Solar System Swarm Probes: *An Earth-based Technology Demonstrator*

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Abstract

As a precursor to future interplanetary probe applications, terrestrial femto-probes (mass < 100 g) could be deployed from host satellites in low Earth orbit to provide in-situ measurements at inaccessible locations, such as onto polar ice sheets or into mid-ocean weather systems, augmenting simultaneous in-orbit remotely sensed data for Earth observation. This would provide a means of de-risking future interplanetary applications, while delivering enhanced terrestrial science returns in the near-term.

This strategy would be a low-cost, high-risk precursor to subsequent interplanetary orbiters hosting femto-probe swarms as secondary payloads. If candidate secondary payloads like this were firstly demonstrated through Earth-based mission applications, this could provide a pathway to utilization in similar or related applications on deep space missions, such as to Europa for surface science, or to Titan for atmospheric science and oceanography.

Mission Scenario

In the scenario considered, ChipSat femto-probes [1] (approx. 3 cm x 3 cm, 10 g, Fig. 1) are contained within CubeSat sized deployers in circular polar orbits of 400 km altitude. Deployers either be standalone or attached onto larger satellites. Equipped with micro-electro-mechanical-sensor (MEMS) suites, PCB-based probes can be rapidly produced at low cost. In a shift away from traditional approaches, a swarm of these tiny sensor nodes could operate with a large degree of redundancy, where individual probes are considered disposable, and only a small fraction need to survive surface impact and extreme entry and descent conditions for mission success.

A CubeSat carrier would be comparable terms of size and mass with previous secondary payloads on previous interplanetary missions, such as the MarCO CubeSats [2]. Carriers would deploy a swarm of up to 100 probes when desired to escape LEO and reenter the atmosphere, de-orbiting to remote terrestrial locations and gathering distributed in-situ measurements. In descent, and upon landing, the femto-probes form an ad-hoc wireless sensor network, relaying sensor data between femto-probes and their deploying CubeSat while in line-of-sight.

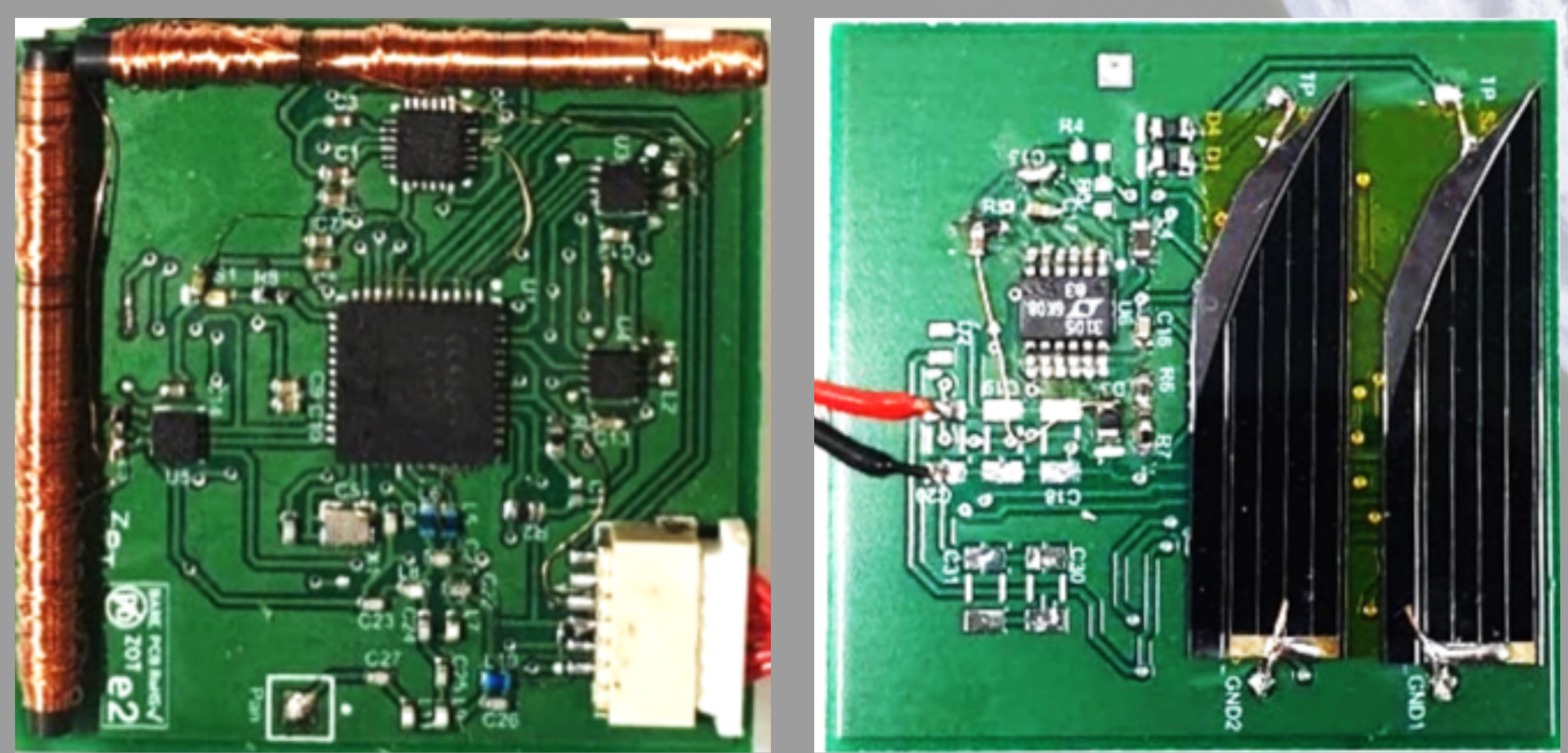

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Figure 1: University of Glasgow Femto-spacecraft

