Planeterrella Installation for Research in Space Weather and Instrumentation

Project Synopsis:

This proposal is to fund the construction and installation of a Planeterrella[1] plasma discharge system in UAA's Compact Plasma Science Platform (CPSP, a portable vacuum chamber purposed to (1) Host student-led projects in plasma science research, and (2) Travel to communities throughout Alaska for educational outreach.) Installing a Planeterrella serves the primary purpose by equipping the CPSP with functionalities in conducting space weather simulations for research and instrumentation projects.

Last semester the Alaska Space Grant Program awarded Ana Lambrano funds to design and construct the CPSP as a team of three engineering students—Two mechanical (Mandy Bowman & Ana Lambrano) plus one electrical (author of this proposal, Blair Munro). In five weeks we expect to reach full CPSP vacuum and power functionality, and the ability to demonstrate simple plasma generation using a hot tungsten filament discharge. This will conclude our CPSP project in a success as the 2015-2016 Space Grant Program comes to a close. We have been keen to see the CPSP begin hosting student projects, so I decided to commit a portion of my summer to prepare the CPSP for just that. Growing up accustomed to our state's Northern Lights, simulating space weather stands out as a great way to break in the new vacuum chamber. Filament plasma it turns out is not ideal for space plasma simulations, because the generated plasma is non-uniform in the vicinity of the filament. Simulating the aurora requires an embedded magnetic field, and is best served by creating a *DC glow discharge* plasma.[2] A Planeterrella is one solution that can provide both of these, and also mimic solar system geometries. Originally this was called a 'Terrella' experiment, the concept first implemented over a century ago by the Norwegian scientist Kristian Birkeland. His method was similar, allowing electrons to flow between charged globes in a vacuum, while confining movements along magnetic field lines. After dying in 1917, Birkeland's experiment disappeared from the public eye until the early 2000s when French physicist Dr. Jean Lilensten reimagined the concept with 21st century technology. Lilensten now provides his plans free to any institution that wants to build one. The picture at right is typical of how ~18 Planeterrellas worldwide look in operation (incidentally, this Planeterrella is a version NASA built with Lilensten in 2013).[1,3]

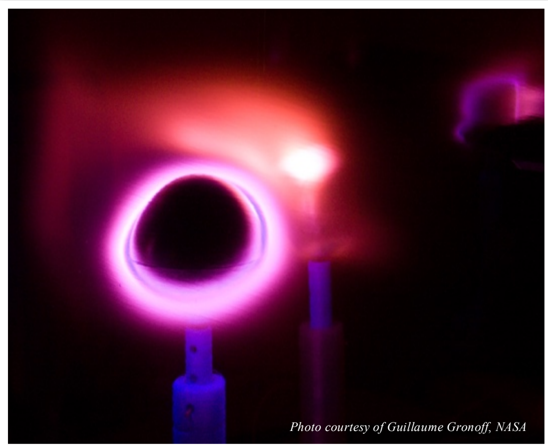


Photo courtesy of Guillaume Gronoff, NASA

Aligned with NASA's Strategic Goal Objective 1.4[4], space weather topics are an excellent way to initiate research with the CPSP. Two decades ago the Auroral Snapshot Explorer (FAST) and Polar missions solidified NASA's interests in auroral effects. The same interests carry on today but with different questions present, served by CINDY, THEMIS, TIMED, the Van Allen Probes. Closely related are missions dedicated to study Earth's magnetosphere (e.g., Cluster, MMS, SAMPEX, and WIND).[5] Planeterrella involves these two mission topics converging in the loose contexts of space weather demonstrations, but two important studies show they have clear potential as tools for new or outstanding research questions. First, Gronoff and Wedlund (2011)[6] discovered that Planeterrella simulations are reliable first-approximations for electron movements in magnetospheres. As one compelling example, the authors used simple orientation data for Uranus and the Sun to reproduce (on the scale of the simulation) the aurora observation captured by Voyager 2, thirty years ago. The second paper (Lilensten et al., 2015)[7] carried this a step further and used Planeterrella to develop a hypothesis and generate a verifiable prediction. In 2005, NASA missions to Mars (Mars Express and MAVEN)[5] detected an ultraviolet aurora, but realized there they did not have a way to look for the visible kind. Observations from Earth were not feasible, and

