter, Don Winget, Alan Wootton.

### Astrophysics:

Don Winget and Jim Bailey

### Magnetized high energy density science:

David Ampleford and Simon Bott

### Particles and Beams:

Marius Schollmeier

### Planetary science:

Thomas Mattsson

### User Meeting:

Gordon Leifeste, Briggs Atherton, Gillis Dyer

## Appendix 2: Attendees

| Last Name | First Name | Affiliation |
|---|---|---|
| Afeyan | Bedros | Polymath Research Inc |
| Aguirre | Maria | University of Texas at Austin |
| Ampleford | David | Sandia National Laboratories |
| Ao | Tommy | Sandia National Laboratories |
| Arefiev | Alexey | University of Texas at Austin |
| Atherton | Briggs | Sandia National Laboratories |
| Bailey | James | Sandia National Laboratories |
| Bengtson | Roger | University of Texas at Austin |
| Bernstein | Aaron | University of Texas at Austin |
| Bott | Simon | University of California, San Diego |
| Briezman | Boris | University of Texas at Austin |
| Collins | Gilbert "Rip" | Lawrence Livermore National Laboratory |
| Covington | Aaron | University of Nevada, Reno |
| Desjarlais | Michael | Sandia National Laboratories |
| Ditmire | Todd | University of Texas at Austin |
| Donovan | Mike | Logos Technologies |
| Dyer | Gilliss | University of Texas at Austin |
| Ellis | Jennifer | University of Texas at Austin |
| Falcon | Ross | University of Texas at Austin |
| Fisch | Nathaniel | Princeton University |
| Flippo | Kirk | Los Alamos National Laboratory |
| Gerlock | Cari | Sandia National Laboratories |
| Hall | Iain | University of Nevada, Reno |
| Hamel | Sebastein | Lawrence Livermore National Laboratory |
| Hanshaw | Heath | Sandia National Laboratories |
| Harding | Eric | Sandia National Laboratories |
| Heffelfinger | Grant | Sandia National Laboratories |
| Herrmann | Mark | Sandia National Laboratories |
| Jacobsen | Stein | Harvard University |
| Keane | Chris | Lawrence Livermore National Laboratory |
| Khudik | Vladimir | University of Texas at Austin |
| Kindel | Joseph | University of Nevada, Reno |
| Koepke | Mark | DOE Fusion Energy Sciences |
| Leifeste | Gordon | Sandia National Laboratories |
| Liang | Edison | Rice University |
| Liedahl | Duane | Lawrence Livermore National Laboratory |
| Mancini | Roberto | University of Nevada, Reno |
| Martin | Matthew | |

| | | |
|---|---|---|
| Mattson | Thomas | Sandia National Laboratories |
| Matzen | M. Keith | Sandia National Laboratories |
| Mayes | Daniel | University of Nevada, Reno/Sandia National Laboratories |
| Montgomery | Michael | University of Texas at Austin |
| Nettelman | Nadine | University of California, Santa Cruz |
| Offerman | Dustin | Los Alamos National Laboratory |
| Porter | John | Sandia National Laboratories |
| Quevedo | Hernan | University of Texas at Austin |
| Redmer | Ronald | University of Rostock |
| Remo | John | Harvard University |
| Rochau | Gregory | Sandia National Laboratories |
| Rose | David | Voss Scientific |
| Ryutov | Dmitri | Lawrence Livermore National Laboratory |
| Saumon | Didier | Los Alamos National Laboratory |
| Sefkow | Adam B | Sandia National Laboratories |
| Schollmeier | Marius | Sandia National Laboratories |
| Shulenburger | Luke | Sandia National Laboratories |
| Shvets | Gennady | University of Texas at Austin |
| Sinars | Daniel | Sandia National Laboratories |
| Struve | Kenneth | Sandia National Laboratories |
| Sweeney | Mary Ann | Sandia National Laboratories |
| Vishniac | Ethan | McMaster University |
| Welch | Dale | Voss Scientific |
| Winget | Don | University of Texas at Austin |
| Wootton | Alan | University of Texas at Austin |

