Integrating Autonomous Active Deorbiting Systems to Microsatellites in LEO

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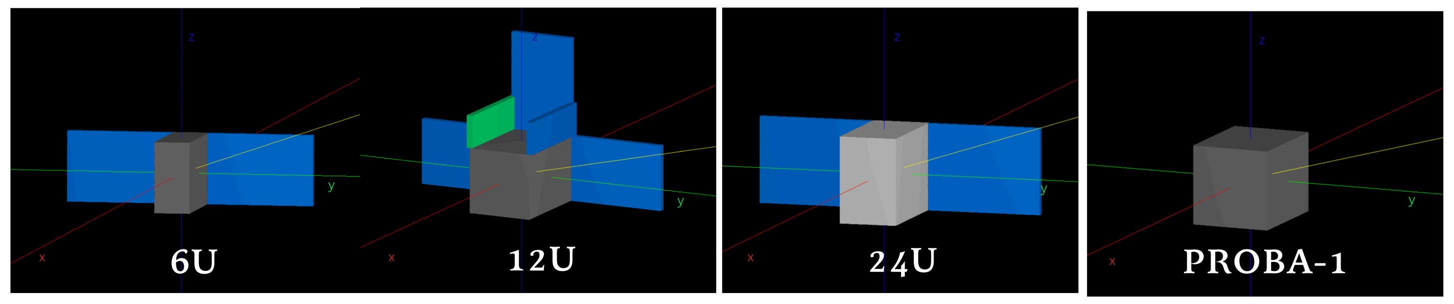
Introduction

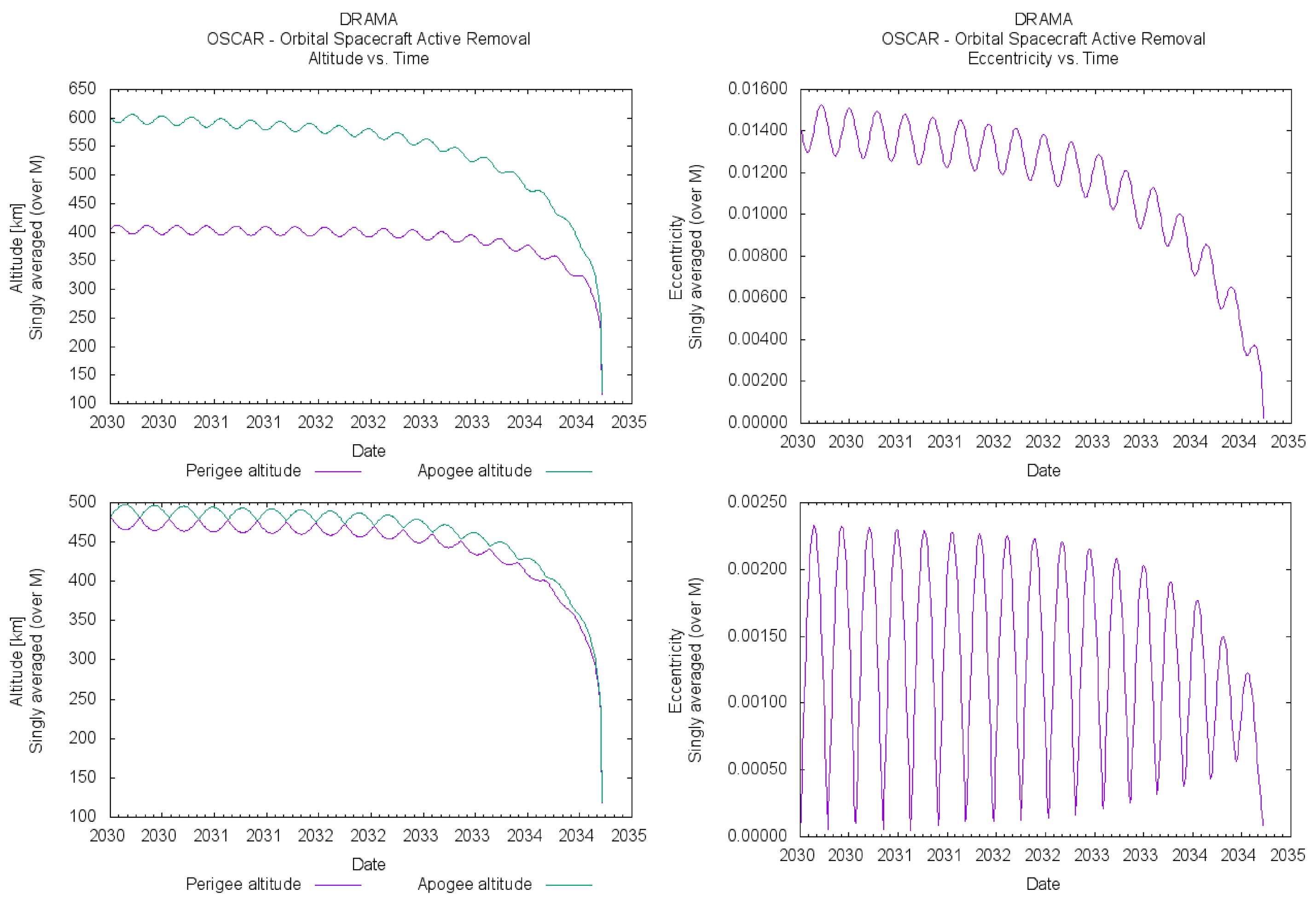
The growing operational and regulatory requirements associated with minimising space debris generation motivate this study of active deorbiting system performance and integration analysis across representative microsatellite mission scenarios.

