Final Report for Period: 09/2009 - 08/2010**Submitted on:** 02/18/2011**Principal Investigator:** Lynn, Alan G.**Award ID:** 0613577**Organization:** University of New Mexico**Submitted By:****Title:**

Experimental study of magnetic bubble expansion as a model for extragalactic radio lobes

Project Participants**Senior Personnel****Name:** Lynn, Alan**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Dr. Alan Lynn has completed all needed design work for the coaxial gun hardware, the pulsed power systems, and the bias magnetic coil. He has had the bias coil fabricated and supervised testing it. He has supervised and assisted with the assembly and testing of the bias coil pulsed power systems. He has assisted with modifications to the existing UNM vacuum chamber to accommodate the PBEX experiment. He has worked on fabricating a magnetic probe array and planning for additional diagnostics. He has supervised the graduate student working on the project.

Name: Hsu, Scott**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Dr. Scott Hsu has provided advice in the design of both the coaxial gun and bias coil. He designed the 3D magnetic probe and the fast gas puff system for the PBEX experiment and was also involved in the design of the pulsed power systems. He assisted with assembly and installation of parts of the vacuum system and the gas puff system. He has assisted in mentoring the graduate student on the project.

Name: Li, Hui**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Dr. Hui Li is running preliminary 3D MHD simulations of magnetized plasma bubble interactions with a lower pressure background plasma. This will assist in experiment design and future data interpretation. It will also allow for theoretical comparison between astrophysical plasma jets and our scaled laboratory experiments. He is also supervising a postdoctoral fellow who is modifying Dr. Li's simulation code to better model the PBEX experiment.

Post-doc**Name:** Liu, Wei**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Dr. Wei Liu is a postdoctoral fellow working under Dr. Hui Li at Los Alamos National Laboratory. He is supported entirely by Los Alamos and not by this grant. He is running Dr. Hui Li's MHD simulation code to model the PBEX experiment and will, in collaboration with Dr. Hui Li, make any modifications to the code (if needed) to support the PBEX experiment.

Graduate Student**Name:** Zhang, Yue**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Yue Zhang has assembled and tested the bias coil power supply, bias coil capacitor bank, and its triggering. He assembled and tested the gun bank power supply and fabricated and assembled the components to connect the gun capacitor bank to the coaxial gun. He assisted in assembling the magnetic probe array and testing the bias magnetic coil. He assisted in assembling vacuum system components for the experiment. He has been operating the experiment and associated diagnostics, and taking data for his

dissertation project.

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Los Alamos National Laboratory

Los Alamos is contributing with computational modeling (done by Dr. Hui Li and his postdoctoral fellow Dr. Wei Li) and assistance with design, assembly, and testing of the experimental hardware (assistance from Dr. Scott Hsu). Los Alamos will assist with planning and analysis of the initial experiments.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

A series of experiments on the existing University of New Mexico HELCAT experiment were conducted to measure properties of an expanded helicon plasma for use as the background plasma for plasma bubble injection.

We have designed the majority of the vacuum and pulsed power hardware for the plasma coaxial gun and have fabricated it. We have assembled and tested the bias coil and its power systems and verified they work as intended. We have assembled the gun bank pulsed power systems and will be testing it soon. We have assembled and installed all necessary vacuum components for the experiment.

Preliminary 3D MHD simulations of propagating magnetized plasma expanding in uniform lower pressure background plasma have been performed at Los Alamos National Laboratory. The simulations have provided detailed predictions of the dynamics of the plasma bubble/plasma background interaction.

Design at Los Alamos has been completed on 3D magnetic probes to measure evolution of the plasma bubble magnetic fields they interact with the background plasma. Fabrication of the 3D probe array is almost complete. Design and fabrication of the fast gas puff system for the PBEX experiment has been completed at Los Alamos National Laboratory and assembled at UNM. Testing of the gas system will be conducted soon.

We plan to complete testing the hardware systems and conduct first experiments this summer (2008).

