JMP and SAFIRE: What makes the sun shine?

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Recent missions to the local earth and interstellar space, such as IBEX and Voyager 1 and 2, show unexpected fluxes of high energy particles directed inward towards our sun. This, coupled with more recent observations of the solar minimum and high resolution imaging of the sun surface from IRIS and SOHO, still do not fully explain certain phenomenon. Why does the surface of the sun operate at in the 3000-4000°K range, while the solar corona exhibits temperatures in the millions of degrees? How do the known current sheets attach our Earth to the Sun? And why are they there? The scientific hypothesis of an externally powered sun has existed for nearly a century, and has recently undergone a revival due to these unanswered questions. For the purposes of this research, it is hypothesized that the emission of the sun, its composition, and its stellar classification is governed by a single mechanism: charged plasma affecting material at a different electrical potential. This presentation will share recent findings of the first and second of three phases of research known as SAFIRE (Stellar Atmospheric Function in Regulation Experiment). From use of JMP Software, results of Design of Experiments (DOE), statistical analysis, data visualization, and regression analysis of electrical diagnostics from a unique 3-dimensional plasma will be discussed. Further analysis using JMP from high resolution emission spectroscopy and mass spectrometry will be shared. These results, along with high resolution video imaging, point to strong similarities between certain phenomenon of the Sun and SAFIRE, indicating that a laboratory plasma can indeed serve as a platform to study certain aspects of the Sun.

Introduction

Solar Study Status

The Interstellar Boundary Explorer (IBEX) is monitoring an unforeseen ribbon-like geometry of energetic and neutral particles streaming into our solar system, as well as electrons. As stated by David McComas, the director of the IBEX program at the Southwest Research Institute, “"These observations show that the interaction of the Sun with the interstellar medium in our neighborhood of the Milky Way galaxy is far more dynamic and variable than anyone envisioned".[1] Another recent perplexing observation in the near earth environment is a net lack of energy required to provide us with the photons (light) that we observe from our galaxy.[2] Another exists with the Core Temperature Paradox,[3] wherein the sun’s photosphere, which is the inner part of the sun (what we observe as radiative and visible emission) is ~3000-4000°K range, but jumps to nearly >3,000,0000°K in the corona, a zone well above the photosphere and chromosphere. This would be analogous to a fireplace yielding heat 1000 times its surface temperature but at the other side of the living room. Such an issue still perplexes the geophysics and astronomical communities. Coupled with direct observations of our own sun, which produces simultaneous flares on opposite sides (and therefore exceeding the speed of light if we assume the events to be related), sunspots, plasma filaments, coronal mass ejections (CMEs), moving granules in the photosphere, and rotation of the plasma atmosphere, these peculiarities and features are yet to be unified under a single theory.

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The Electric Universe Theory

The concept of an externally influenced sun is not new. Kristian Birkeland, of whom Birkeland currents are named after, was a pioneer in the study of the earth's connection to the sun, and was first to hypothesize that electrical currents from the sun drive phenomenon such as the *aurora borealis.*[4] Such reasoning brought him much ridicule and consternation, but he was eventually proven correct in the 1970s with satellite observations. However, he left open the question of what powers the sun in turn. ~~Such~~ In the late 1970's, Ralph Juregens, an electrical engineer, pioneered the hypothesis of an electrical sun, publishing his work in the journal founded by Immanuel Velikovsky *Kronos*.[5] In his concluding remarks, after much discussion about how the sun resembles electric discharges, he states the following:

> "Qualitatively, at least, it would appear that the physical characteristics and the behavior of photospheric granules are responsive to explanation in terms of the anode-tuft hypothesis. The photosphere as a whole seems to add up to yet another strong indication that the Sun draws its energy not from within itself but from its cosmic environment, and that the delivery mechanism is an electric discharge embracing the entire solar system."

