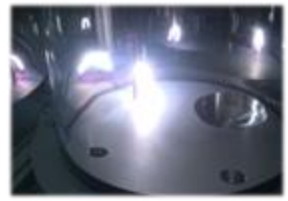
Introducing the *Helicon*: A Favorable Method for Generating Laboratory Plasma

Project Synopsis

This proposal is to develop an advanced "helicon" plasma source for space plasma science experiments at the University of Alaska Anchorage Plasma Physics Lab (UAAPPL). The helicon source will provide high density, low neutral fraction plasma that is suitable for a range of experiments from plasma thrusters to plasma polarimetric magnetic field measurements. As such, the helicon source would represent not only a significant, publishable project for myself, but would also enable many future student research projects as well.

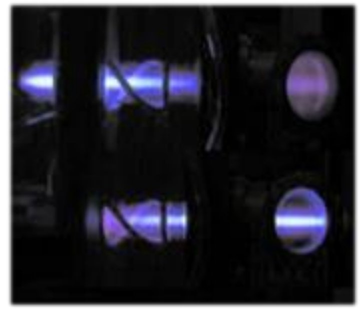


UAAPPL has basic plasma generation techniques at its disposal already, but the helicon would represent a major advancement. *Thermionic discharges*, produced for example by hot tungsten filaments, are suitable for low density discharges, and also contain a high fraction of neutral particles. This method has been successfully tested in the Compact Plasma Science Platform (CPSP, pictured right with plasma), under work performed by 2015 AGSP fellow Ana Lambrano. Over the summer I was an ASGP Fellow, and implemented another common plasma recipe, a *DC Glow Discharge*, and the fellowship project accomplished construction of an auroral simulator (based in part on the *Planeterrella* courtesy ***The Centre National de la Recherche Scientifique***.) Pictured left are the metal spheres in our CPSP that approximate the interaction between the sun and earth. High voltage between these spheres leads to ionization of argon gas, and a characteristic purple argon plasma glow.

These two approaches to plasma production are straightforward and--as I have found--represent an excellent platform to learn about plasma physics, but they are limited by low plasma density and ionization fraction. The helicon source proposed here, by virtue of its low neutral content, will open the door to the use of our mentor Prof. Hicks' large, ultra-high vacuum (UHV) chamber. Student research projects such as my own will thereby access a much broader plasma parameter space, and experiments in plasma propulsion, laboratory space plasma simulation, and advanced plasma diagnostics will become accessible to UAA undergrads.

To illustrate the benefit of the helicon plasma source further: with a helicon plasma source available, ASGP nominee Brendan Stassel will have the basis for implementing a version of the helicon double-layer thruster design.[1][2][3] My other current research project in dual-heterodyne plasma polarimetry and interferometry will have a suitable testing ground for plasma measurement systems. Moreover, the helicon source will enable student research pertaining to Prof. Hicks' basic plasma studies of variable electric multipole confinement. These are just three examples of how this project will immediately result in research projects that both align and contribute toward achieving NASA's objectives and goals as outlined in the Strategic Plan. To highlight a few, consider Objective 1.1, to "Expand human presence into the solar system." Brendan's propulsion project involves a thruster design that is gaining attention as a viable interplanetary propulsion engine. Objective 1.4, to "Understand the Sun [...] including space weather," will be addressed by the capability of the combined helicon-UHV chamber system for space plasma studies in the established model of the HELIX-LEIA system of West Virginia University.[4] Finally, regarding Objective 1.7, to "Transform NASA missions and advance the Nation's capabilities by maturing crosscutting and innovative space technologies." Our research in plasma polarimetry seeks to develop an advanced polarimeter for magnetic field measurements that is compact, light-weight and low cost, and robust to common noise sources. In addition to the intrinsic scientific merit of the helicon itself (helicon source research is an active frontier in plasma science), these three sub-topics that the helicon enables will afford students with NASA-relevant projects for years to come.