During the Fall 2008 and Spring 2009 all hardware systems were tested and made operational. The 3D probe array was completed and bench tested. Since the high-speed digitizer we had originally planned to borrow from LANL was being used for another project, a new digitizer was purchased for use on PBEX. This system was integrated into the existing HelCat data acquisition system during the early summer 2009.

Some performance issues with the coaxial gun were identified in summer 2009. A design modification was developed to fix these issues and is currently being fabricated. A fast camera system, essential to the PBEX experiment, was originally going to be provided on loan from LANL. This system was taken by another experiment, requiring a loan of a different camera to be arranged. This new camera loan only recently became available and is being readied for use on the PBEX experiment.

For 2010, operating and fielded diagnostics include a fast visible imaging camera for overall morphology and time evolution observation and electrostatic probes for density measurement and bubble propagation velocity. The 3D high-resolution (spatial and temporal) magnetic probe has been built but is still undergoing testing to eliminate electrical noise issues relating to the pulsed power systems. The device is now ready to conduct full physics studies of the bubble interaction with background plasma. The graduate student on the project will be conducting experiments and taking data for his dissertation.

Findings:

Training and Development:

Graduate student Yue Zhang is gaining valuable experience in mechanical design of the capacitor bank. He has gained a great deal of experience with vacuum system technology and operation. He has gained considerable experience in electrical design and testing. Principal investigator Dr. Alan Lynn has gained valuable experience in pulsed power engineering in the design of the coaxial gun hardware.

Yue Zhang is currently (2010) conducting experiments needed for his Ph.D. dissertation.

Outreach Activities:

Our lab on campus has hosted at least 10 tours this past year by high school classes from the local community as part of the university's efforts to encourage and recruit graduating high school seniors to pursue college education in science and engineering fields. This summer (2007) we will have a high school student working in the lab for a week as part of our general outreach efforts. In 2008 we will have at least 1-2 undergraduates working in the lab, and are planning to recruit additional graduate students into the plasma science program in our department.

In 2009 and 2010, we have recruited an additional undergraduate and Masters student into our research group.

Journal Publications

Wei Liu, Scott C. Hsu, Hui Li, Shengtai Li, and Alan G. Lynn, "Ideal magnetohydrodynamic simulation of magnetic bubble expansion as a model for extragalactic radio lobes", *Physics of Plasmas*, p. , vol. 15, (2008). Published,

Wei Liu, Hui Li, Shengtai Li, and Scott C. Hsu, "LONG-TERM EVOLUTION OF MAGNETIZED BUBBLES IN GALAXY CLUSTERS", *The Astrophysical Journal*, p. L57, vol. 684, (2008). Published,

Books or Other One-time Publications

Yue Zhang, Alan G. Lynn, Scott Hsu, C.Watts, and M.Gilmore
 , "Design of a Compact Coaxial Magnetized Plasma Gun for Laboratory Studies of Plasma Relaxation", (2007). Conference Proceeding, Published
 Collection: Proceedings of the 34th IEEE Pulsed Power and Plasma Science Conference and the 16th IEEE International Pulsed Power Conference
 Bibliography: ISBN: 978-1-4244-0915-0

Y. Zhang, A. G. Lynn, C. Watts, M. Gilmore, S.C. Hsu, W. Liu, and H. Li, "Design and Construction of the Plasma Bubble Expansion Experiment", (2007). Conference Proceeding, Published
 Collection: Bulletin of the American Physical Society

Bibliography: Volume 52, Number 11

A.G. LYNN, Y. ZHANG, M. GILMORE, CHRISTOPHER WATTS, S.C. HSU, W. LIU, and H. LI
 , "Experimental and Numerical Studies of Magnetic Bubble Expansion as a Model for Extra-Galactic Radio Lobes", (2007). Conference Proceeding, Published
 Collection: Bulletin of the American Physical Society
 Bibliography: Volume 52, Number 11

Y. Zhang, A. G. Lynn, C. Watts, M. Gilmore, Scott Hsu, H. Li, and W. Liu, "Design and Construction of the Plasma Bubble Expansion Experiment", (2008). Conference Proceeding, Published
 Collection: Bulletin of the American Physical Society
 Bibliography: Volume 53, Number 14