Fast forward to the IBEX mission referenced above, in particular the finding of high energy particle fluxes entering our solar system,[6] and the potential for an electrical explanation for the sun becomes more plausible. The effect of external electrical stimulation from outside our solar system is unknown. It is known that when excess current comes into contact with matter at a different electrical potential, it will radiate heat and emit photons of various energies to equilibrate with the new charge potential. Further refinements in Juregen's theory have been put forth,[7] but the exact mechanism that could account for an electrically powered sun is still under question. Fundamentally, if the sun is part of an external, yet unknown, electrical circuit, it should behave similar to measurable plasma phenomenon. Electrical phenomenon, when compared to fluvial and gravitational, are scalable over many orders of magnitude.[8] Recent observations of the universe lend much support to the scalability of electrical phenomenon, where Birkeland currents are now accepted to travel over many kiloparsecs of space.[9] It is therefore highly probable that a properly designed experiment at the laboratory level could replicate electrical phenomenon many orders of magnitude larger. Already, significant work was performed in attempts to replicate the auroral phenomenon at the laboratory scale.[10, 11] These early experiments were successful both qualitatively and semi-quantitatively in replication of auroral phenomenon, which are electrical in nature. The estimated surface wattage of the sun is ~6 x 10^6 watts/m^2, and therefore a high aspect ratio, spherical discharge could indeed supply such wattage for proper experimentation.

Experimental

Instrumentation

SAFIRE was envisioned to proceed in three stages, the first was a thorough assessment of the electric sun model and how it relates to the current fusion/gravitational model.[12] The next stage was to assemble a small scale "prove out" to test instrumentation capabilities and satisfactory concepts. The work presented in this paper will report on this second stage work. The final third stage would be the actual scaled instrument capable of supplying the desired wattage upon the electrode assembly. Figure 1 shows the final layout of the small bell jar (SBJ) apparatus for phase 2 of testing. It consists of a standard laboratory vacuum bell jar system, instrumented with a Princeton Instruments Isoplane SCT320 spectrometer, Granville Philips 835 VQM residual gas analyzer (mass spectrometer), vacuum pressure gauges, high voltage probes, and related voltmeters and oscilloscopes, as well as video and camera equipment. The proprietary anode/cathode assembly is at the center, and consists of a copper cathode and an anode. The anode is centered within the cathode, and the cathode consisted of various geometries for different tests. The initial power supply was a 600 volt DC with up to 2 amps current limited.

Figure 1. The small bell jar (SBJ) setup for initial SAFIRE experimentation. 1) control station 2) high voltage voltmeter/ammeter 3) fiber optic spectrometer 4) mass spectrometer 5) anode/cathode assembly 6) gas control module (pressure, gas flow) 7) power supply.

JMP 11 Statistical Discovery Software was employed to study the various current/voltage/pressure relationships, as well as to identify differences between various configurations, and to analyze data. The gases used in the experiment consisted of hydrogen, helium, argon, or a 10% helium/hydrogen mixture and were passed through molecular sieve and activated carbon traps to ensure clean gas supply.

Results and Discussion

Design of Experiments

In a literature search, DOE was used only to a small degree in various plasma applications, such as plasma torch cutting[13] and chemical vapor deposition[14]. Such industrial processes are ideal for optimization and utilization of JMP's platform, but no literature was found utilizing DOEs for basic, fundamental plasma research. In this laboratory plasma design, the response of voltage drop across the plasma to the anode is strongly non-linear and exhibits non-Ohmic behavior. This is because, classically, a plasma has various regions of different current flow depending on the amount of ionization. Figure 2 shows the effect of increasing the current on a linear gas discharge system, much like a fluorescent light but using direct current (DC) instead of the alternating current (AC) that comes from wall outlets. As current increases, the ability of the gas to carry charge is overwhelmed and arcing occurs (right side of Figure 2), which is akin to lightening or an arc welder. One should note that in Figure 2, there may not be visible emission despite there still being current flow (dark current or dark discharge mode). In SAFIRE's unique 3-dimensional design, it is a departure from the classical 1 and 2-dimensional plasmas like a fluorescent light or glow plasma tube. The electric field is greatly multiplied upon impingement onto the anode, thus increasing chances of unique reactions not otherwise observed in traditional plasma. A constraint on the initial DOEs was time, since the iron anode would only withstand a few minutes of exposure to high voltage and current in the experiment due to the high electric field and current flow.