Microsatellite missions in LEO are subject to the SDM requirements related to passivation, post-mission disposal, collision avoidance, and design for removal [1]. Within this broader framework, the scope of the present analysis is limited to disposal through active deorbiting systems.

Framework for Trade-off Analysis of Deorbit Propulsion Solutions for Microsatellites

ORBITAL MECHANICS	SPACECRAFTS AND ORBITS	MARKET STUDY	SIMULATION PIPELINE	LEO CLEARANCE-COMPLIANT DEORBIT MODEL
What are the equations governing the mechanics of circular orbits and propulsion?	What are the boundary conditions for the orbital propagation models in LEO?	What are the capabilities and limitations of commercially available propulsion systems?	What is the mission design, and how can propulsion performance scale to meet the requirements?	What are the key engineering considerations in the selection of a propulsion system?
Ballistic coefficient (B_c), Hohman transfer, Tsiolokovsky ideal rocket equation, system-level characteristics of propulsion systems	Platform classes 6U, 12U, 24U and PROBA-1 SSO from 400 km to 800 km	Characterisation of high-thrust impulsive operations and continuous low-thrust acceleration modes	Thruster performance evaluation with fixed Δv Trade-off analysis of propulsion systems for microsatellite deorbiting	Spacecraft-specific B_c, altitude-dependent Δv, platform constraints (mass, volume, power budgets) and technology limitations



