

Lifetime extension of electrospray thrusters using ionic liquids through advanced diagnostics and analysis of vacuum facility effects

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Motivation

Satellite Manoeuvrability and Electric Propulsion Scalability

Small satellites are increasingly deployed in large constellations, where each spacecraft must perform different manoeuvres frequently. This operational paradigm makes on-board propulsion essential for every unit in the constellation, driving demand for systems that are compact, efficient, and long-lived. Electrospray thrusters using ionic liquids offer unique advantages for micro- and nanosatellites: low mass and volume, no neutraliser, high efficiency at low power, and inherent scalability.

The Open Challenge: Performance Degradation due to Ground-Testing Effects

Performance degradation over time is driven by physical mechanisms that are still poorly understood, particularly the interaction between the emitted beam and vacuum facility surfaces during ground testing, so-called facility effects. These effects can alter propellant properties, distort diagnostic measurements, and accelerate emitter erosion, making it difficult to distinguish intrinsic thruster degradation from artifacts of the test environment.

Additionally, to avoid life-limiting electrochemical reactions, advanced electrospray thrusters operate in bipolar mode (alternating extraction voltage polarity), which introduces new complexity in how the beam interacts with surrounding surfaces.

State of the Art

Electrospray thrusters emit beams of charged species (ions and droplets) extracted from ionic liquid menisci by strong electric fields. Externally-wetted emitters, as used in IENAI SPACE's ATHENA, represent a less-studied morphology compared to capillary or porous emitters, and limited lifetime data exist for this configuration.

Uchizono et al. [1] demonstrated that secondary species emission (SSE) from beam-impacted surfaces inside vacuum chambers can significantly contaminate propellant and alter thruster behaviour, even when SSE currents are orders of magnitude below the primary beam current. Beam targets – surfaces placed to intercept the plume – have been proposed to mitigate these effects, and biasing them has been shown to suppress or redirect SSE.

RESEARCH GAP

Existing beam-target design and biasing guidelines address only single-polarity operation of capillary or porous emitters. The interaction between a bipolar beam or several emitter arrays firing simultaneously in opposite polarity and a biased beam target has not been investigated, leaving a gap in the understanding needed for reliable lifetime testing of externally wetted electrospray systems.

Objectives

Objective 1

Identify, characterise and understand the physical mechanisms responsible for performance degradation over time of externally-wetted electrospray thrusters.

Objective 2

Design and develop different beam-target configurations and characterise their ability to mitigate vacuum facility effects on externally-wetted electrospray thrusters.

Objective 3

Analyse vacuum facility effects by comparing lifetime test results across different vacuum chambers (IENAI SPACE vs. EP2/UC3M facilities).

Methodology

Phase 1

Literature Review & Classification of Lifetime Limiting Factors

Identification of lifetime limiting factors of electrospray thruster such as thruster design & operation, space environment, and facility effects, among others. Fundamental understanding of SSE and its role in ground-testing degradation.

Phase 2

Facility Effects Characterisation & Mitigation

Quantification of facility effects and development of different beam targets and biasing configurations using an iterative process between design and short-duration testing campaigns considering alternating emitter operations. Development of additional diagnostics to evaluate the degradation trends under each configuration. Formulation of guidelines for on-ground testing of electrospray systems.

Phase 3

Lifetime Testing

Extended operation campaigns using the optimised beam target, full diagnostic suite and guidelines. Tests repeated in a larger vacuum chamber at EP2 to isolate the effect of chamber geometry on degradation rates.