In the case of SAFIRE, using the JMP DOE platform, we first explored the general effect of gas pressure, power supply voltage, and power supply current on the plasma voltage. In a plasma, once the current begins to flow due to ionization of the gases, it is dissipated by both elastic or inelastic collisions

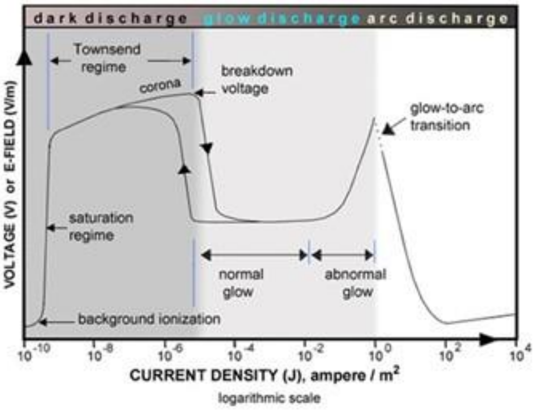
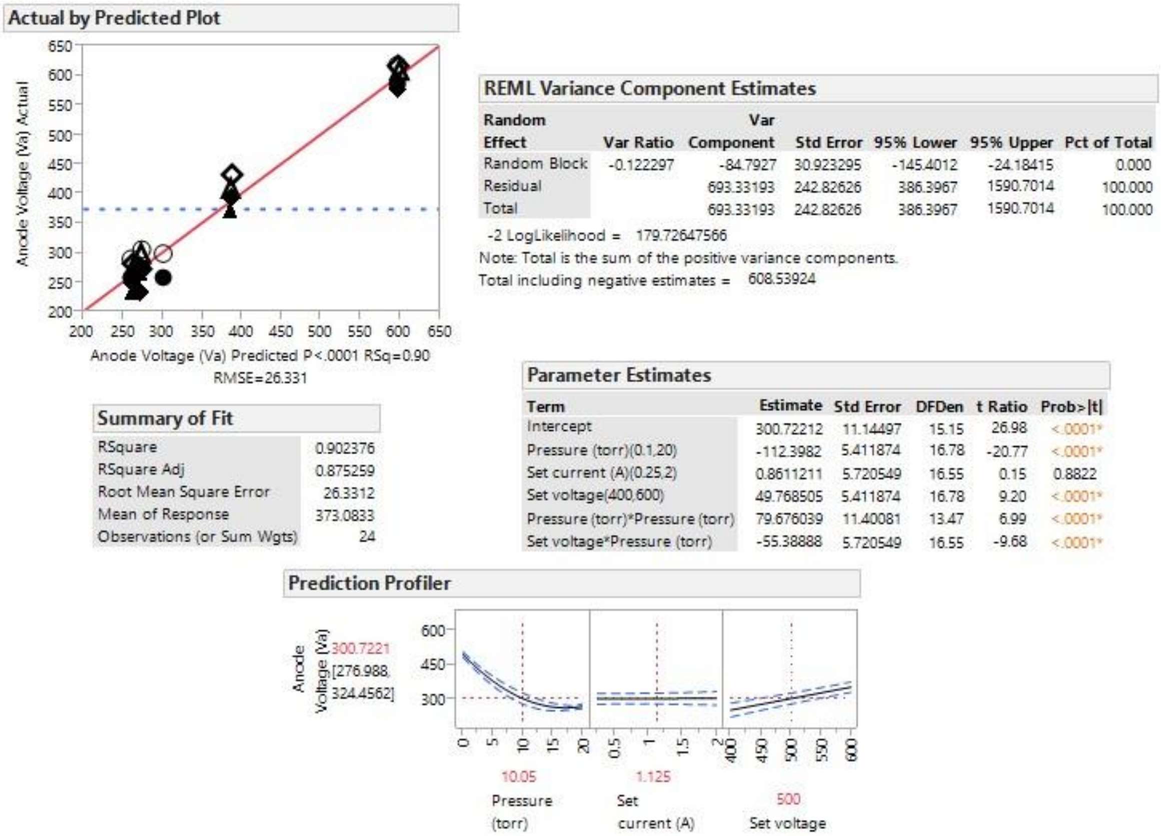


Figure 2. Typical cross section of a linear plasma voltage drop (y-axis) as a function of current density.