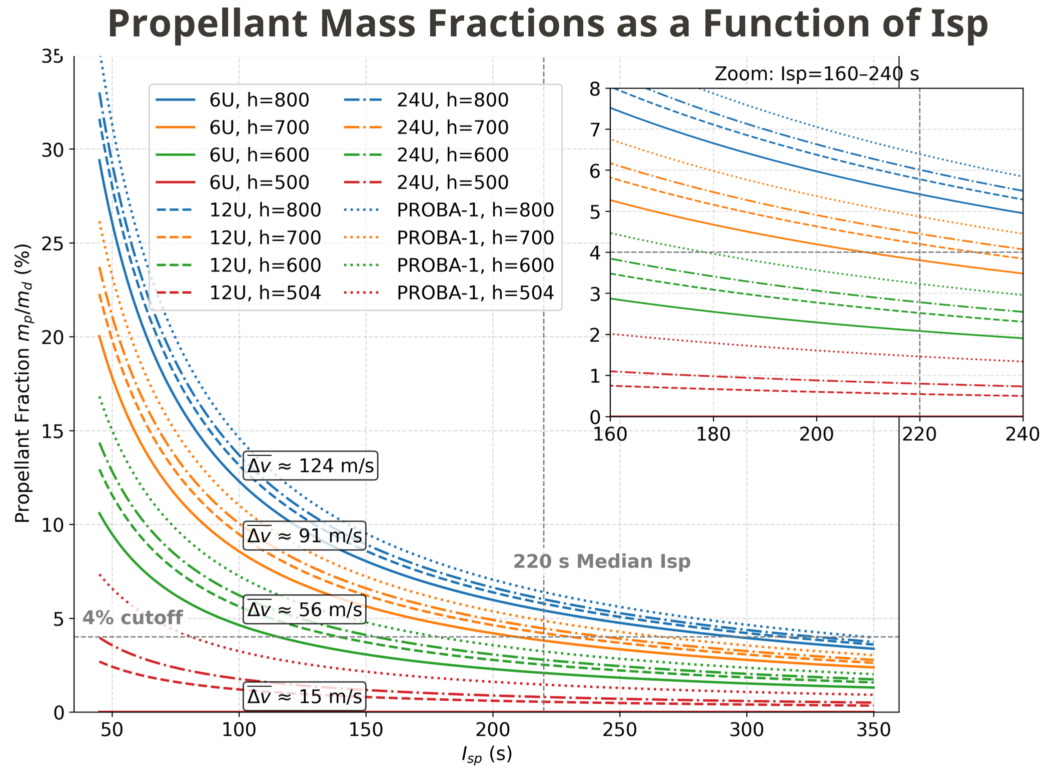


Perigee, apogee and eccentricity evolution for the delayed deorbit disposal of the 12U CubeSat from 600 km at epoch 2030-01-01 using chemical (top) and electric propulsion (bottom). Orbital propagation by ESA DRAMA [2].