## Appendix 3: Agenda

**Wednesday, August 4th**

**Session 1: New Ideas**

| | |
|---|---|
| 8:45 – 9:15 | Todd Ditmire (UT), Next generation lasers and light sources |
| 9:15 – 9:45 | Nathaniel Fisch (Princeton), Wave Compression in Plasma |
| 9:45 – 10:15 | Gilbert Collins (LLNL), Planetary cores |
| 10:30 – 11:00 | Edison Liang (Rice), Generation and Application of Superstrong Magnetic Fields with Ultra-Intense Lasers |
| 11:00 – 11:30 | Bedros Afeyan (Polymath), Nonlinear Optical Processes and their Control in High Energy Density Plasmas |
| 11:30 – 12:00 | Duane Liedahl (LLNL), X-rays from black hole accretion disks |
| 1:15 – 1:45 | Didier Saumon (LANL), Unsolved problems in dense hydrogen and helium |
| 1:45 – 2:15 | Dmitri Ryutov (LLNL), Magnetized high energy density plasmas |
| 2:15 – 2:45 | Ronald Redmer (Rostok), High-pressure phase diagram and planetary interiors |
| 2:45 – 3:15 | Joseph Kindel (UNR), Research at the Nevada Terawatt Facility |

**Session 2: User Science**

| | |
|---|---|
| 3:30 – 4:00 | Don Winget (UT), White dwarf photospheres |
| 4:00 – 4:30 | Roberto Mancini (UNR), Experiments and modeling of photoionized plasmas at Z |
| 4:30 – 5:00 | Jim Bailey (SNL), Laboratory tests of stellar interior opacity models |
| 5:00 – 5:30 | Daniel Sinars (SNL), Measurements of magneto-Rayleigh-Taylor instability growth in solid liners on the 20 MA Z Facility |
| 5:30 – 6:00 | Mike Desjarlais (SNL), Materials at high pressure |

**Thursday, August 5th**

**Session 2: User Science (Continuation from Day 1):**

| | |
|---|---|
| 8:15 – 9:00 | Aaron Bernstein (UT), Current research using the UT laser systems |
| 9:00 – 9:30 | Marius Schollmeier (SNL), Proton acceleration experiments |
| 9:30 – 9:45 | Alexey Arefiev (UT), Proton production theory |

**Session 3: Planning for users**

| | |
|---|---|
| 9:45 – 10: 30 | Gilliss Dyer (UT), The UT laser facilities and diagnostics: what they can do and how to become a user |
| 10:45 11:15 | Gordon Leifeste (SNL), Z Fundamental Science Collaboration Program |
| 11:15 11:45 | Greg Rochau (SNL), Fundamental Science Experiments on Z: A Diagnostic Perspective |
| 11:45 – 12:30 | Briggs Atherton (SNL), The SNL laser facilities (including diagnostics) and how to become a user |

**Working Groups:** Sunset, Pinon, Chaparral & Turquoise rooms
1:15 – 6:00 pm
Breakout 1: Radiative astrophysics, organized by Don Winget and Jim Bailey – Sunset Room
Breakout 2: Planetary and materials science, organized by Thomas Mattsson – Pinon Room
Breakout 3: Magnetized high energy density science organized by David Ampleford – Chaparral Room
Breakout 4: Proton acceleration, organized by Marius Schollmeier – Turquoise Room

**Friday, August 6th**

Session 4: Round table discussion (half day)

| | |
|---|---|
| 9:00 – 9:15 | Chris Keane (LLNL), NIF Governance and Basic Science Proposal Process |
| 9:15 – 9:30 | Don Winget (UT), Astro working session report |
| 9:30 – 9:45 | Thomas Mattsson (SNL), Planetary science working session report |
| 9:45 – 10:00 | David Ampleford (SNL), Magnetized HED working session |
| 10:00 – 10:15 | Marius Schollmeier (SNL), Proton acceleration |
| 10:15 – 10:25 | Ken Struve (SNL), Students and SNL |
| 10:25 – 10:35 | The White Dwarf team (UT), Our experiences at SNL |
| 10:35 – 12:00 | Discussion |