and other radiative losses between atoms. In the first set of experiments, a DOE was planned to study the characteristics of the plasma discharge and its effects on the anode. A particular concern was that high temperatures would affect the anode over time. The DOE utilized a simple full factorial with centerpoints to detect possible higher order interactions. The experiments were randomly blocked into 4 data points for each set, in between which the anode was cooled. The following high and low settings were used: source voltage, 250-600 volts, source current, 0.25-2.0 amps, and pressure 0.1 to 20 torr. Figure 3 shows the model output after stepwise regression analysis of the data. It was found that the experimental blocking did not resolve any effect when compared to the residuals. The final model revealed a significant interaction between voltage and pressure as well as a squared term (most likely pressure x pressure due to increasing gas concentration resulting in increased voltage drop). Interestingly, the current in the system



REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Random Block	-0.122297	-84.7927	30.923295	-145.4012	-24.18415	0.000
Residual		693.33193	242.82626	386.3967	1590.7014	100.000
Total		693.33193	242.82626	386.3967	1590.7014	100.000

-2 LogLikelihood = 179.72647566

Note: Total is the sum of the positive variance components.

Total including negative estimates = 608.53924

Summary of Fit

RSquare	0.902376
RSquare Adj	0.875259
Root Mean Square Error	26.3312
Mean of Response	373.0833
Observations (or Sum Wgts)	24

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	300.72212	11.14497	15.15	26.98	<.0001*
Pressure (torr)(0.1,20)	-112.3982	5.411874	16.78	-20.77	<.0001*
Set current (A)(0.25,2)	0.8611211	5.720549	16.55	0.15	0.8822
Set voltage(400,600)	49.768505	5.411874	16.78	9.20	<.0001*
Pressure (torr)*Pressure (torr)	79.676039	11.40081	13.47	6.99	<.0001*
Set voltage*Pressure (torr)	-55.38888	5.720549	16.55	-9.68	<.0001*

Prediction Profiler

Figure 3. Model output for initial DOE. A centerpoint with a full factorial was used to initially screen and explore the design space of the small bell jar apparatus.

was not a significant factor in this design space; the current was maintained no matter the voltage drop. The current was left in the model to visually observe that it has no effect in the profiler.

The curvature in the voltage response of Figure 3 shows a distinct 2nd order interaction of pressure and voltage, interpreted as the collisions of a higher number of gas molecules at higher pressures, which results in less voltage being maintained across the cathode-anode gap. At low pressures, there are fewer collisions between atoms (large mean free path), and the power supply voltage supplies all the voltage taken by the plasma. But as pressure increases, the plasma voltage potential drops due to increased number of inelastic and elastic collisions between atoms and thermal effects. Since pressure can be thought of as atom density (atoms per volume), design of the large SAFIRE chamber and power supply must take such effects into account. Future studies in the final SAFIRE design will utilize Langmuir probes to quantify regions of highest spatial charge separation (otherwise known as double layers) along with ion and electron densities and fluxes. Such data will further elucidate the plasma "temperature", which is an important factor when it comes to comparing a laboratory test with the actual sun and immediate solar environment. The temperature effects will be discussed in more detail momentarily.

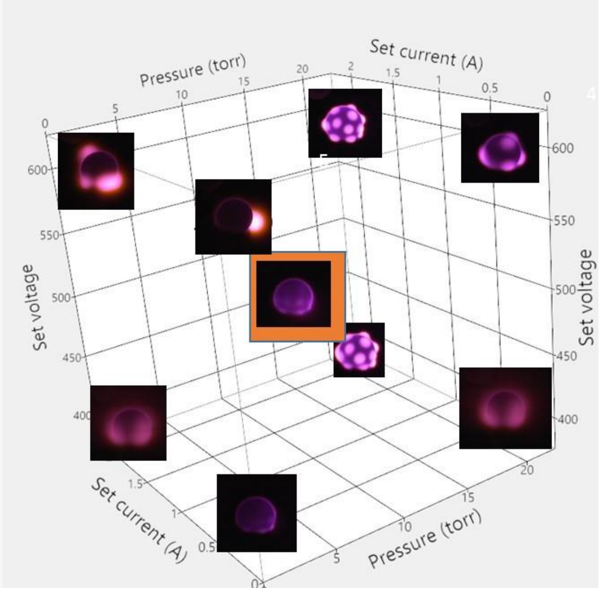


Figure 4. Various plasma configurations as a function of DOE settings. Not strong visual changes associated with current increase. Center picture with colored border is centerpoint.