Project Description



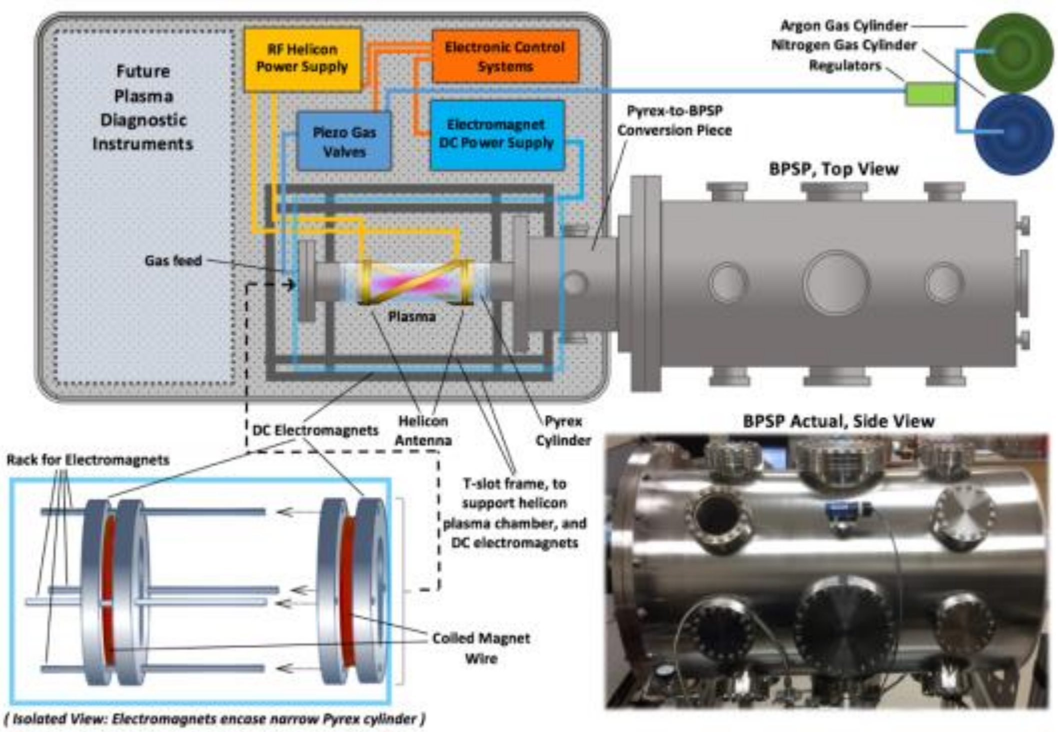
My role in this project is to set up the helicon plasma source by installing it on the UAAPPL UHV chamber (also known as *BPSP* for *Big* Plasma Science Platform), which reaches a base pressure on the order of 10^{-9} torr (~1 trillionth of our atmosphere.) Such low base pressure and clean vacuum conditions are an essential prerequisite to performing the plasma experiments already mentioned. Once we have a helicon installed, we expect to attain plasma source density of ~10^{19} m^{-3}. But what is a helicon anyway?

A helicon plasma discharge is ionized by helicon waves generated by a helical RF antenna, the RF is typically in the range of a few to tens of MHz. Helicon waves are a bounded subset of "whistler waves" familiar from ionospheric observations,[5] and are set up in a laboratory chamber (typically a Pyrex cylinder) by interaciton between the external RF field and the DC magnetic field of an external solenoid. Above is a picture of a helicon plasma forming within two tubes.[6] The spiral shape around the glass chamber is the helicon antenna actively exciting the glowing plasma within. Helicon plasma sources of this sort are commonly used in large-scale space plasma laboratory experiments and many space thruster studies. For our purposes, the helicon is a perfect fit that provides a single plasma source for basic plasma confinement studies, propulsion experiments, plasma diagnostics, and energetic space weather experiments.

Implementing a helicon will involve five main tasks, and their combination is depicted in the figure following this list:

1) Build frame to hold the antenna, Pyrex tube, and direct current (DC) electromagnets.
2) Build and setup a DC pair of adjustable electromagnets to provide a uniform magnetic field in the tube.
3) Build and setup the radiofrequency power supply and antenna.
4) Integrate Argon and Nitrogen cylinders into the helicon system
5) Tie these subsystems together with an electronic control system.

Fortunately, the larger crucial components (e.g. Pyrex + stainless steel sub-chambers; RF supply; water cooling system; DC supply) have already been purchased. Fellowship funds will enable me to acquire the balance of remaining components and put everything together. The basic helicon design is complete, and the helicon is ready to construct and install—optimizing RF power coupling to the plasma will be a major focus of my research project.