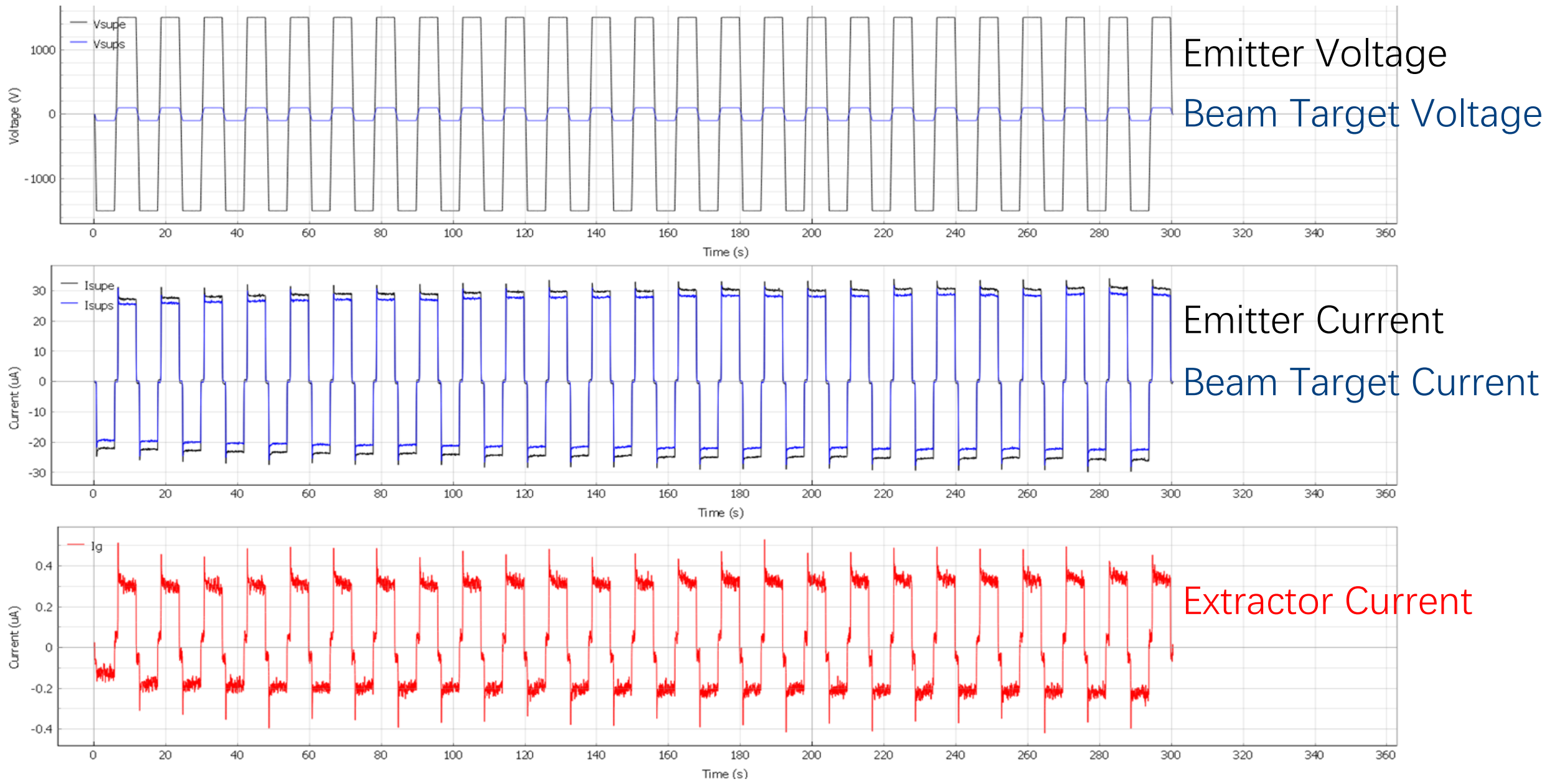
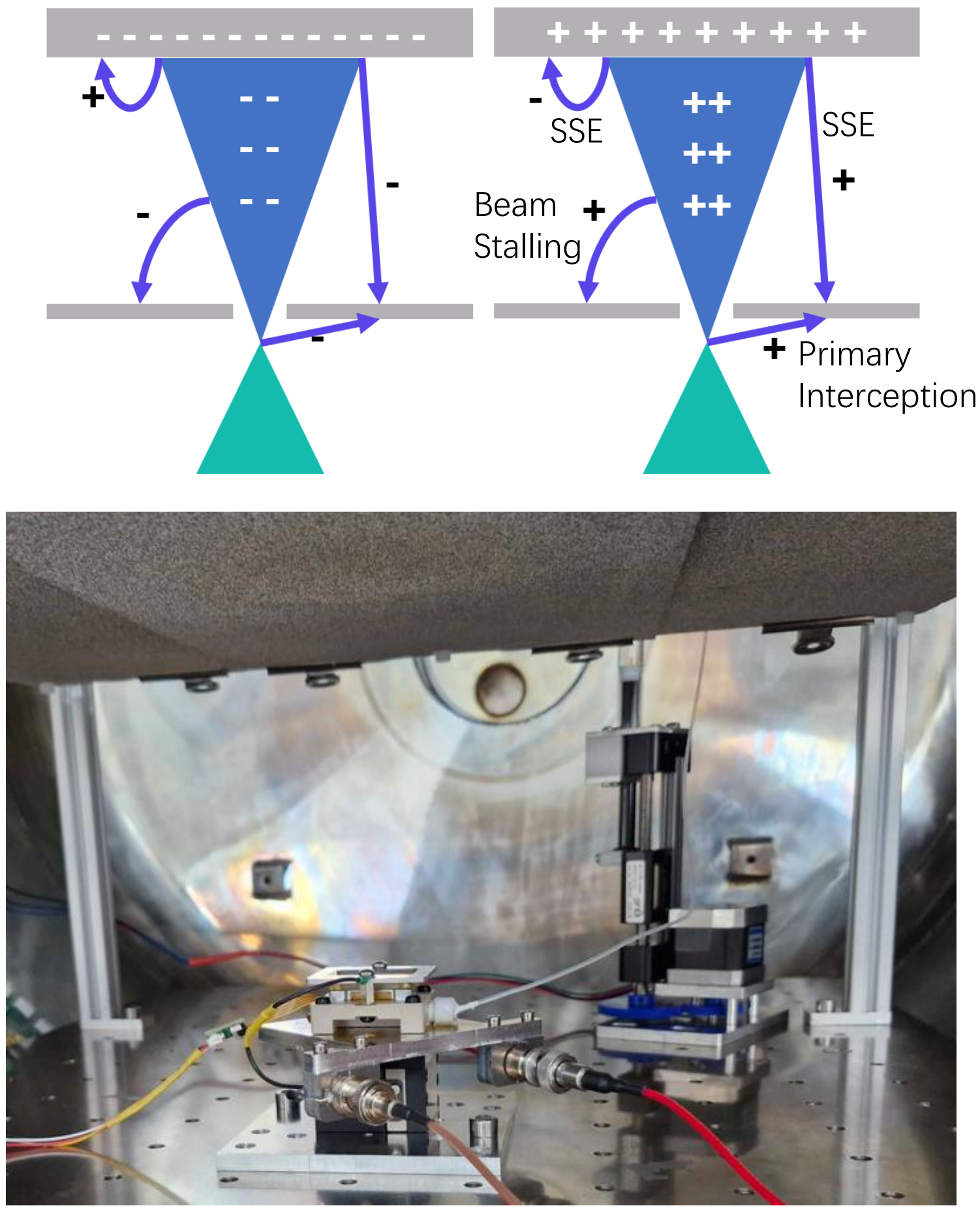
Transversal