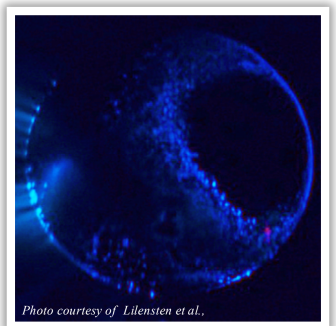
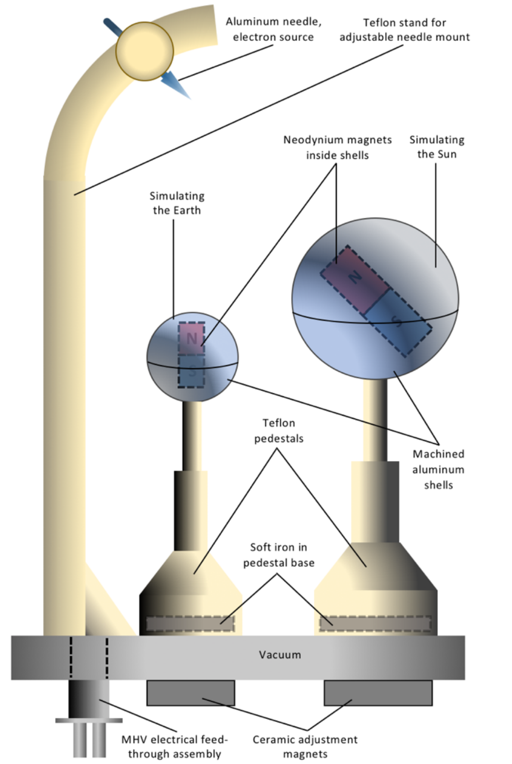


Photo courtesy of Lilensten et al.,

this dilemma went on for years. Lilensten et al. decided to use a Planeterrella and computer to instead see if progress might be made by deliberate computer simulation studies and Planeterrella experiments. It worked, and the study concluded with strong evidence suggesting red, green, and blue aurorae occur regularly on Mars. Spectrum analysis of the Planeterrella simulations was conducted, and this data will serve as the quantitative predictions to compare against actual observation. These studies illustrate the scientific utility of a Planeterrella setup, that can be well adapted to NASA aurora and magnetosphere mission space weather objectives. The CPSP mission of student-led research is thus well-served by Planeterrella functionality, and the outreach mission is also satisfied by opportunities to simulate aurorae, and engage local Alaskan audiences.



ABOVE: Diagrammed key elements and materials. The tall stand bolts to baseplate, while the pedestals are free to move. The top-plate is not shown, and the diagram is not to scale.

BELOW: Example Planeterrella photo from design plans, courtesy Jean Lilensten. Note, our CPSP uses two aluminum plates and a Pyrex cylinder, instead of one plate and a bell jar pictured.

Project Description:

I currently possess a copy of Planeterrella plans, and intend to order parts immediately on funding. After a 3-week conservative estimate for shipping, by the first week in June I will begin fabricating elements, in two phases, spanning three weeks total: (1) Machine aluminum spherical shells, needle electrode, and Teflon parts, then (2) drill/tap holes and do perform finish-work. Fabricating the large components first will afford time for design revision if necessary. Between phases, I will schedule a firm meeting date to scrutinize the fabrication progress, and reevaluate the design plan. I plan to have finished parts by the end of June, and, in the first half of July, I will assemble the Planeterrella. Two weeks is adequate, but extra time for unexpected shop visits has been built in as well. Finally, I will be testing, adjusting electronic/gas equipment, and refining operation in the last half of July. The electronics and gas equipment will be linked and controlled by LabVIEW. August will be my self-imposed deadline for having a fully functional Planeterrella, but I plan on refining the operation up until the program project-deadline.

Machining will be the primary material challenge in this project. Unusual shapes cut from soft materials are a potential source of complications to cause the project timeline to slip. The prior work with the CPSP had our team in direct contact and good working terms with the machinist that will makes the parts. In simple cases, quick machining is free, and fortunately UAA provides discounted in-house shop-rates for more time-intensive work. I will maintain regular communication with the machinist the scheduled reevaluation between fabrication phases will help avoid lost time. One machining design-challenge is to translate and modify the French plans to ensure our Planeterrella stays within CPSP constraints.

Other challenges exist, but they pose little risk for causing timeline setbacks. First, I require the system to be high-vacuum compatible (~10^{-6} Torr). This requires special assembly and material considerations regarding vacuum quality. Unforeseen challenges may stem from electrical and/or mechanical issues, but my electrical engineering background prepares me to surmount these. I have continual support from my Faculty Mentor, Dr. Nathaniel Hicks, an experimental plasma physicist. His experience with plasma production, high voltage electronics, and vacuum systems will help make sure minor troubleshooting issues do not become intractable problems. Finally, Dr. Lilensten and the growing network of Planeterrella users provide another source of advice and troubleshooting tips.

Project Budget:[7,8,9]