Trade-off Analysis of Propulsion Systems for Microsatellite Deorbiting

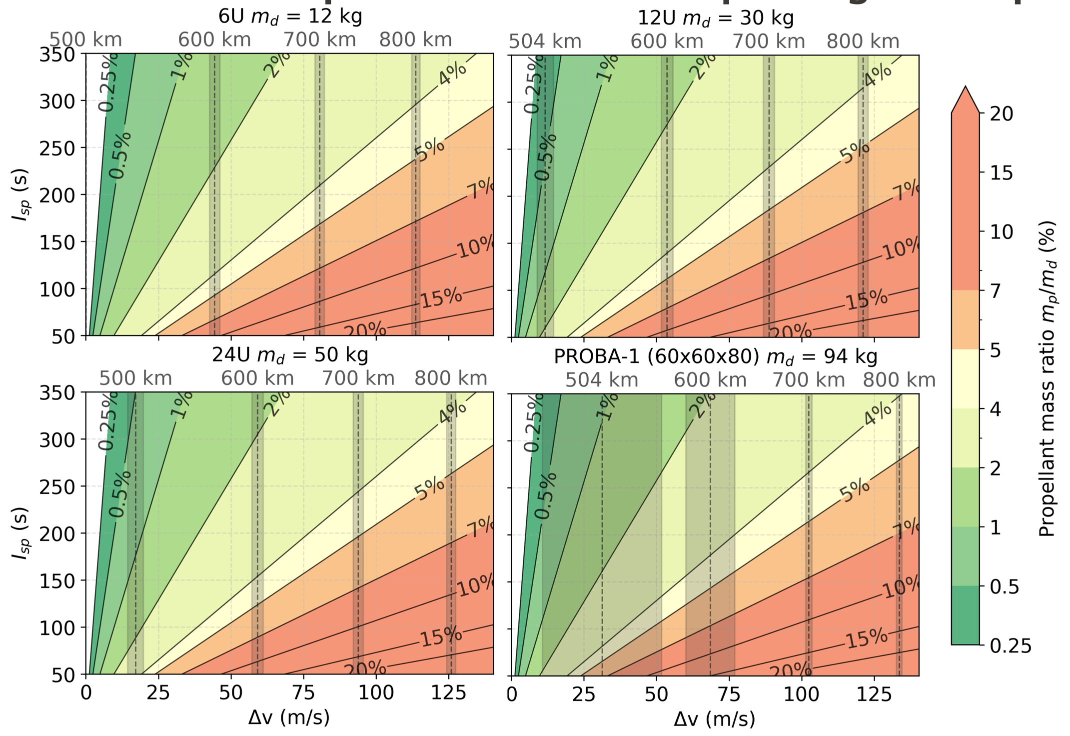
Chemical Propulsion

Propellant Mass Fractions as a Function of Isp



With 4% mass ratio threshold and median 