NSF'S PLASMA PHYSICS PROGRAM

Presented by
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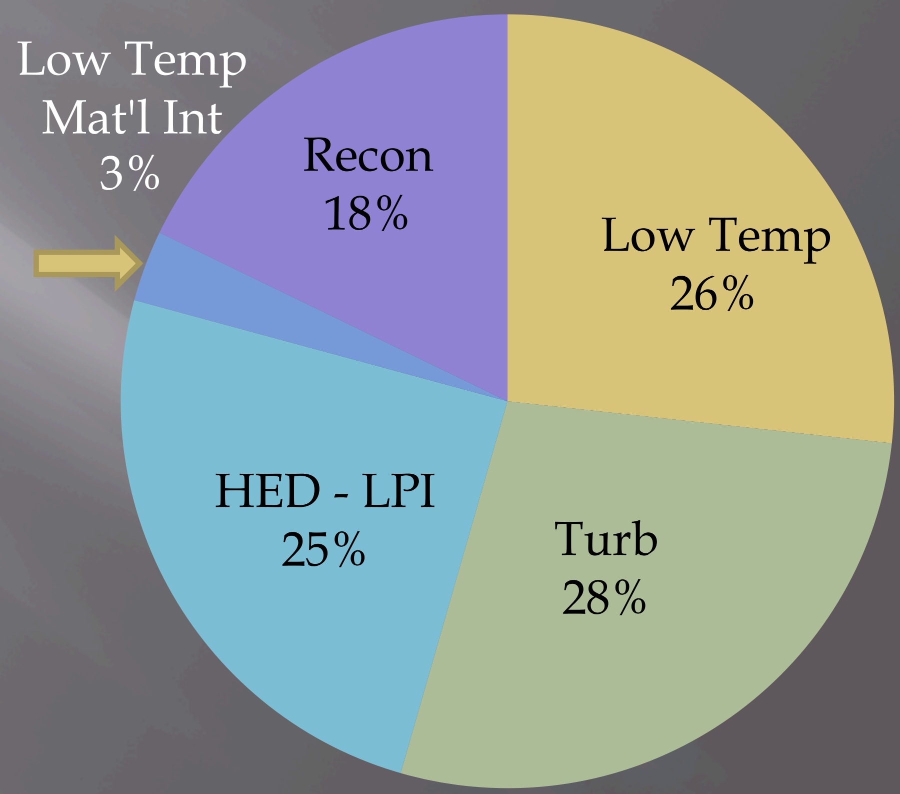
Plasma Physics Program - Overview

- NSF/DOE Partnership in Basic Plasma Science & Engineering (solicitation NSF 13-596)
  - in existence since 1997, under interagency MOU
  - combined funding level $4.9 M FY14 (new starts)
  - NSF (7 programs), DOE OFES BPS, & AFOSR
  - 10% of submissions funded (FY14)
  - "Proposals directly related to fusion energy studies are not eligible."
- NSF Career Awards
  - 5 yr grants, 8 awarded since 2005, young faculty
- Conference/Workshop grants
- Other opportunities @ NSF
  - e.g. Accelerator Science, MRI, PIF, CDS&E, PFC, EPSCoR, GOALI, CAREER, PIRE, CREATIV, SAVI, Mid Scale
  - [see NSF web site for more info … www.nsf.gov]

Current Plasma Physics Portfolio

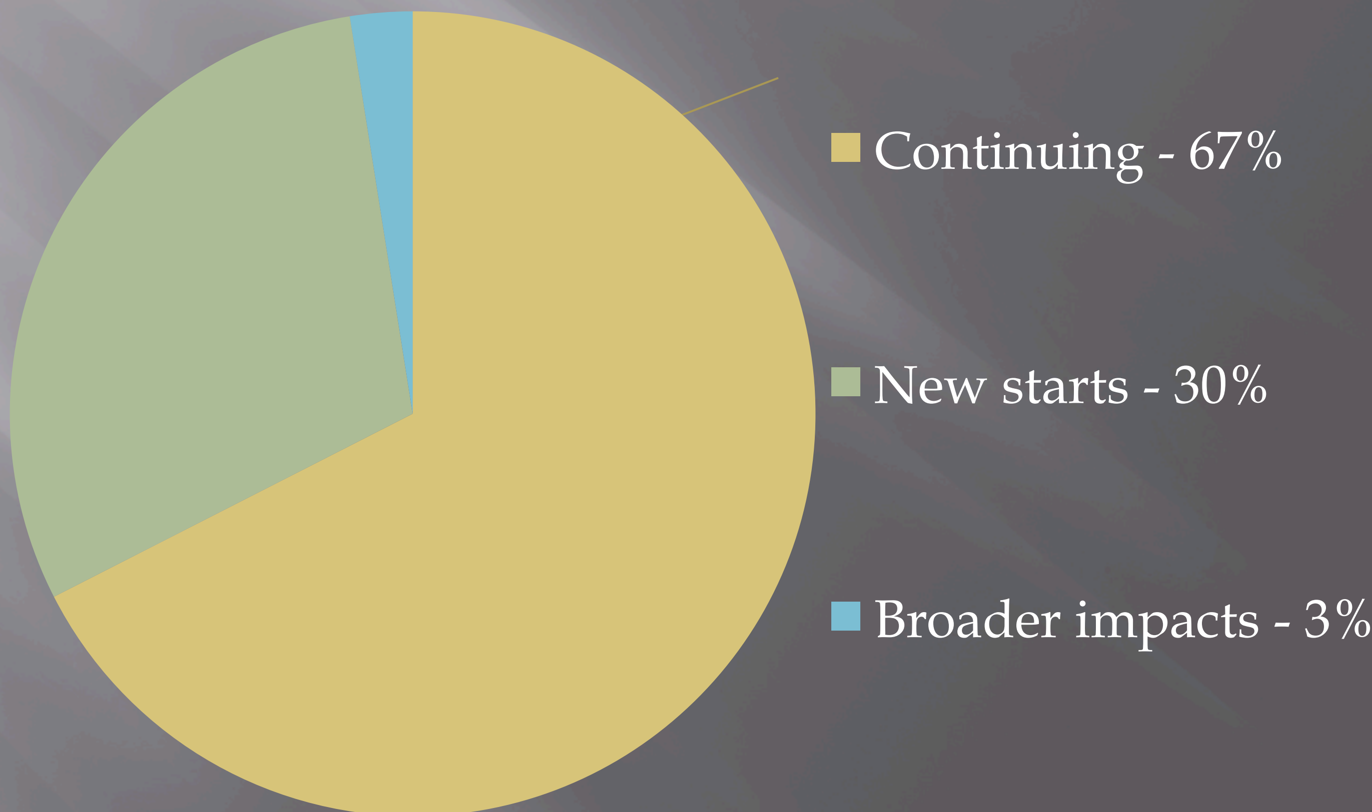
- HED/LPI … 20
- Low Temp … 21
- Turb, etc. … 22
- Recon … 14
- LTP – MI … 2
- Total … 79 projects