The block diagram illustrates these primary components in what will roughly be the helicon's final form. We have LabVIEW for computer-based control and data acquisition, we have precise piezo valves to meter the Nitrogen and Argon on hand. Large vacuum components are in the mail, including the Pyrex cylinder, endplates, and the Pyrex-to-BPSP converter. Both RF and DC power supplies are on hand, as well as the sturdy table needed to mount the installation. Fellowship funds would pay for materials to fabricate the electromagnets pictured lower-left in the diagram. These magnets will be adjustable along the rods they are mounted on. These rods will anchor to a sturdy T-slot frame that is secured to the lab table. The only other fabrication step will be making the helicon antenna itself, and, as mentioned, the commissioning step of optimizing forward power coupling into the plasma.

Purchases	Item Description	Price	Part Number	Notes
Kurt J. Lesker	275i series gauge	$ 346.00	KJL275804LLMB	Measure helicon-side pressure
	CF RF feedthrough, 13.56MHz, 20kW, 10kV, 2-tube, 2.75"CF	$ 1,250.00	FTT1023253	Electromagnet power feed + cooling
McMaster-Carr	3" Aluminum 6061 rod, 16"OD (2x)	$ 730.00	1610T78	
	1" Aluminum 2024 rod, 3' (5x)	$ 140.00	86985K58	Electromagnet support structure
	Standard T-slot 1" rod holder (10x)	$ 370.00	47065T41	
	Shatter-proof polycarbonate, 1/8", 2' x 2' (2x)	$ 128.00	8707K114	
	T-slot hinges (6x)	$ 114.00	47065T161	Pyrex safety shield
	1" T-slot Single Corner, 3' (8x)	$ 104.00	47065T85	
	3" T-slot double, 6'	$ 73.00	47065T109	
	3" T-slot quad, 6'	$ 152.00	47065T502	Apparatus frame
	T-slot quad 90 deg plate (4x)	$ 78.00	47065T277	
	Magnet wire, 18 AWG, 1200'	$ 148.00	7588K63	Electomagnets
	Bendable copper tubing for water, 3/4"OD, 60'	$ 177.00	50475K64	Electromagnet cooling
	Copper 101 tubing, 3/4"OD, 6' (2x)	$ 136.00	8965K28	Antenna, plus cooling
Miscellaneous	*Estimated Shipping*	$ 500.00		
	High Density Plasma Sources: Design, Physics and Performance (book)	$ 190.00		
	Project Supplies & Consumables	$ 364.00		
	TOTAL:	$ 5,000.00		

Being in charge of installing a helicon plasma source would provide hands-on experience that will help me grow professionally in the right direction. Through my prior experience building the Planeterrella with ASGP funding, I discovered I thrive having projects of this sort to work on. Through the successful completion of this summer's Undergraduate Research Fellowship, I contributed to UAAPPL moving one step closer toward its goals for student research and plasma science education. This is my final year of my undergraduate education, and I think it would be a wonderful privilege to have ASGP support to spend this remaining time to investigate a fascinating, publishable topic in applied plasma physics and in so doing to help UAAPPL to reach the next level of advanced student research projects.

References

[1] Charles, C., "High source potential upstream of a current-free electric double layer," *Physics of Plasmas*, (2005) Vol. 12:044508

[2] Charles, C. and Boswell, R. W., "The magnetic-field-induced transition from an expanding plasma to a double layer containing expanding plasma," *Applied Physics Letters*, (2007) Vol. 91:201505

[3] Charles, C., Alexander, P., Costa, C., Sutherland, O., Boswell, R. W. "Helicon Double Layer Thrusters," *Presented at the 29th International Electric Propulsion Conference*, Princeton University, (2005) Oct. 31 – Nov. 4,

[4] Scime, E. E. et al. "The hot hELicon eXperiment (HELIX) and the large experiment on instabilities and anisotropy (LEIA)" *Physics of Plasmas* (2009)

[5] Chen, F. "Helicon discharges and sources: a review" *Plasma Sources Science and Technology* (2015)

[6] Lee, Charles et al. "Measurements and modeling of radio frequency field structures in a helicon plasma," *Physics of Plasmas*, (2011) Vol. 18 Issue 1:013501, 10p

[7] Kurt J. Lesker Company. (2016): Retrieved February 25, 2016. www.lesker.com

[8] McMaster-Carr. (2016): Retrieved February 25, 2016. <mcmaster.com>

[9] NASA Strategic Plan 2014. *NASA Headquarters.* (2014)