220 s Isp. Colors denote altitude. Line style represents platform. The curves group into distinct families according to Δv.

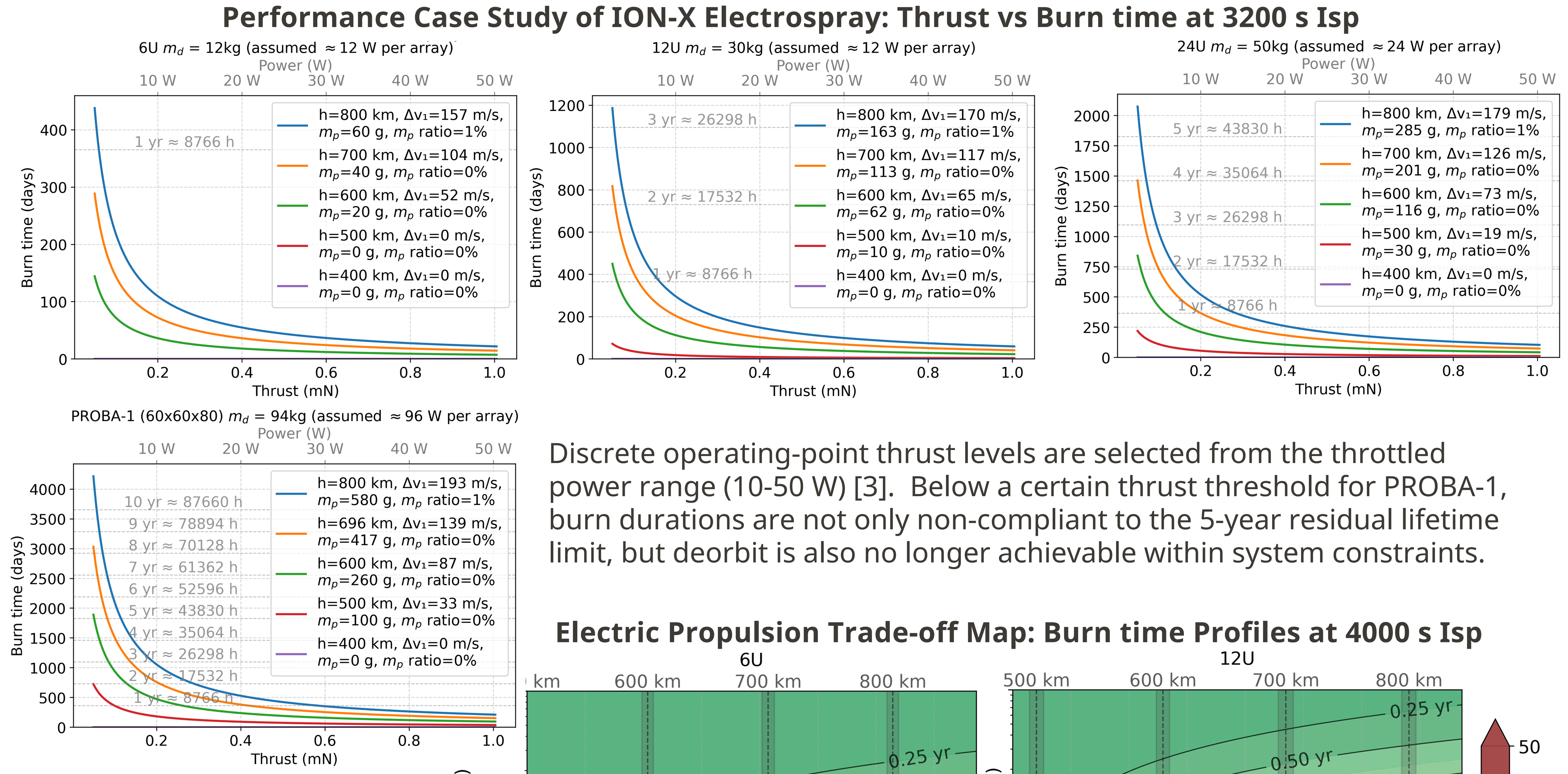
Chemical Propulsion Trade-off Map: Δv against Isp