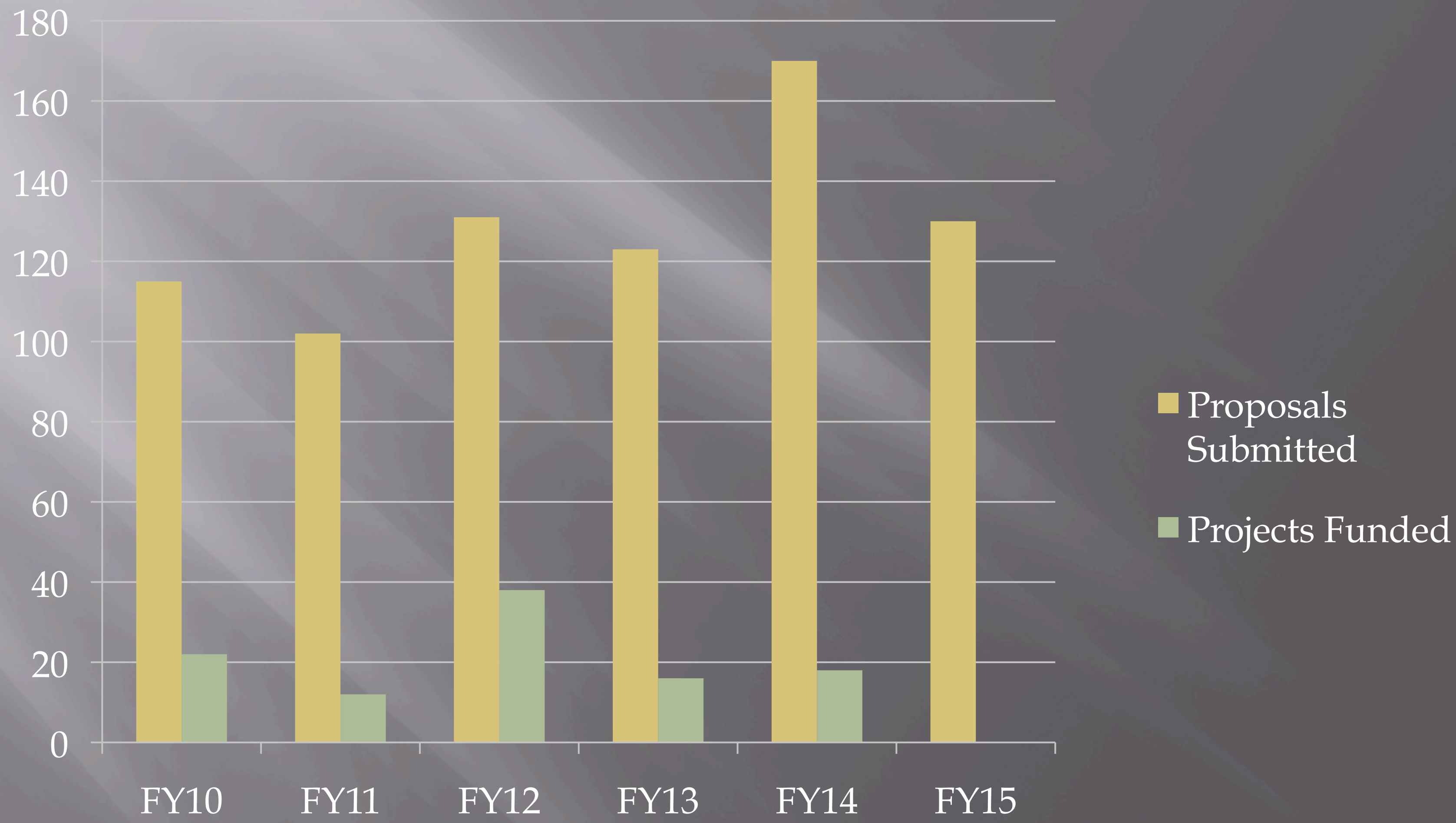
Thru end of FY14

NSF Plasma Program FY14 Budget Breakdown

- Funding areas … continuing grants, new starts, & conferences/workshops/REUs/etc.