The differences in the plasma appearance in relation to the DOE is shown in Figure 4. Of particular note is the appearance of anode tufts, which are the small, beadlike emissions on the surface of the anode. These particular tufts would rotate upon changes in pressure or voltage, and then dissipate into an even anode glow (quiescent phase) at a particular setting. The tufts are caused by enhanced electric fields around high points on the surface of the anode, which provide localized enhancement of electric field and a sputtering effect of the metal and the gaseous ions. The double layers then repulse one another leading to rotation and separation. To the investigators' knowledge, this is the first time anode tufting was stable and regularly observed in a spherical configuration.

The parallel between certain aspects of the sun's atmosphere and such a discharge may lie in the supergranulation aspect of the photosphere. Figure 5 shows a typical high resolution picture of a sunspot, showing the photospheric granules "reaching" thorough the atmosphere in the opening. On the right are the anode tufts in our experiments. It is logical to assume that with a higher current density they would closely packed and forced together. The wattage of the SBJ setup in which anode tufts are obtained is on the order of ~10^4, which is two orders of magnitude less than the sun's estimated ~10^6 watts/m^2. We further explored ways of studying this similarities between the granules and the laboratory tufts.

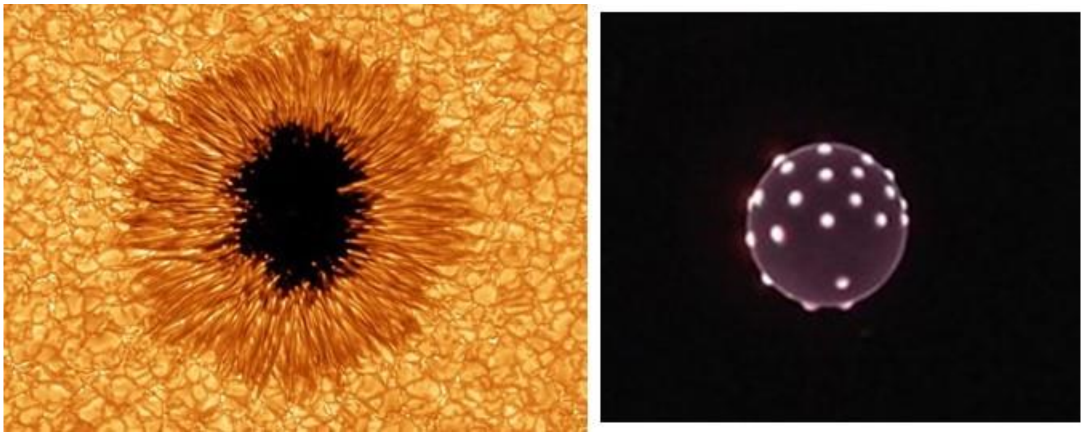
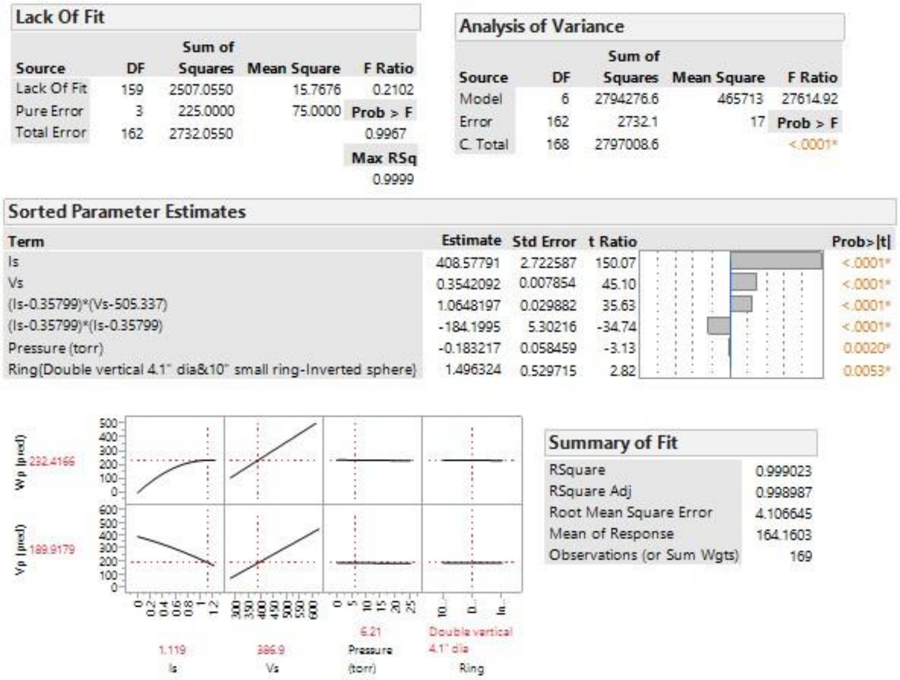