Coloured contours representing mp ratio. A 4% mp ratio is adopted so that green regions correspond to low m_p requirements, while red indicates high mass fractions.

Electric Propulsion

Performance Case Study of ION-X Electrospray: Thrust vs Burn time at 3200 s Isp

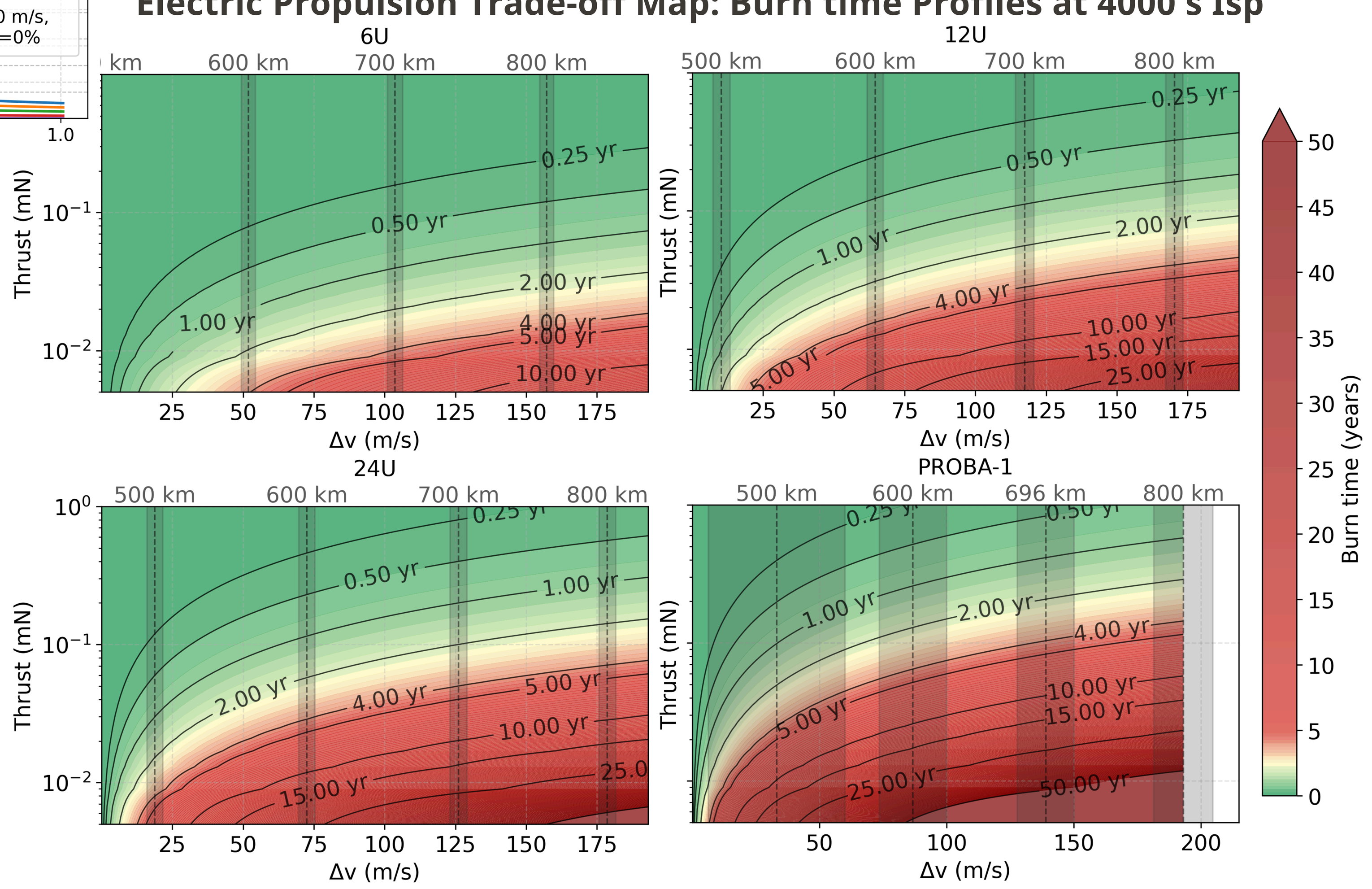


Discrete operating-point thrust levels are selected from the throttled power range (10-50 W) [3]. Below a certain thrust threshold for PROBA-1, burn durations are not only non-compliant to the 5-year residual lifetime limit, but deorbit is also no longer achievable within system constraints.