NSF Plasma Program Recent History: Proposals & Projects



Other Opportunities at NSF

- MRI – Major Research Infrastructure
- Accelerator Science (see NSF 14-576) - NEW
- PIF – Physics at the Information Frontier
- CDS&E – Computational & Data-Enabled Science & Engineering
- PFC – Physics Frontier Centers
- EPSCoR – Experimental Program to Stimulate Competitive Research
- GOALI – Grant Opportunities for Academic Liaison with Industry
- CAREER – young faculty, 5 year grants
- PIRE – Partnerships for International Research and Education
- INSPIRE – Integrated NSF Support Promoting Interdisciplinary Research & Education
- SAVI – Science Across Virtual Institutes
- Midscale Level Instrumentation – (see NSF 14-116)
- see NSF web site for more info – www.nsf.gov

Current Plasma Projects at NSF

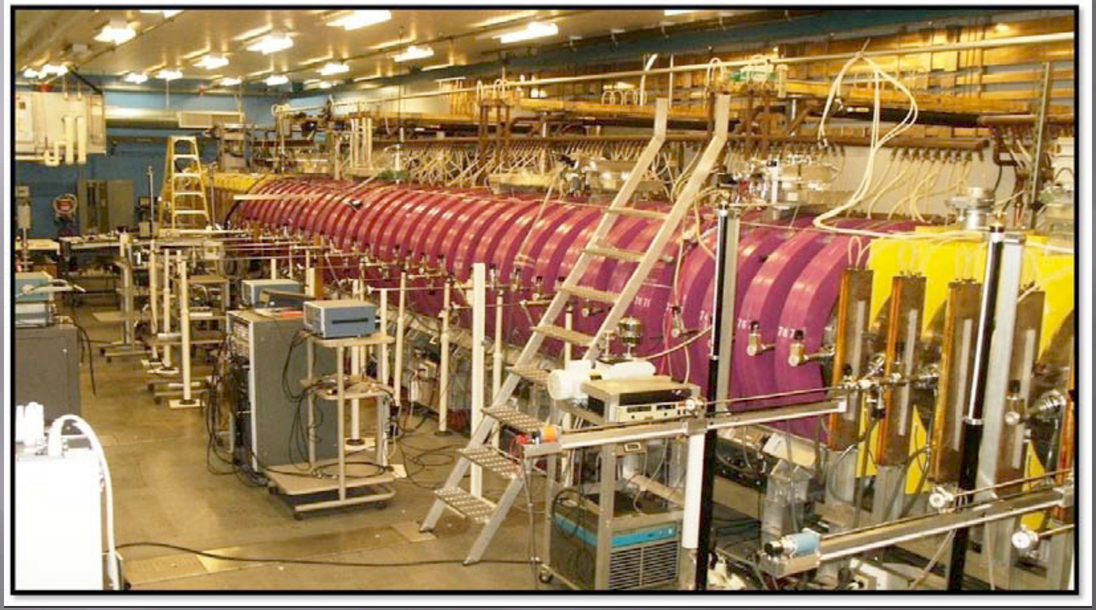
- MRI – Major Research Infrastructure
  - NSF 1337831 - MRI Consortium: Development of A Large Plasma Device for Studies of Magnetic Reconnection and Related Phenomena (PI: Hantao Ji, Princeton University)
  - NSF 1229408 - MRI: Acquisition of Computer Cluster for Heliophysics, Plasma, and Turbulence Modeling (PI: Joachim Raeder, University of New Hampshire)
  - NSF 1126067 - MRI: Development of a Magnetized Dusty Plasma Device (PI: Edward Thomas, Auburn University)
- PFC – Physics Frontier Centers
  - NSF 0821899 - Center for Magnetic Self Organization in Laboratory & Astrophysical Plasmas (PI: Ellen Zweibel, University of Wisconsin)
- GOALI – Grant Opportunities for Academic Liaison with Industry
  - NSF 1102244 - GOALI: Advancing the underlying science of in-line RF metrology and pulsed RF power delivery in plasma enhanced manufacturing systems (PI: Steven Shannon, North Carolina State University)

