Parametric Experiments In Mitigating Spacecraft Charging Via Plasma Contactor

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Abstract

Spacecraft charge mitigation is critical for a host of space plasma measurement techniques. However, charge mitigation in tenuous space plasmas can be a difficult problem. It is especially difficult and essential during active experiments that feature ion or electron beams, as collection from the ambient plasma is often insufficient to balance the beam emission current. For electron emission experiments, the use of a plasma contactor that emits an ionized gas is the only practical option. A series of parametric chamber experiments were completed to address how spacecraft charge mitigation using a plasma contactor may scale in tenuous space plasmas. Experiments focus on how spacecraft potential scales with beam emission current, contactor current (the rate at which the contactor generates quasi-neutral plasma), and contactor expellant mass (ion mass). These experimental results are compared to scaling laws derived via Curvilinear Particle-In-Cell (CPIC) simulations for further validation and physical insights. Implications for improving space plasma measurements and enabling future active experiments such as the Connections Explorer (CONNEX) mission are discussed.

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Introduction

Spacecraft charge mitigation is essential during space experiments that feature ion or electron beams. For electron emission experiments in tenuous space plasmas, the use of a plasma contactor (which emits an ionized gas) is the only practical option. Experiments were completed to address how spacecraft charge mitigation using a plasma contactor may scale in tenuous space plasmas. Experiments focus on how spacecraft potential scales with electron beam current, contactor current (the rate at which the contactor generates quasi-neutral plasma), and contactor expellant mass (ion mass). These experimental results are compared to scaling laws derived via simulation for further validation and physical insights.

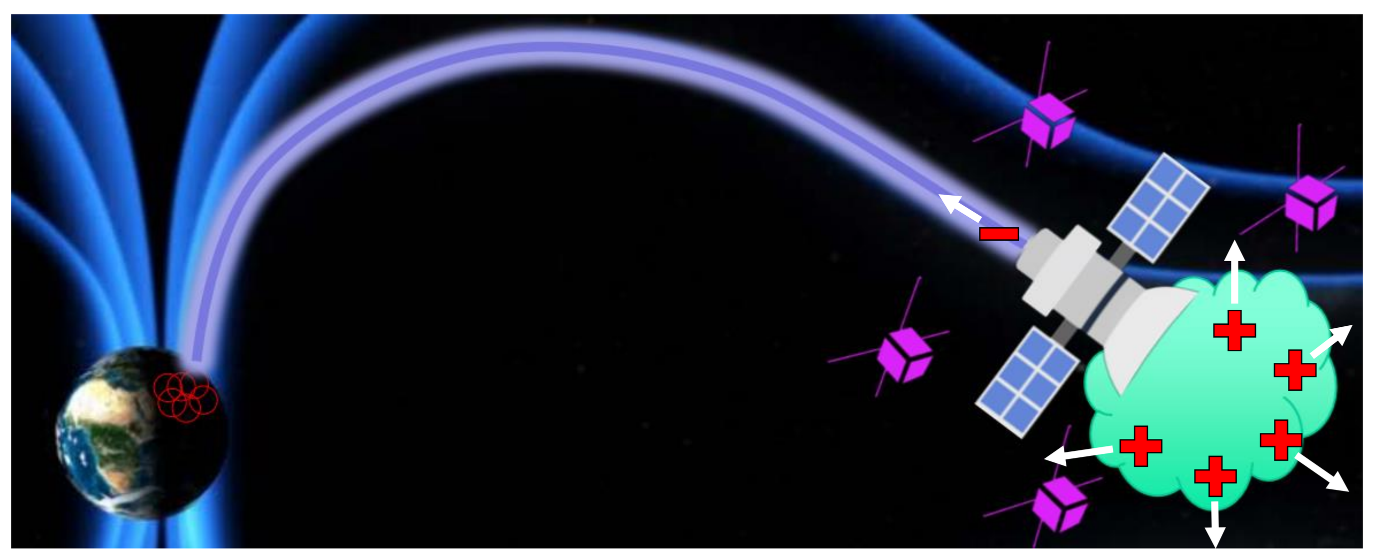

Figure 1. The CONNEX mission concept during electron beam emission. The beam (highlighted) traces the Earth's magnetic field while the plasma contactor (teal) mitigates spacecraft charging by emitting ions.