Literature Review, Analysis & Dissemination

Journal publications, conference presentations, and thesis preparation.

Preliminary Research/Results

A first experimental campaign has been completed with the ATHENA thruster (passively-fed, externally-wetted, bipolar mode) and a simple porous nickel-foam beam target. Four bias configurations were systematically evaluated: **In-Phase** (Target bias follows beam polarity), **Out-of-Phase** (Target bias opposite to beam), **Constant +** (Constant positive bias), **Constant –** (Constant negative bias). Simultaneous current measurements at emitter, extractor, and beam target revealed that SSE can dominate over primary interception and backstreaming due to beam stalling as described by Jia-Richards [2]: Out-of-Phase biasing produced extractor current polarity reversals, while In-Phase biasing yielded more representative measurements and reduced adverse plume–surface interactions.



KEY FINDING – BIASING IN BIPOLAR MODE

Maintaining the beam target at the same polarity as the beam (in-phase) provides the most representative current diagnostics and promotes electrostatic repulsion of backstreaming particles, potentially mitigating emitter degradation during long-duration operation. This behaviour – specific to bipolar operation – has not been previously described in the literature and will be presented at IAC 2026.

References

[1] N. M. Uchizono et al., "The role of secondary species emission in vacuum facility effects for electrospray thrusters," J. Appl. Phys. 130, 2021.
[2] O. Jia-Richards, "Partial beam stalling as an alternative source of intercepted current in ionic-liquid electrospray thrusters", J. Appl. Phys. 139, 2026