Current Plasma Projects at NSF

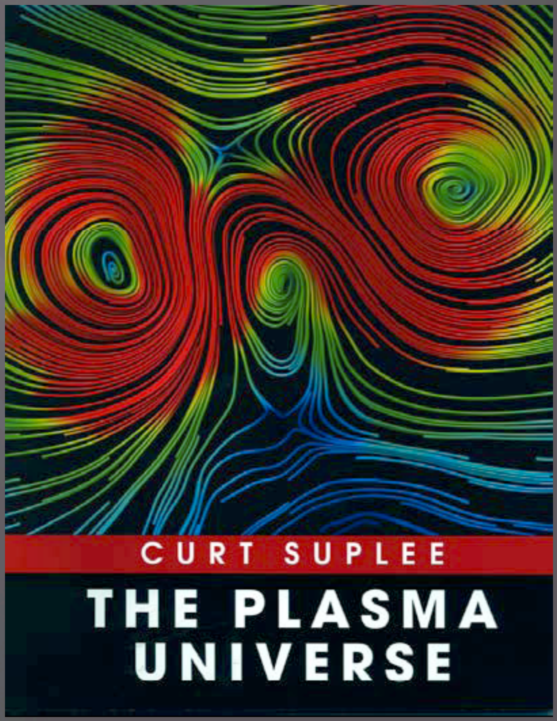
- CAREER – young faculty, 5 year grants
  - NSF 1351455- CAREER: A Single Shot Camera Capturing Ultrafast Dynamic Phenomena (PI: Ki-Yong Kim, University of Maryland)
  - NSF 1254273 - CAREER: Low Temperature Microplasmas For Thermal Energy Conversion, Education, and Outreach (PI: David Go, University of Notre Dame)
  - NSF 1057175 - CAREER: Micro- and Nano- Scale Plasma Discharges in High Density Fluids (PI: David Staack, Texas A&M University)
  - NSF 1054164 - CAREER: Bright femtosecond x- and gamma-ray pulse production using ultra-intense lasers (PI: Alec Thomas, University of Michigan)
  - NSF 0953595 - CAREER: Investigation of the thermal and transport properties of a dusty plasma (PI: Jeremiah Williams, Wittenberg University)
- INSPIRE / CREATIV
  - NSF 1344303 - INSPIRE Track 1: Concept Development for Active Magnetospheric, Radiation Belt, and Ionospheric Experiments using In-situ Relativistic Electron Beam Injection (PI: Ennio Sanchez, SRI International)
  - NSF 1246929 - Statistical State Dynamics of Turbulent Systems (PI: Brian Farrell, Harvard Universrsity)
- SAVI – Science Across Virtual Institutes
  - NSF 1144374 - SAVI: A Max-Planck/Princeton Research Center for Plasma Physics (PI: James Stone, Princeton University)

Plasma Program – research areas

- Basic Plasma Science Facility at UCLA was renewed thru 2016 … shared funding between DOE Office of Science & several NSF divisions



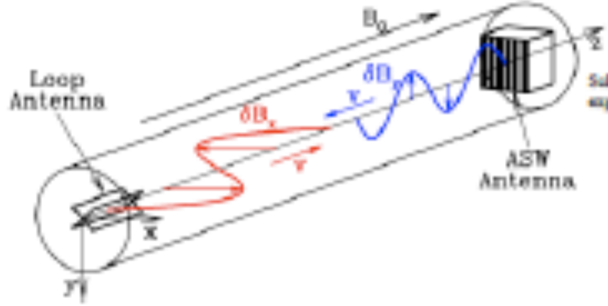
NSF – PHY 1036140 – Walter Gekelman, PI



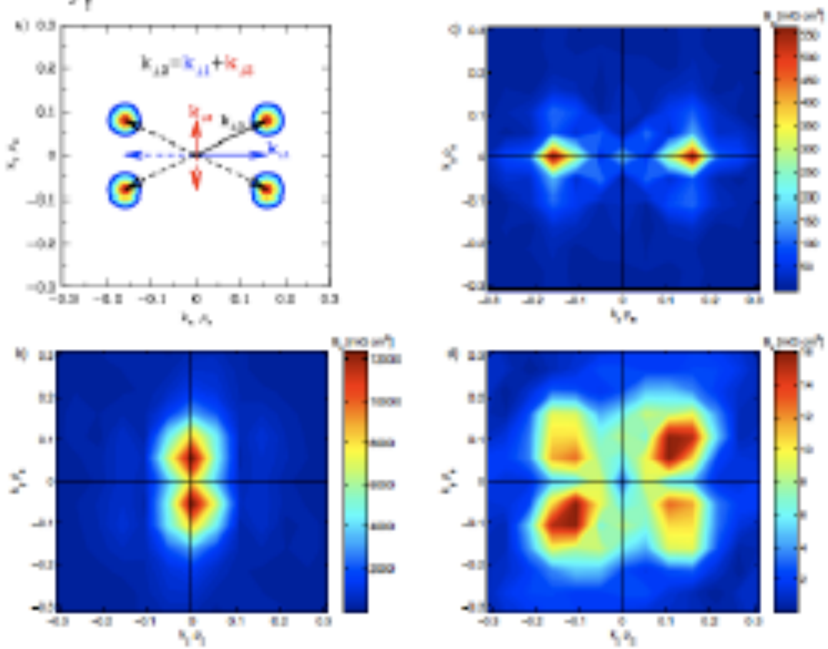
Plasma Program – research areas

Gregory G. Howes, F. Skiff, C. A. Kletzing, D. J. Drake, K. D. Nielson (University of Iowa), T. A. Carter (UCLA)

"Basic Laboratory Experiments of Plasma Turbulence: Alfven Wave Collisions"



Schematic of Alfven wave turbulence experiment on the LAPD



a) Diagram of wavevector addition to generate the nonlinear daughter wave. Power in Fourier transform (wavevector) space is shown for the Loop antenna wave (b), ASW antenna wave (c), and the nonlinear daughter wave (d).

Alfven waves play a central role in the dynamics of magnetized plasma turbulence. Theoretical studies suggest that the nonlinear interactions that constitute the turbulence occur only between Alfven waves traveling in opposite directions along the magnetic field. Therefore it is these interactions, often referred to simply as "collisions" between counterpropagating Alfven waves, that form the fundamental building blocks of plasma turbulence. Modern theories of anisotropic magnetized plasma turbulence have been developed based on this intuitive concept of counter-propagating Alfven wave collisions. Yet the applicability of these idealized theories to realistic plasma conditions found in space and astrophysical plasmas has not been established. **This experimental program has verified in the laboratory the theoretically proposed properties of Alfven wave collisions.**