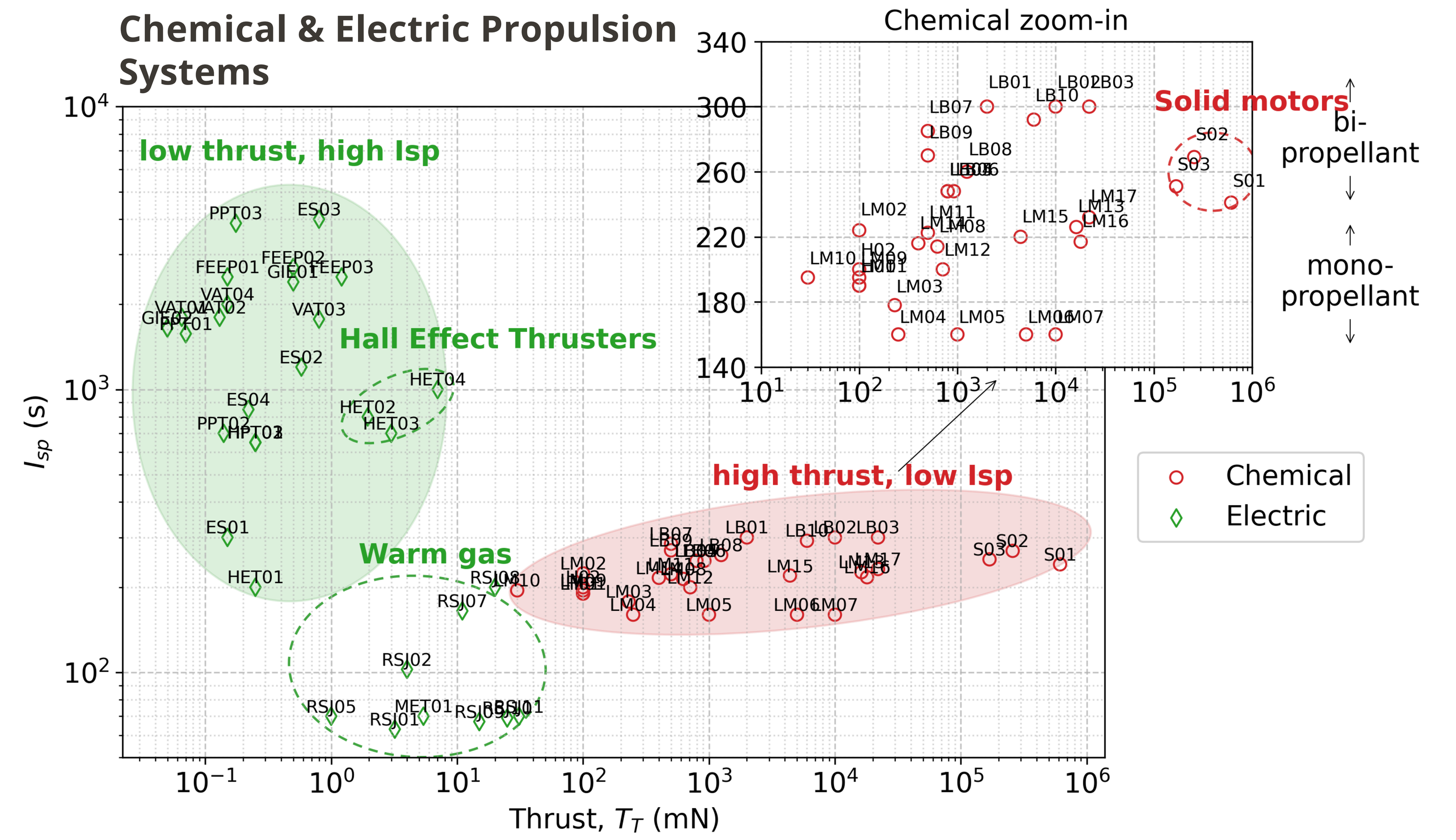
Electric Propulsion Trade-off Map: Burn time Profiles at 4000 s Isp

The 5-year t_b threshold defines a transition between the LEO-clearance compliant residual lifetimes and non-compliant cases. Green: t_b<5y; red: t_b≥5y.

Two time scales: (1) SDM requirements-compliant time frame based on 5-years residual orbital lifetime, and (2) thruster-lifetime-based deorbit, derived from a practical operational lifetime of the thruster.



Market Survey of Propulsion Systems



Isp and Thrust of 32 chemical and 36 electric propulsion systems. The upper bounds of the thrusters and modules are 6 kg in mass, 4U form factor and 100 W.

