**White Paper for *Frontiers of Plasma Science Panel***

| Date of Submission: | June 19, 2015 |
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Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

| | "P", "S" |
|---|---|
| • Plasma Atomic physics and the interface with chemistry and biology | |
| • Turbulence and transport | S |
| • Interactions of plasmas and waves | P |
| • Plasma self-organization | |
| • Statistical mechanics of plasmas | |

Indicate type of presentation desired at Town Hall Meeting.

| | "X" |
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| Oral | |
| Poster | |
| Either Oral or Poster | |
| Will not attend | X |

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|---|---|
| Title: | Alfvén wave heating in small-scale laboratory plasmas |
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**(Limit text to 3-pages including this form. Font Times Roman size 11.**
**1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)**

- ***Describe the research frontier* and importance of the scientific challenge.**

Among the great mysteries in solar physics is the cause of the anomalously high temperature of the solar atmosphere, or corona. The high ion temperatures in the corona challenge our understanding of solar heat transport and plasma physics. Popular theories purporting to explain the heating include magnetic reconnection-induced heating [1], double layer particle energization and subsequent instabilities [2], and heating caused and/or modulated by Alfvén waves [3]. Several Alfvén wave heating theories exist - standard Kolmogorov turbulent decay of Alfvén waves driven by photospheric motions at the base of the corona [4], ion cyclotron damping of Alfvén waves [5], turbulent decay due to counter-propagating Alfvén wave interactions [6,7], and parametric decay of Alfvén waves in strong perpendicular gradients in the Alfvén speed [8].

Clearly, in-situ measurements of the corona are not feasible. Remote spectroscopic measurements are line-integrated and it is difficult to correlate observed ion with specific wave activity or other phenomena in the corona. Extrapolations are made from limited data from spacecraft, such as the Japanese Hinode mission [9], and some progress is being made in exploring this important issue. However, laboratory investigation of Alfvén waves would allow for rigorous, high-resolution investigation of a variety of phenomena that might result in particle heating. While existing laboratory experiments are investigating heating due to reconnection [10] and particle acceleration in double layers [11], laboratory investigation of Alfvén waves remains elusive. One of the impediments to progress is that fact that for typical

laboratory operating parameters ($n_e \sim 10^{12}$ cm$^{-3}$, B ~ 0.1 T), Alfvén waves do not fit in any, but the largest, laboratory apparatus, such as LAPD. Even in these systems, experiments are not trivial to perform. Typically, measurements employ many hundreds to thousands of plasma pulses, and density gradients and shear flows must be imposed. Furthermore, such systems run a variety of experiments because of their vast utility for many different plasma physics investigations, limiting the time devoted to one particular measurement.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

Helicon plasma sources provide a unique opportunity to study Alfvén waves in a low power, low cost, small-scale experiment. Helicon sources are the most efficient plasma sources known, producing high-density ($n_e \sim 10^{13}$ cm$^{-3}$), highly ionized ($n_e/n_n \sim 0.1$ to 0.99) plasmas at just a few hundred Watts of input power, and moderate background magnetic fields (0.05 to 0.1 T) [12]. They naturally produce radial density gradients on the order of $10^{20}$ m$^{-4}$. This permits launch and propagation of Alfvén waves in an apparatus ~ 1 meter long, depending on the gas species. The presence of density gradients and natural velocity shear [13] allows for investigation of Alfvén wave decay in the presence of such background effects and the ability to test specific theories of Alfvén wave heating. Recently, Alfvén wave propagation has been demonstrated in the 1.5 m long HELIX helicon source in helium [14] and argon [15] plasmas at West Virginia University (Figures 1 & 2). Thus, with the appropriate diagnostics, Alfvén wave decay can be studied in a controlled fashion on any of the multitude of helicon sources at numerous universities and laboratories, allowing for research on this exciting problem to be pursued by many research groups, rather than only on the largest machines.

Current limitations to these experiments are a lack of helium ion distribution diagnostics and high power, high fidelity amplifiers in the frequency range ideal for Alfvén waves. These may be remediated by ongoing research on two-photon laser-induced fluorescence in helium at WVU [16].

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

Understanding the heating mechanisms in the solar atmosphere is necessary for models investigating energy transfer from the Sun to the solar wind, and the Earth's near space environment. Understanding energy transfer processes in this system is crucial for predicting "space weather," or the plasma phenomena that occur between the Earth and the Sun. Such phenomena are the cause of beautiful polar aurora, but also have the ability to disable crucial man made satellites and power systems on the Earth's surface; with potentially drastic consequences in our highly technology-based society [17].