Materials and Methods

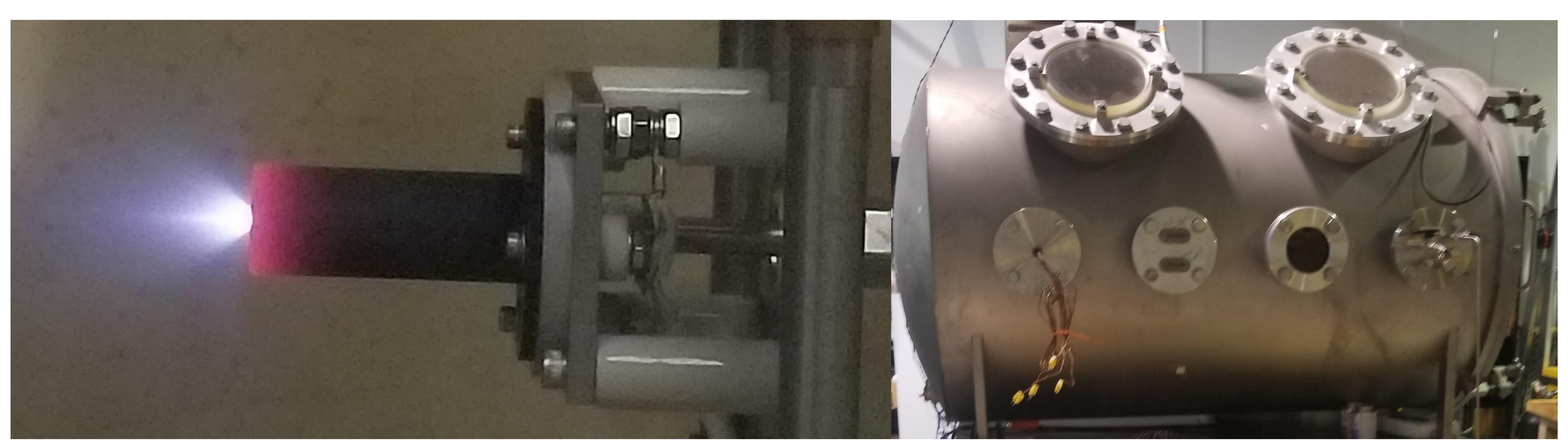

Figure 2. ¼" heaterless hollow cathode operating as a small, representative spacecraft with a plasma contactor in the lab (left). 2m x 1.5m EDA vacuum chamber used for this series of experiments (right).

		Gas Flowrate						
		0.2	0.5	1	2	5	10	20
Keeper Current	0.3			K			K	AK
	0.4	K	K	K	A		AK	AK
	0.5	KX	KX	AK	A		AK	AK
	0.6	KX	KX	AK	AK	A	AK	AK
	0.7	KX	KX	AK	AK	AK	AK	AK
	0.8	KX	AKX	AK	AK	AKX	AKX	AKX
	0.9	KX	AKX	AKX	AKX	AKX	AKX	AKX
	1	KX	AKX	AKX	AKX	AKX	AKX	AKX
	1.1	KX	AKX	AKX	AKX	AKX	AKX	AKX
	1.2	KX	AKX	AKX	AKX	AKX	AKX	AKX
	1.3	KX	AKX	AKX	AKX	AKX	AKX	AKX

Table 1. Stable plasma contactor flowrate and keeper current configurations studied. The letter A represents Argon expellant use, K represents Krypton, and X represents Xenon.