Figure 5. High resolution of sunspot and surrounding granulation on sun (left)[15] and initial SBJ experiments (right). Increasing the current led to an increase in the number and a decrease in the width of the granules on the anode.

For research purposes, the power requirements necessary to obtain the sun's surface wattage were extrapolated from a model fit of test data. First, a least squares regression fit of plasma wattage per square meter of the anode was derived from a randomized collection of data points from various geometries of cathodes and separate experiments. The data gathered was taken through the Stepwise Regression analysis. A stepwise fit to second order interactions and second order polynomials was carried out, using the minimum AICc method, resulting in the parameter estimates in Figure 6. The



Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	159	2507.0550	15.7676	0.2102
Pure Error	3	225.0000	75.0000	Prob > F
Total Error	162	2732.0550		0.9967
				Max RSq
				0.9999

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	2794276.6	465713	27614.92
Error	162	2732.1	17	Prob > F
C. Total	168	2797008.6		<.0001*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Is	408.57791	2.722587	150.07	<.0001*
Vs	0.3542092	0.007854	45.10	<.0001*
(Is-0.35799)*(Vs-505.337)	1.0648197	0.029882	35.63	<.0001*
(Is-0.35799)*(Is-0.35799)	-184.1995	5.30216	-34.74	<.0001*
Pressure (torr)	-0.183217	0.058459	-3.13	0.0020*
Ring{Double vertical 4.1" dia&10" small ring-Inverted sphere}	1.496324	0.529715	2.82	0.0053*

Summary of Fit

RSquare	0.999023
RSquare Adj	0.998987
Root Mean Square Error	4.106645
Mean of Response	164.1603
Observations (or Sum Wgts)	169

Figure 6. Least squares fit from analysis of types of cathode, pressure, source voltage, and source current. The statistics are from the fit for Wp (anode wattage); Vp is calculated separately. The profiler is from combined least squares fits of Vp and Wp.