Furthermore, understanding wave-plasma interactions and heating is important for a variety of technological plasma applications, such as radio-frequency plasma processing sources. While most sources do not employ kHz frequency heating, the mechanisms of turbulent breakdown of driven electromagnetic waves are hotly debated. As such, any further research on this topic will contribute to our understanding of processes vital for modern day manufacturing systems that employ radio frequency-heated plasmas [18].

## References (Maximum 1 page)


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## Figures (maximum 1 page)

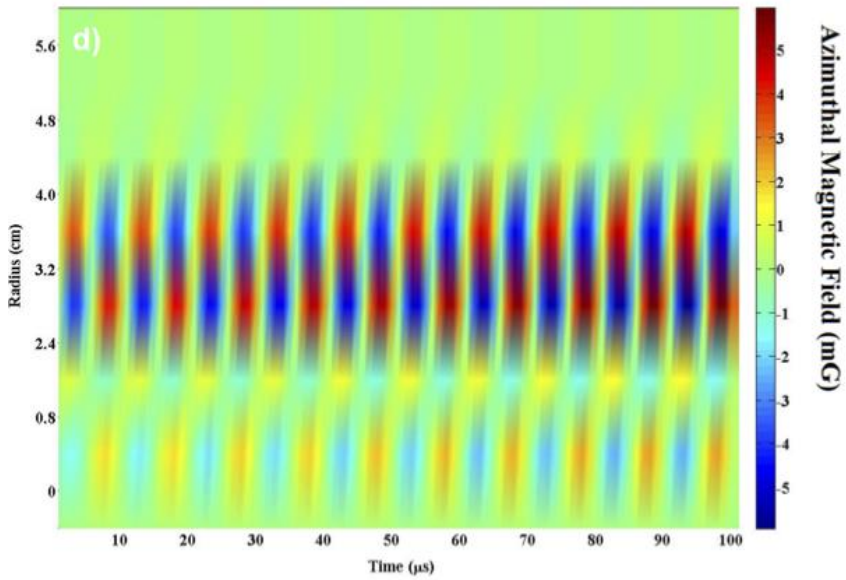


**Figure 1**: Magnetic field fluctuations caused by a launched, ducted Alfvén wave in a helium helicon plasma at WVU [14].

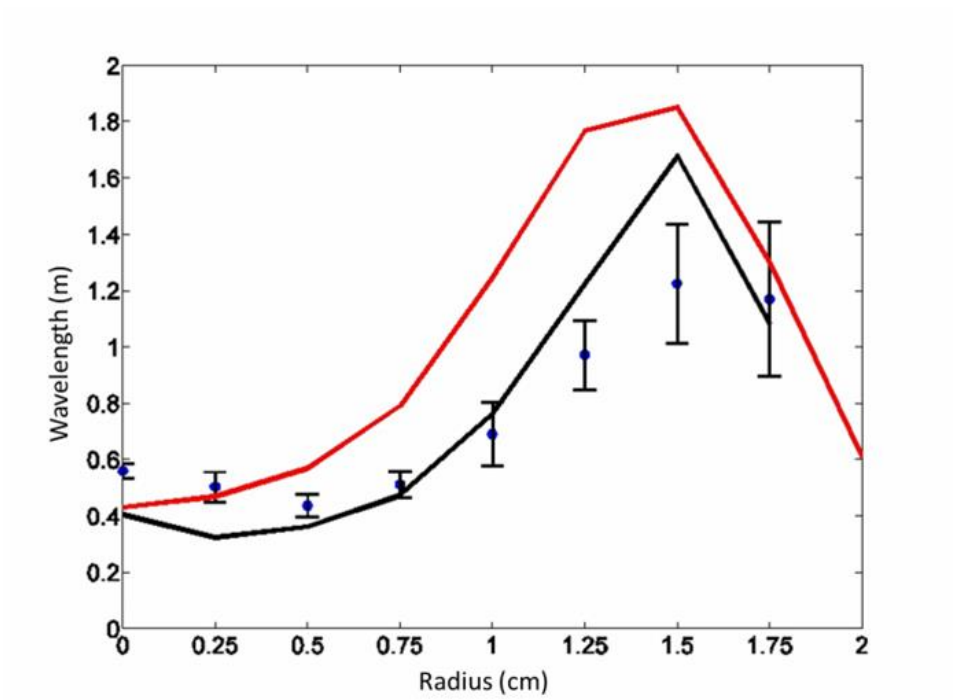


**Figure 2**. Measured wavelength (solid circles) from magnetic sense coil measurements compared to theoretical predictions in argon helicon plasma. The red curve is the prediction from a simple inertial Alfvén wave dispersion relation while the black curve is the full dispersion relation including collisional and finite perpendicular scale effects.