Results and Discussion

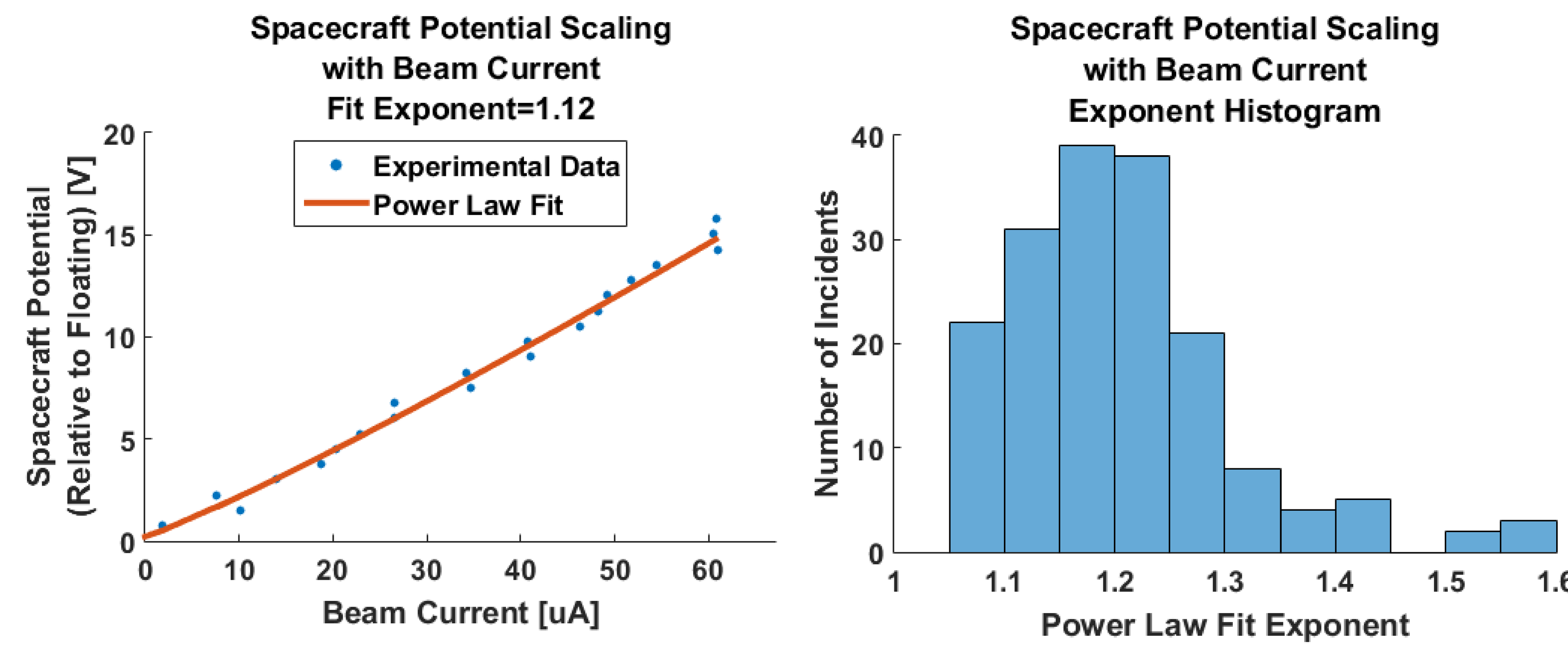

Figure 3. A randomly selected measurement of spacecraft potential versus beam current overlaid with a power law fit (left). A histogram of the exponents for every spacecraft potential versus beam current fit in which the average exponent is 1.21 (right).