At the top on the left is a schematic diagram of the Alfven wave collision experiment performed at the Large Plasma Device (LAPD) at UCLA, published in Physical Review Letters in December 2012. In this experiment, two Alfven waves are launched towards each other, a large amplitude Alfven wave launched by a Loop antenna, and a smaller amplitude Alfven wave from the Arbitrary Spatial Waveform (ASW) antenna. The power in Fourier space is shown in the lower plot for the Loop antenna wave (b) and ASW antenna wave (c). The nonlinear interaction between these two waves leads to a daughter Alfven wave with a wavevector that is a sum of the two primary waves, as depicted in (a). In panel (d) is shown the measured signal of the nonlinear daughter wave, confirming that we have indeed successfully measured the nonlinear interaction between counterpropagating Alfven waves. **These results confirm the theoretically predicted properties of this nonlinear interaction and establish a firm basis for the application of theoretical concepts derived in idealized models to realistic space and astrophysical plasmas.**

Plasma Program – research areas

Impact of the Hall Effect on plasma density and stability.

NSF – PHY 1102471 -- PI Pierre Gourdain … *Cornell University , Ithaca NY, USA,*

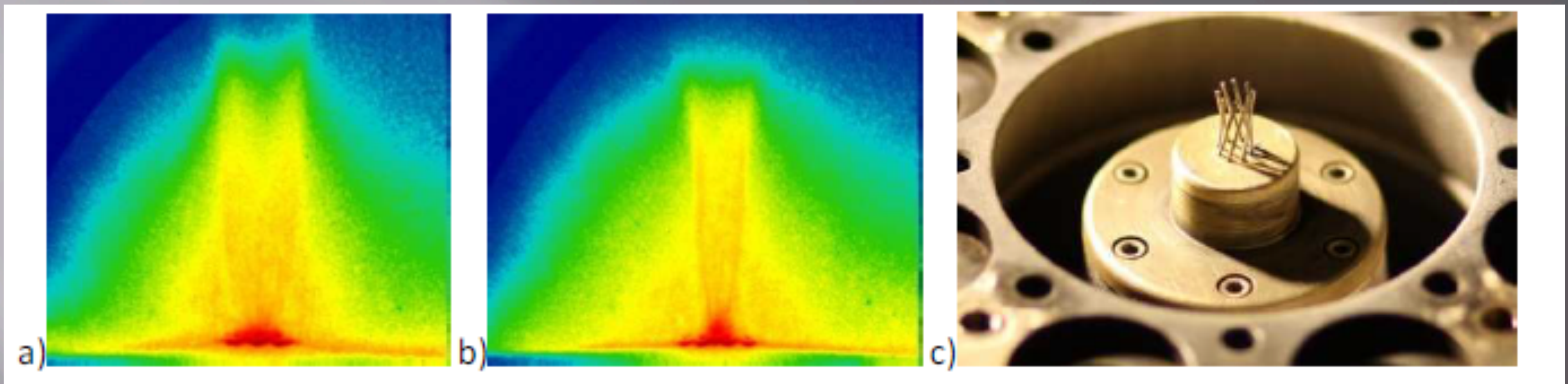
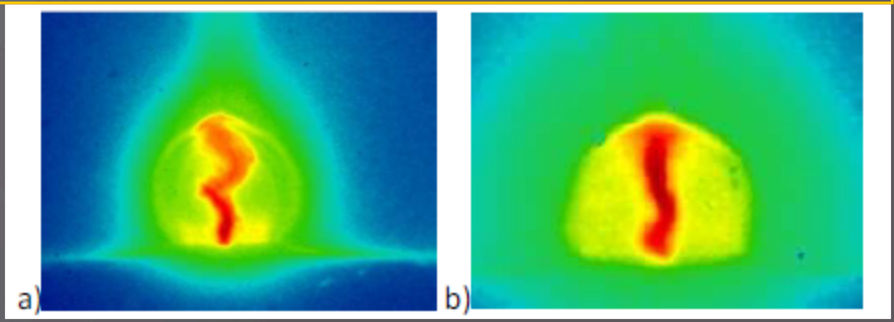


Figure 3. Extreme UV imaging showing the plasma jet with a) standard and b) reverse current polarity with a 10 T axial field applied at the base of the base of the plasma jet. c) The twisted pin hardware located under the foil is used to produce a 10 T field at the base of the jet.

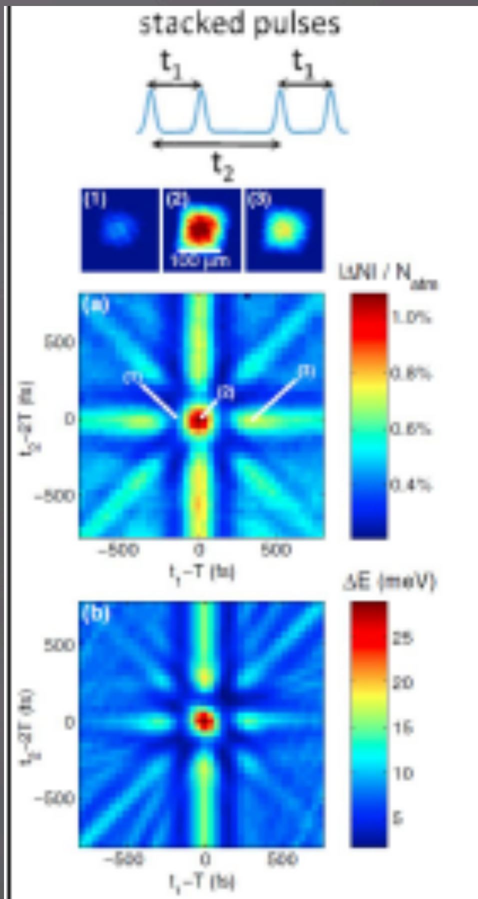
Figure 4. Extreme UV imaging of the kink instability in a) standard and b) reverse polarity.