Alan G. Lynn, Yue Zhang,
 Scott C. Hsu, Hui Li, Wei Liu, Mark Gilmore, Christopher Watts, "Magnetic Bubble Expansion as an Experimental Model for Extra-Galactic Radio Lobes", (2008). Conference Proceeding, Published

Collection: Bulletin of the American Physical Society
Bibliography: Volume 53, Number 14

Scott Hsu, Alan Lynn, Yue Zhang, Wei Liu, Hui Li, Christopher Watts, and Mark Gilmore², "Experimental Study of Magnetic Bubble Expansion as a Model for Extra-galactic Radio Lobes", (2008). Conference Proceeding, Published
Collection: Bulletin of the American Physical Society
Bibliography: Volume 53, Number 5

Y. Zhang, A.G. Lynn, C. Watts, M. Gilmore, S. Hsu, H. Li, and W. Liu, "Design of a Compact Coaxial Magnetized Plasma Gun for Magnetic Bubble Expansion Experiments", (2009). Conference Proceeding, Published
Collection: Proceedings of the 36th International Conference on Plasma Science and 23rd Symposium on Fusion Engineering
Bibliography: ISBN: 978-1-4244-2617-1

Y. Zhang, A. G. Lynn, S. C. Hsu, M. Gilmore, and C. Watts, "DESIGN OF A COMPACT COAXIAL MAGNETIZED PLASMA GUN FOR MAGNETIC BUBBLE EXPANSION EXPERIMENTS", (2009). Conference Proceeding, Published
Collection: Proceeding of the 17th IEEE International Pulsed Power Conference
Bibliography: ISBN: 978-1-4244-4064-1

A. G. Lynn, Y. Zhang, S. C. Hsu, H. Li, W. Liu, M. Gilmore, and C. Watts, "Magnetic Bubble Expansion as an Experimental Model for Extra-Galactic Radio Lobes", (2009). Conference Proceeding, Accepted
Collection: Proceeding of the 36th European Physical Society Conference on Plasma Physics
Bibliography: Europhysics Conference Abstracts Vol. 33 (2009)

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

Contributions to Other Disciplines:

The development of the compact coaxial gun for the project is being studied by groups in the fusion energy science community as a source for testing transient plasma effects on material surfaces.

Contributions to Human Resource Development:

Thus far, the project has trained one graduate student and a few (1-2 at various times) undergraduates over its lifetime.

Contributions to Resources for Research and Education:

The experimental facilities built for the project continue to be used for undergraduate and graduate student training.

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Activities and Findings: Any Findings

Any Web/Internet Site

Any Product

Contributions: To Any within Discipline

Contributions: To Any Beyond Science and Engineering

Any Conference

Experimental Results

Images were acquired with a fast CCD camera to verify that plasma is ejected from the gun, as shown in Figure 1. In this image, plasma is visible leaving the gun, expanding into the vacuum chamber and impinging on the probe. A multi-tip Langmuir probe was used to measure ion saturation current (I_{sat}) signals of the plasma bubble. The probe has 10 separate tips with a 5.7mm spacing between tips in a linear array. The tips are cylindrical shape, 2.5 mm long and 0.5 mm in diameter. Based on I_{sat} traces, the plasma density can be estimated. Additionally, the time delay between two I_{sat} traces indicates the propagation speed. The plasma produced by the coaxial gun has the following global parameters based on these measurements to date: density $n \sim 10^{20} \text{ m}^{-3}$, $T_e \sim T_i \sim 5\text{-}10 \text{ eV}$, propagation speed $\sim 0.5 \text{ cm}/\mu\text{s}$ (Argon plasma) and $\sim 1.5 \text{ cm}/\mu\text{s}$ (helium plasma), which corresponds approximately to the ion sound speed of the bubble plasma.

Figure 1. Image showing the plasma bubble detaching from the gun (top). I_{sat} signals from multi-tip Langmuir probe (bottom).