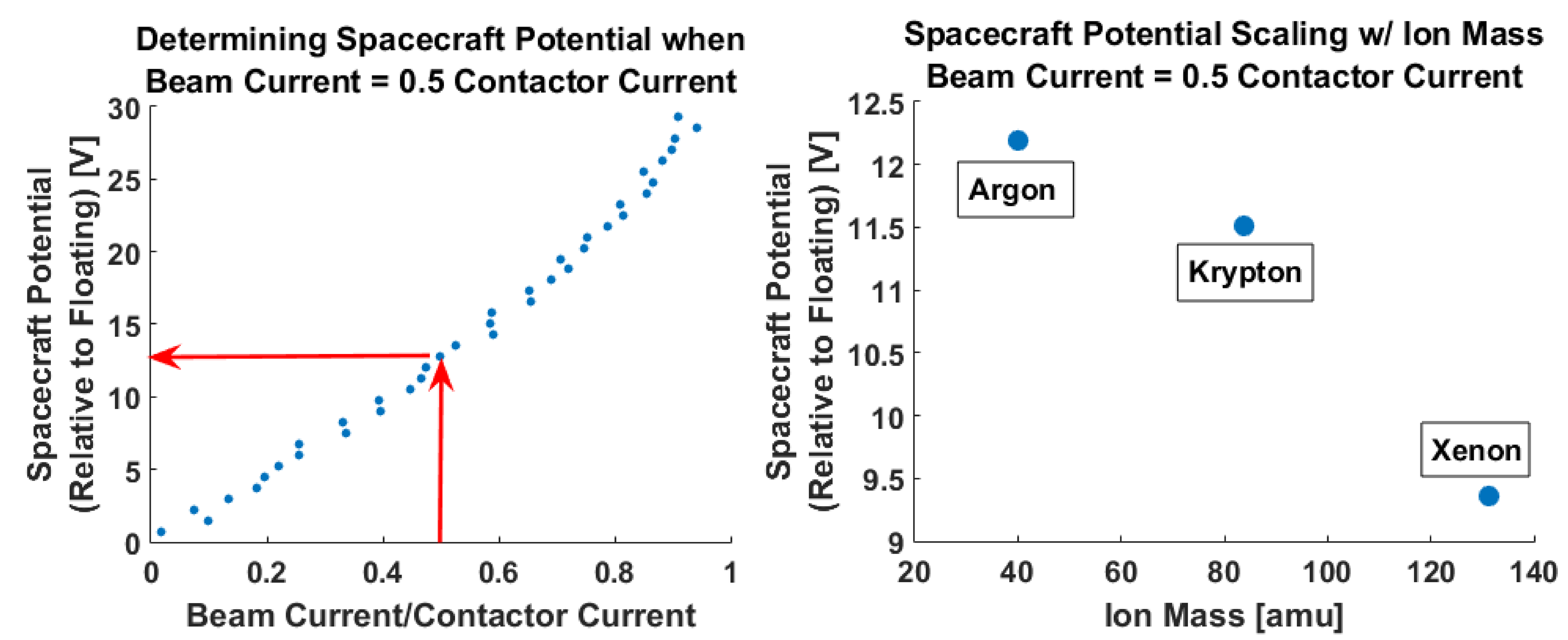

Figure 4. An example of determining the spacecraft potential when the beam current is half the contactor current (left). This analysis shows spacecraft potential decreases with increasing ion mass, which is counter to the scaling predicted by simulation (right).