Plasma Program – research areas

Quantum control of molecular gas hydrodynamics

In this work shows that in femtosecond filamentation of single pulses in gases, molecular rotational heating is the dominant source of energy absorption, even greater than losses due to plasma generation. By using a timing-adjustable train of 4 nonionizing pulses, shown at the right, significantly greater gas (nitrogen) heating can be generated by timing the pulses to the quantum rotational recurrences. Heating was measured interferometrically The figure shows experimental 2D plots (top) and density matrix simulation (bottom) of nitrogen heating as a function of the delays t1 and t2 in the pulse train. The greatest heating (translating into the deepest gas density hole) is in the center of the plot, when the 4 pulses are separated by the full rotational revival time T. The gas heating is equivalent to what a femtosecond filament plasma of density 10**16 cm**-3 and temperature 50 eV could induce

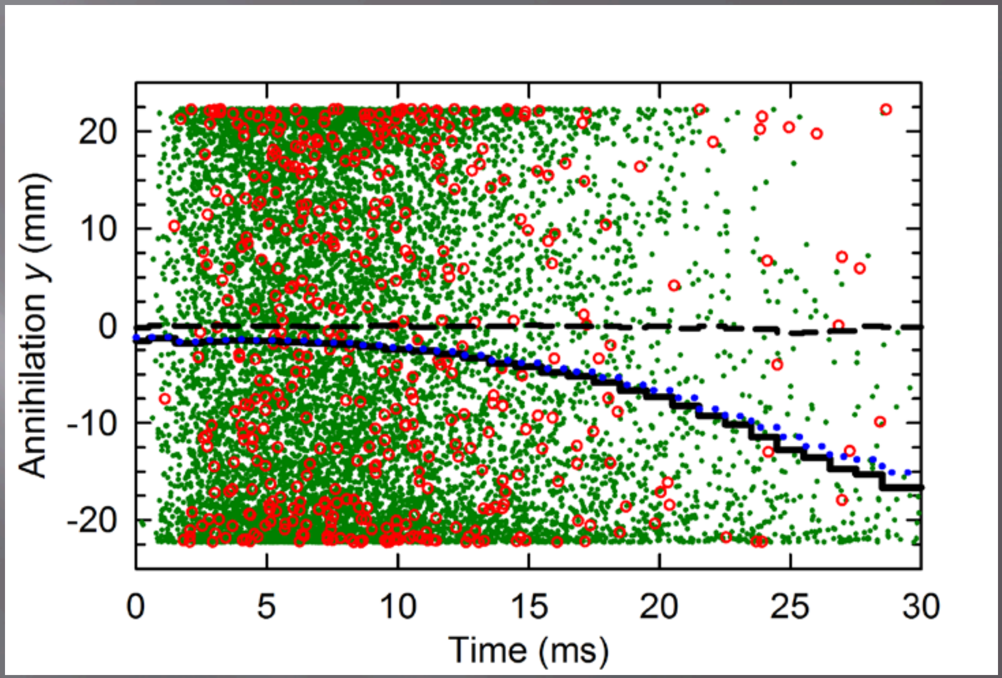


NSF – PHY 1301948 -- PI Howard Milchberg; … *Univ of Maryland, College Park MD*

Plasma Program – research areas

Collaborative Research: Experimental and Theoretical Study of the Plasma Physics of Antihydrogen Generation and Trapping

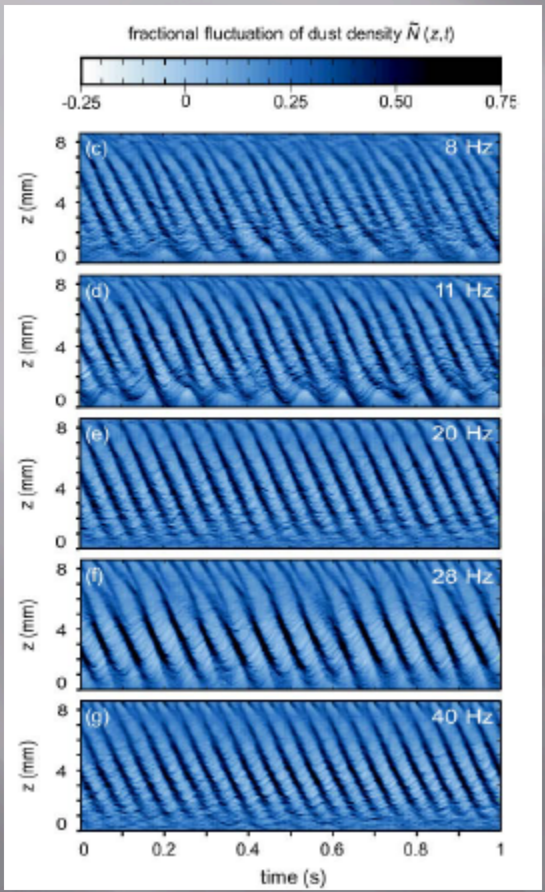
NSF – PHY – 1202519 – Joel Fajans, Jonathan Wurtele, University of California - Berkeley