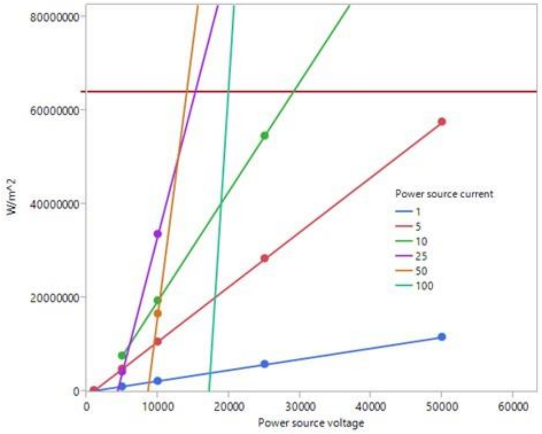


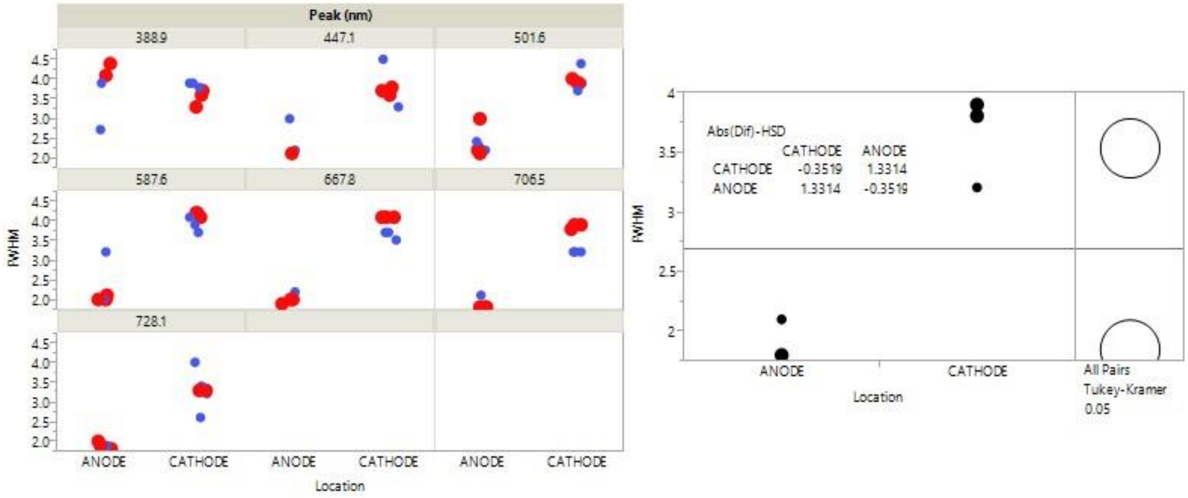
Figure 7. Power requirements for larger voltage/current source (DC) extrapolated from wattage least squares equation.

same procedure was used to determine the voltage across the plasma (Vp) and a prediction equation generated, which was plotted as a graphical profiler along with the wattage (Wp) in Figure 6. The current in the plasma was most affected by voltage; pressure was only a minor factor in both the plasma voltage and anode wattage. This was a different result from the original factorial results of Figure 2, thought to be due to the use of a hydrogen/helium mixture in the experiments of Figure 6. It is apparent that as the current increased, sufficient voltage is necessary to maintain current flow. If there is not enough voltage potential, the current impinging the anode levels out and it cannot facilitate accepting any higher electron flow.

Finally, the least squares equation for the wattage in Figure 6 was used to extrapolate voltage and current required to obtain the same surface wattage as the sun. The equation was entered into a Microsoft Excel spreadsheet with user inputs of voltage, current, and pressure. The calculator was used to plot power requirements curves (Figure 7). The sun's wattage is the red line; any curves that surpass this line denote the voltage/current requirements of the next power source. From a first principles estimate and assessment, the project now anticipates significant safety resources and risk management, as well as materials design of the anode. It must be able to withstand significant temperatures (>3000°C) for ample periods of time for measurements.

Spectroscopy

Visible light emission arises from the atmosphere (photosphere and chromosphere) of the sun, not the core. This is known because the temperature of the layer below the chromosphere (the layer below the sunspots as in Figure 5) was measured using various spectrographic techniques, and is estimated to only be ~4000°K. We know the corona exhibits extremely high temperatures because we observe elements in highly ionized states by spectroscopy. Such atomic ionization states require an immense amount of thermal energy, so much that the standard fusion or magnetic reconnection models do not suffice. Interestingly, an electrical discharge in the laboratory is capable of ionizing many electrons from the iron atom, or many other atoms. Therefore, the measure of ionization states and temperature estimates from spectroscopy is an important tool to gauge the atmosphere around the SAFIRE anode for comparison to the sun. Techniques such as Boltzmann plots yield information about the temperature of ionized gases. The Boltzmann plot utilizes the ratio of line widths and intensities between different peaks in the spectrum to derive an estimated temperature from a statistical population of energetic states.[16] In the SAFIRE configuration, a large amount of data at regular intervals streams from the spectrometer, and it was desired to quickly visualize peak pairs to yield the highest difference, and thus the highest signal to noise ratio. A spectrometer disperses light from individual fiber optics positioned within the vacuum bell jar onto a grating, which then disperses the light into its component wavelengths. The dispersed light is placed onto a CCD array, which results in a spectrum with various peaks. The peaks are the emission of particular wavelengths of light from various paths of electron relaxation around atoms and/or molecules, and provides a “fingerprint” of the plasma at those particular conditions (pressure, temperature, voltage, current, etc.). Figure 8 shows a JMP Graph Builder of such data. The colors and size denote the system pressure (blue small – low; red large - high), and the y-axis the full width half maximum (FWHM) of the measured peaks. Upon One-way Analysis and use of Tukey-Kramer HSD (Honest significance Test), the highest spread in data was found with the 667.8 nm peak (right graphic in Figure 8). Of particular note was that the FWHM of the light gathered from a distance *far away* from the anode (“CATHODE”) was qualitatively higher (from FWHM measurements) than that light gathered right on the anode surface (“ANODE”). This perplexing result is still under analysis, but addresses the “temperature paradox” discussed previously. Using this scripting method, analysis of peaks can quickly occur in real time as DOEs are carried out. In the final phase, the output will be integrated with real time analysis to provide immediate measures of temperature in localized areas of the plasma.