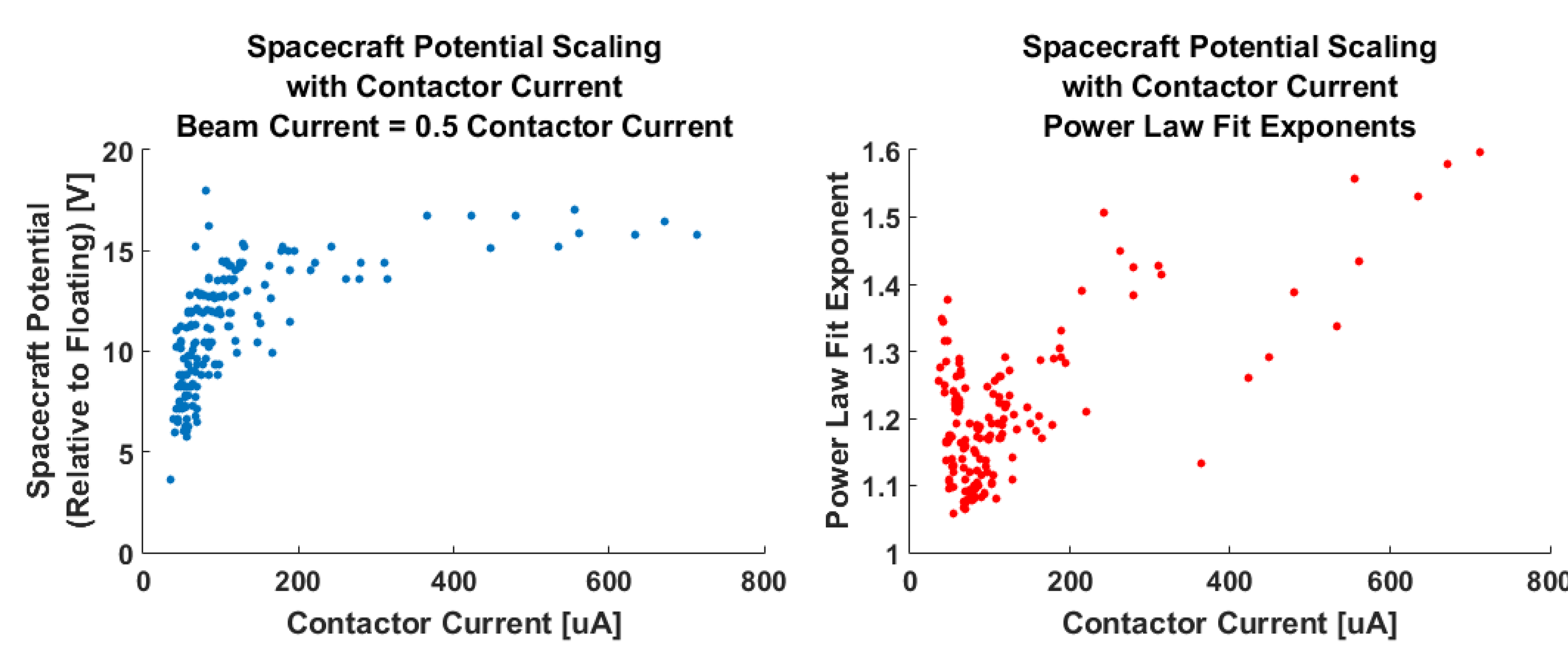

Figure 5. How the spacecraft potential scales with contactor current. The metrics used were spacecraft potential when the beam current is half the contactor current (left) and the power law fit exponent similar to those in figure 3 (right).

Column below is the dependent variable in correlation coefficient calculation	Cathode (SC) Potential	Ion Mass	Gas Flowrate	Keeper Current	Ion Emission (Beam) Current	Expellant Utilization	Contactor Current	Floating Potential	Keeper Voltage	Keeper Power	Ion Emission Power	SC Potential @ Ib = 0.5Icon	Chamber Pressure	Floating Potential Index	Minimum Sweep Voltage	Maximum Sweep Voltage	Sweep Voltage Range
Cathode (SC) Potential																	
Ion Mass						-0.02	0.08	-0.22	-0.31	-0.07	0.19	-0.36	0.28	0.06	-0.15	-0.51	-0.40
Gas Flowrate						-0.47	0.53	-0.62	-0.30	-0.36	0.25	0.21	0.76	-0.57	-0.05	-0.34	-0.29
Keeper Current						0.14	0.16	-0.20	-0.61	0.75	0.08	-0.01	0.05	-0.16	0.10	-0.14	-0.18
Ion Emission (Beam) Current																	
Expellant Utilization		-0.02	-0.47	0.14			0.03	-0.01	0.41	0.55	0.15	0.11	-0.38	-0.05	-0.10	0.14	0.17
Contactor Current		0.08	0.53	0.16		0.03		-0.83	-0.18	0.05	0.69	0.60	0.74	-0.93	-0.35	-0.06	0.10
Floating Potential		-0.22	-0.62	-0.20		-0.01	-0.83		0.26	-0.03	-0.58	-0.38	-0.73	0.85	0.42	0.50	0.26
Keeper Voltage		-0.31	-0.30	-0.61		0.41	-0.18	0.26		0.03	-0.04	0.00	-0.39	0.17	0.05	0.22	0.18
Keeper Power		-0.07	-0.36	0.75		0.55	0.05	-0.03	0.03		0.08	0.00	-0.26	-0.06	0.21	0.02	-0.07
Ion Emission Power		0.19	0.25	0.08		0.15	0.69	-0.58	-0.04	0.08		0.24	0.49	-0.56	-0.37	-0.12	0.06
SC Potential @ Ib = 0.5Icon		-0.36	0.21	-0.01		0.11	0.60	-0.38	0.00	0.00	0.24		0.24	-0.73	-0.34	0.55	0.66
Chamber Pressure		0.28	0.76	0.05		-0.38	0.74	-0.73	0.39	-0.26	0.49	0.24		-0.67	-0.16	-0.41	-0.30
Floating Potential Index		0.06	-0.57	-0.16		-0.05	-0.93	0.85	0.17	-0.06	-0.56	-0.73	-0.67		0.29	0.00	-0.13
Minimum Sweep Voltage		-0.15	-0.05	0.10		-0.10	-0.35	0.42	0.05	0.21	-0.37	-0.34	-0.16	0.29		0.04	-0.42
Maximum Sweep Voltage		-0.51	-0.34	-0.14		0.14	-0.06	0.50	0.22	0.02	-0.12	0.55	-0.41	0.00	0.04		0.89
Sweep Voltage Range		-0.40	-0.29	-0.18		0.17	0.10	0.26	0.18	-0.07	0.06	0.66	-0.30	-0.13	-0.42	0.89	

Table 2. Correlation coefficient between all measured experimental parameters.