The times and vertical (y) annihilation locations (green dots) of computer simulated antihydrogen atoms in the ALPHA trap under the assumption that gravity for antimatter is 100 times stronger than for normal matter. As can be seen by the solid black line, the average position of the annihilations tends towards the bottom of the trap, especially at late times. The experimental data (red circles) shows no such trend. From Description and first application of a new technique to measure the gravitational mass of antihydrogen, Nature Comm., 4 1785, 2013

Plasma Program – research areas

Nonlinear Synchronization of the Dust Acoustic Wave



A famous topic in nonlinear dynamics is the synchronization of oscillators that are coupled by a nonlinear mechanism. The traditional textbook treatment of synchronization centers on temporal behavior only. In this project we extend the phenomenon to the spatio-temporal realm. We use an experimental physical system that is ideally suited for observation: a dusty plasma. A dusty plasma is a partially ionized gas that also contains highly charged micron-size particles of solid matter. This plasma sustains a compressional wave, called the dust-acoustic wave (DAW). The wave is visible as it propagates. It occurs spontaneously due to free energy from an ion flow. The observable in the experiment is the spatio-temporal dependence of the concentration of dust. Using image-analysis techniques, we can identify wave fronts as they move. We apply an external modulation at a specified frequency, such as 11 Hz, and observe the wave as it changes its frequency to synchronize with this modulation. This effect is seen in the space-time diagram shown on the left.

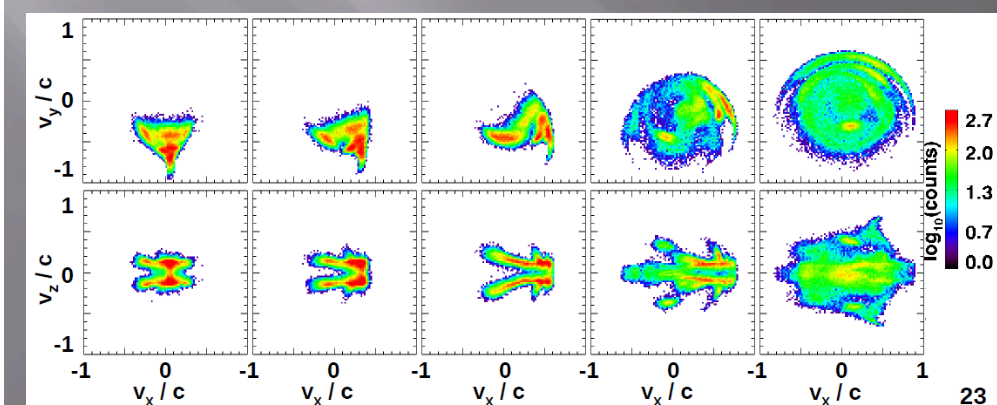
NSF – PHY – 1162645 – John Goree, PI – publ in Phys Rev E and IEEE Trans Plasma Sci with co-authors Suranga-Ruhunusiri and J. Goree– Univ of Iowa

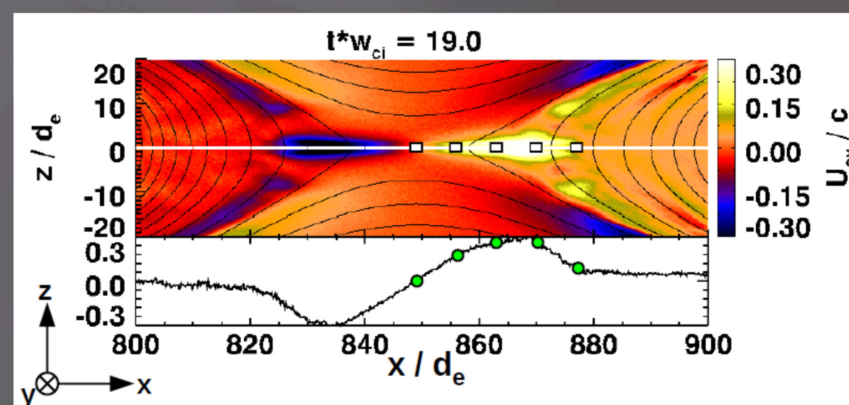
Plasma Program – research areas

Distinct electron regions in 2D and 3D collisionless reconnection

NSF – PHY – 0903923 – Li-Jen Chen, University of New Hampshire

How electrons are heated and accelerated throughout the electron diffusion region (EDR) of collisionless magnetic reconnection are unanswered questions central to solving the ultimate mystery of collisionless reconnection. By characterizing the spatial and temporal evolution of electron distributions in the EDR, we establish a prediction for the complex, three dimensional (3D) velocity space electron structure. These distributions also evolve in time, becoming even more highly structured after the peak reconnection rate.