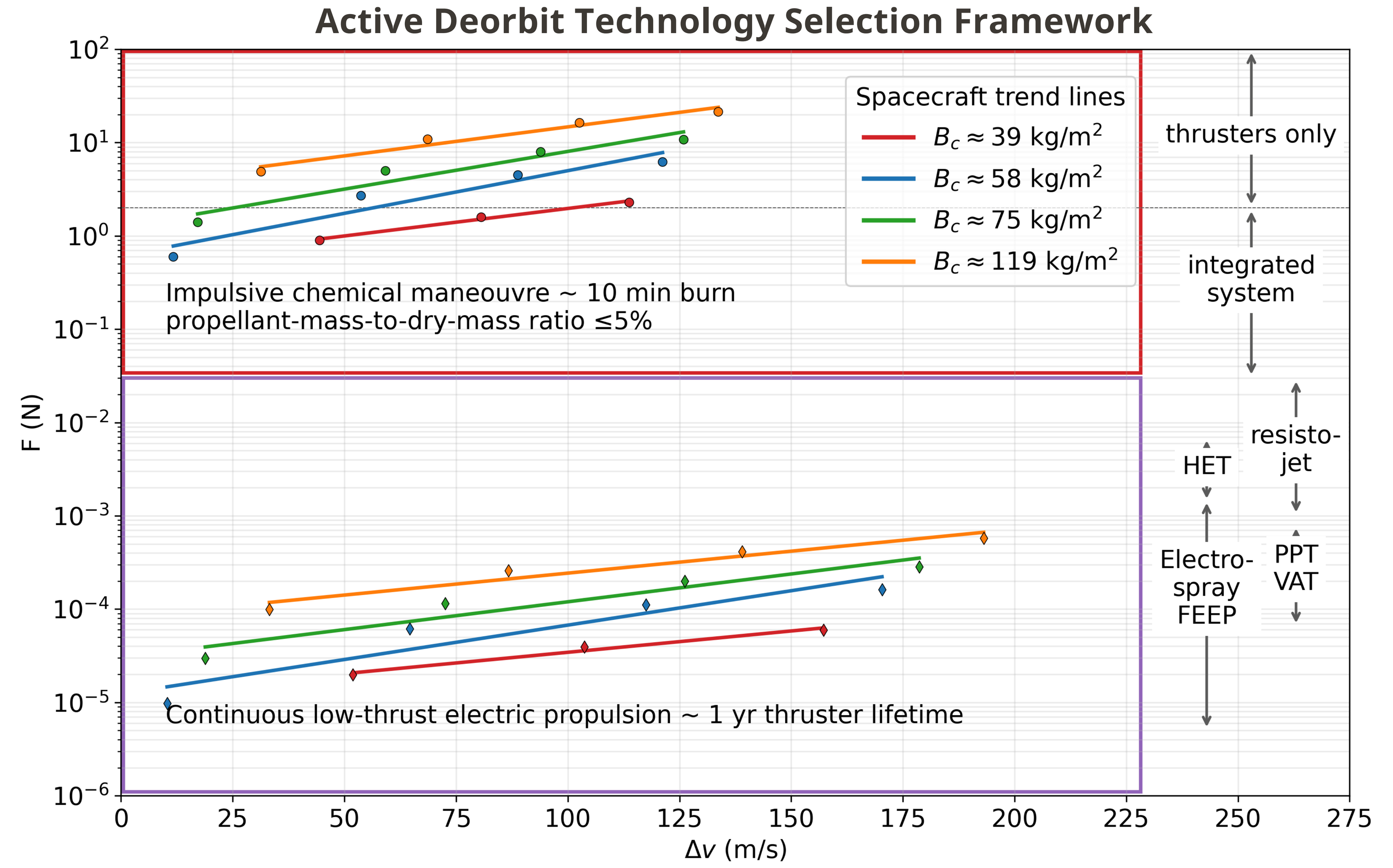
Conclusion

Propulsion-assisted deorbit, as a disposal strategy for microsatellites in LEO:

Impulsive chemical maneouvres are constrained by burn duration, t_b and propellant- mass-to-spacecraft-dry-mass ratio, mp/mf, such that the thrust, F, required to deorbit a spacecraft in LEO is approximated by ***F = (Δv, Bc, Isp = 220 s, t_b~10 min, mp/mf≤ 5%)***

For continuous low-thrust acceleration using electric propulsion, the thrust, F, is approximated by ***F = (Δv, Bc, Isp = 4000 s, t_b~1 yr)***

Active Deorbit Technology Selection Framework



Representative spacecraft trendlines annotated by Bc (C_D=2.2)

References

[1] Space Debris Mitigation Team, ESA's Space Debris Mitigation Requirements, Presentation slides, European Space Agency, Oct. 2024.

[2] ESA OPS-SD, DRAMA Software User Manual, Issue 2.5, GEN-SW-SUM-00342-OPS-SD, Manual, Oct. 2024.

[3] ION-X, Advanced Propulsion System for Smallsats: 1U-50W Ionic Liquid Electrospray, Technical Specification, Unpublished; France, 2021.