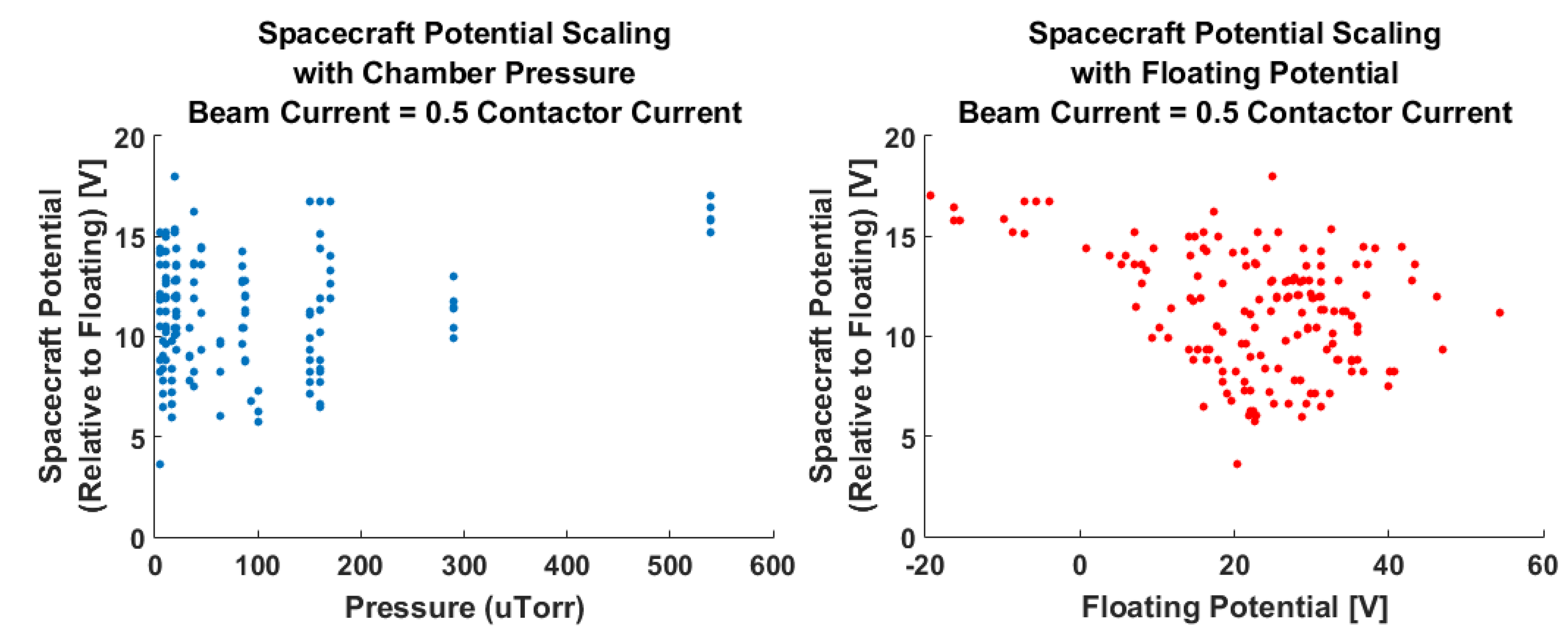

Figure 6. Additional plasma parameters correlated with spacecraft charging. Chamber pressure (left) and floating potential (right) are plotted against spacecraft potential when the beam current is half the contactor current .

Conclusions

- Spacecraft potential was found to scale as the beam current to the 1.21 power (compares very favorably to the 1.2 exponent predicted via simulation)
- Spacecraft potential was found to decrease slightly with increasing ion mass (opposite the trend predicted via simulation)
- Spacecraft potential was found to be loosely correlated with contactor current
- A correlation study reveals complicating parameters which should be examined and used for detrending

Acknowledgements

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