Purchases	Item Description	Price	Part Number	Notes:
Kurt J. Lesker	Electrical feedthrough, MHV KF40	$ 260.00	IFTMG042038B	Requisite vacuum chamber port hardware, suited for high vacuum and high voltage conditions.
	Vacuum flange, 2 1/2", KF40 full nipple	$ 154.00	FN-Q33028	
	Centering O-ring, KF40	$ 9.00	QF40-150-ARV	
	Cast aluminum clamp, KF40	$ 9.00	QF40-150-C	
Accu-Glass	Power cable, 4', MHV airside (3X)	$ 180.00	110194	Vacuum-compatible electrical hardware. Rated for safe high voltage operation.
	Vacuum-compatable wire, 16awg, spool	$ 80.00	110360	
	In-line wire connector, 0.120", packet	$ 39.00	110112	
	Vented screws, 1/4-20 ss, 1 1/4", packet	$ 27.00	210033	Vented screws ensure quality vacuum by eliminating virtual leaks.
	Vented screws, 10-24 ss, 1/2", packet	$ 15.00	210076	
	Vented screws, 1/4-20 ss, 3/4", packet	$ 15.00	210315	
McMaster-Carr	Aluminum rod, 1', 4"OD, 7075	$ 202.00	90465K46	Aluminum stock to fabricate metal spheres and electron needle.
	Aluminum rod, 2 1/8"OD, 1', 7075	$ 57.00	8974K22	
	Aluminum stick, 6mmOD, 1m, 6060	$ 11.00	1681T23	
	Ceramic magnet, steel casing (2X)	$ 52.00	57005K57	Neodynium magnets simulate planetary cores, and ceramics to make position adjustments.
	Cast iron bar, 2"x1/4", 1'	$ 35.00	8928K69	
	Neodynium magnet, nickel-plated (4X)	$ 132.00	5862K39	
	Teflon bar, 1"x4", 2'	$ 407.00	8735K62	Materials for fabricating pedestals and mounts. Teflon crucial for applications involving high-vacuum, and also good electrical insulation.
	Teflon rod, 3", 4"OD	$ 128.00	1396T23	
	Teflon rod, 3", 3"OD	$ 72.00	1396T22	
	Teflon tube, 1"OD, 5/8"ID, 1'	$ 31.00	8547K46	
	Teflon tube, 5/8"OD, 1/4"ID, 2'	$ 29.00	8547K32	
	Teflon rod, 5/8"OD, 1'	$ 11.00	8546K14	
	Teflon sheet, 12"x12", 1/8" thick	$ 73.00	8545K24	Materials necessary to support magnets inside the metal spheres.
	Teflon rod, 1 1/4"OD, 1'	$ 41.00	8546K17	
Other Expenses	Miscrosoft Surface Pro 4, 256GB, i5,16GB	$ 1,399.00		
	Student stipend	$ 1,000.00		
	Estimated shipping costs	$ 250.00		
	Machining (5hrs, $50/hr shoprate)	$ 282.00		
TOTAL		**$5,000.00**		

This budget is a comprehensive list of materials, a tablet PC computer, a student stipend, shipping costs, and machining labor. After costs for materials, shipping, and machining labor, I allotted this stipend to spend toward daily personal expenses like food and gas. The Microsoft Surface Pro 4 is equipment we need to control the vacuum and and electrical systems using the computer program called LabVIEW. A tablet is important for the CPSP because outreach presentations will likely involve remote-control electronics, gas, and vacuum while presenting. When the computer is not in use, it will be reserved for the CPSP to act as a lab e-notebook for any future student-led CPSP research.

Proper funding will provide the resources I need to build a working Planeterrella here at UAA—the first in Alaska. This addition to the CPSP will equip the portable vacuum chamber with one system that can serve for both outreach in Alaska, and original student research in the lab. In the past two semesters I have spent many hours contemplating and researching options for building a similar plasma physics simulator for the CPSP. The best avenue still turned out to be plans from France. Since then I studied the plans in depth and understand exactly what needs to happen. Furthermore, my academic concentration in electrical engineering makes a good technical fit a large portion of project. In my opinion, this project's success would be near certain, and I say this because I genuinely want to see the Planeterrella at UAA, around my home-town, and in Alaska. Ultimately funding a Planeterrella is a long-term investment that will give NASA and the Alaska Space Grant Program exposure throughout the community, and so I think this project will make for a very sensible investment.

References:

[1] Lilensten, J. Planeterrella Documentation, Plans, and Technical Support. *Editor in Chief of Space Weather and Space Climate,* (2016): Institute de Planétologie et d'Astrophysique de Grenoble, CNRS

[2] Wissel, Stephanie A., et al. "The use of Dc Glow Discharges as Undergraduate Educational Tools." *American Journal of Physics,* 81.9 (2013): 663-9.

[3] LaPan, J. Photo from "Scientists Recreate Earth's Northern Lights." *National Aeronautics and Space Administration*, (2015): Retrieved February 23, 2016. www.nasa.gov/larc/scientists-recreate-earth-s-northern-lights

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

[5] National Aeronautics and Space Administration. (2016): Retrieved February 25, 2016. <www.nasa.gov>

[6] Gronoff, G., and C. S. Wedlund. "Auroral Formation and Plasma Interaction between Magnetized Objects Simulated with the Planeterrella." *IEEE Transactions on Plasma Science,* 39.11 (2011): 2712-3.

[7] Lilensten, J., et al. "Prediction of Blue, Red and Green Aurorae at Mars." *Planetary and Space Science,* 115 (2015): 48.

[8] Accu-Glass Products, Inc. (2016): Retrieved February 25, 2016. <accuglassproducts.com>

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

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