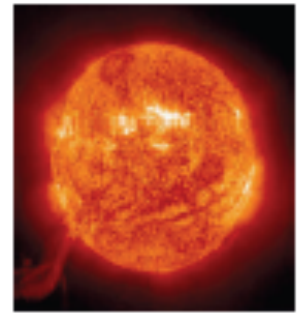




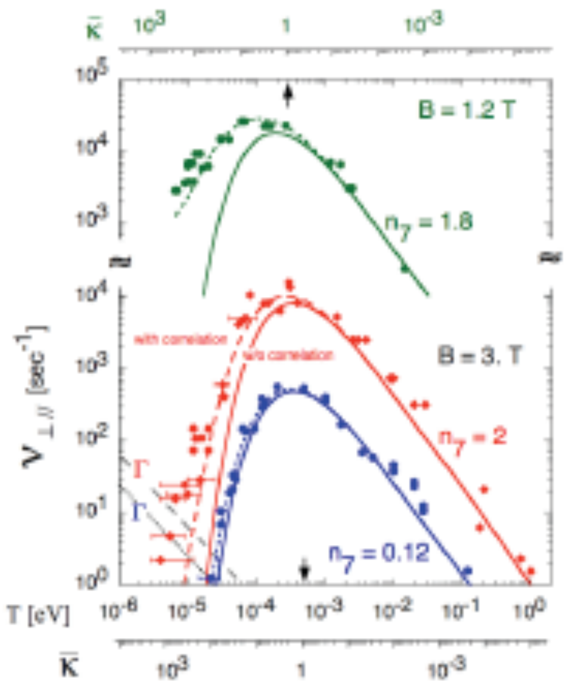
Plasma Program – research areas

O'Neil /Driscoll /Dubin NSF-0903877

Correlation-Enhanced Collisions, *à la* Salpeter



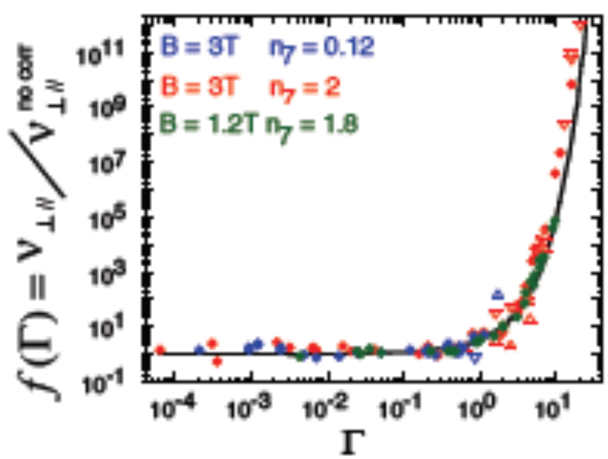
Salpeter predicted that the nuclear fusion rate in a dense, strongly correlated plasma (e.g., a white dwarf star) is enhanced by inter-particle correlations. The predicted enhancement is approximately $exp(\Gamma)$, where Γ is the correlation parameter.



Dubin (2008) proved this is isomorphic to enhanced perp-to-parallel collisions in a pure ion plasma at low temperatures. For $T<10^{-3}$ and strong magnetization (large κ), an adiabatic invariant suppresses collisions (solid curves), but correlation re-enhances them (dashed curves).

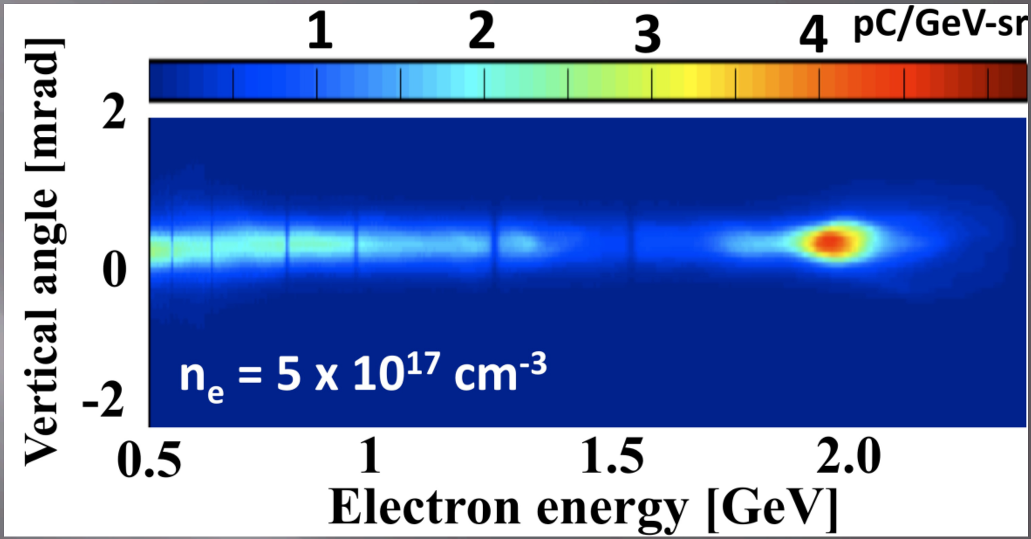
Our measurements (dots) clearly show the large κ suppression, and show enhancement at low T and high density (n_7= 1.8, 2) where Γ>1. Collecting the data on a single graph shows enhancements $f(\Gamma)$ up to 9 orders of magnitude (Anderegg 2012).

Recent DoE/HEDLP funds enabled purchase of laser equipment to cool and diagnose plasmas below 10^{-5} eV. Experiments at higher Γ will address the theory controversy over "equilibrium" vs "dyamical" screening in close energetic collisions.



Plasma Program – research areas

Quasi-monoenergetic laser-plasma acceleration of electrons to 2 GeV



NSF – PHY - 0936283–
Michael Downer,
University of Texas

Previous laser-plasma accelerators had produced nearly monoenergetic electron bunches with energy up to 1 GeV. By applying new petawatt laser technology, we accelerated electrons quasi-monoenergetically to 2 GeV with unprecedented sub-milliradian divergence. Petawatt pulses inject ambient plasma electrons into the laser-driven accelerator at much lower density than was previously possible, thereby overcoming the principal physical barriers to multi- GeV acceleration: dephasing between laser-driven wake and accelerating electrons and laser pulse erosion. Simulations indicate that acceleration to > 10 GeV is theoretically possible with the available pulse energy, opening the prospect of building x-ray free electron lasers on a table-top.

Wang *et al*., Nature Commun. **4**, 1988 (2013)