Abs(Dif)-HSD

	CATHODE	ANODE
CATHODE	-0.3519	1.3314
ANODE	1.3314	-0.3519

Figure 8. Depiction of full width/half maximum measurements from spectroscopy. The “Anode” fiber optic gathered light immediately off the anode surface, while the “cathode” fiber optic looked away from anode near the cathode. Red/large data points are high pressure; blue/small points are low pressure; each wrapped number is the wavelength of the peak analyzed (left graph). The right graph is from one-way analysis using Tukey-Kramer HSD for the 667.8 nm peak.

Conclusions

Combining a number of other experiments, redesigns, and refinements, further testing revealed structurally similar discharges on the anode that were very similar to the sun’s plasma (Figure 9). Double layers, caused by charge (+/-) separation in plasmas, which produce granules and cellular layers in plasmas[17], were visually and/or qualitatively observed near the surface of the anode. The sun too exhibits extensive charge separation, temperature changes, and granulation as a function of distance from the core. The sun exhibits coronal ejections; the anode exhibited eruptions at regular intervals. The sun goes through emission solar cycles; the anode exhibited regular pulses despite a fully regulated DC input and clean power supply. The sun possesses a higher coronal temperature at a farther distance from the core as gauged by spectroscopy; our SBJ assembly possesses an increase temperature farther from the anode as gauged from emission spectroscopy. The trihydrogen cation (H_3^+) is the most abundant molecule in the universe; H_3^+ was detected at high percentage levels with the mass spectrometer in our experiment. Visually, the anode bears a striking resemblance to the sun, and visible layers of charge separation (Figure 9). These observations lend both quantitative and qualitative indications that the electric sun hypothesis warrants further critical study and evaluation. JMP continues to be an integral tool in the design, test, and analysis of this hypothesis.

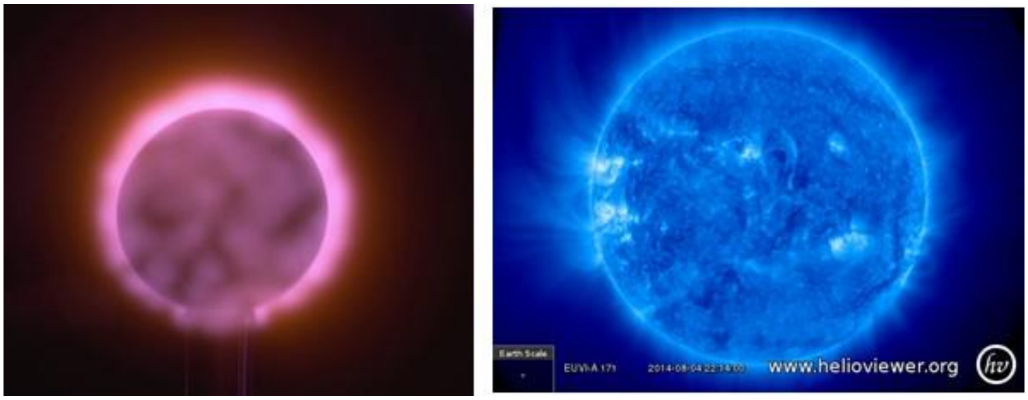


Figure 5. A quiescent anode discharge in the SBJ unit (left) and a screen capture from Stereo-A Secchi EUVI detector at 171 nanometer wavelength.

Acknowledgments

The authors would like to thank Dr. Don Scott, Wal Thornhill, Dr. Lowell Morgan, and Jim Ryder for guidance and stimulating discussions, and Ben Gedlow for the photography. The SAFIRE project is supported by Aurtas International.

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