Simulation

We model the potential entry, descent and landing trajectories of a femto-probe swarm deployed from one such satellite carrier in a circular polar orbit of 400 km altitude using a three-degree-of-freedom EDL code [3]. We vary the ejection velocity from the carrier between 200-400 m/s, in all directions below the local horizon of the carrier. This order of magnitude of ejection impulse would be possible via magnetic rail gun ejection methods [4].

To assess the landing capabilities with this ejection velocity range, we perform a sensitivity analysis for a swarm ejected on a polar orbit to find the spread of reachable landing targets. As shown in Fig 2., this covers between 100-140° of latitude and 2.2-6° of longitude for an ejection Δv between 200-400 m/s. This shows relative achievable coordinates, where the relative latitude upon impact is between 45-180° ahead of the deployment latitude. An equivalent dispersion concentrated over different regions can be achieved by delaying the deployment.

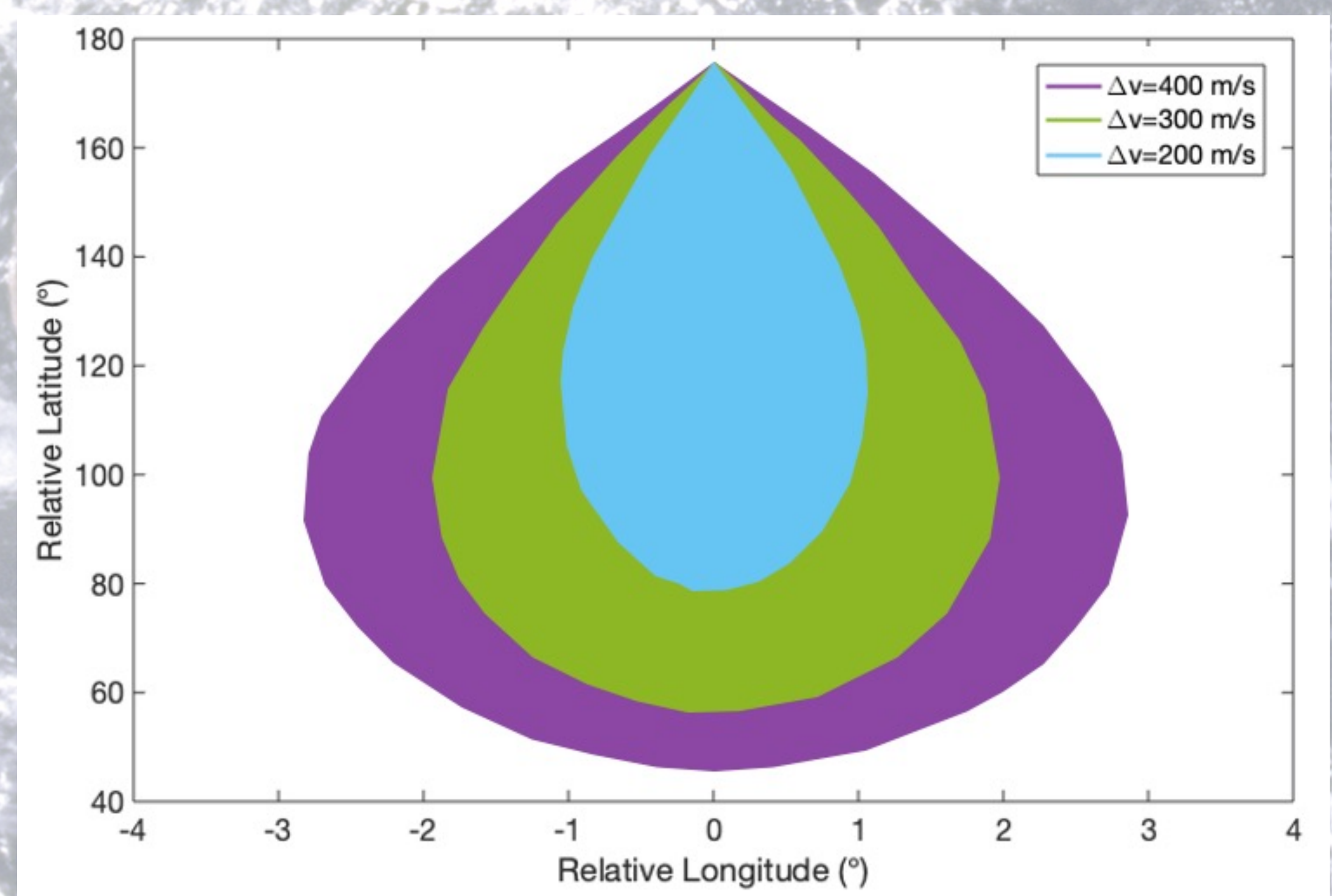

Figure 2: Femto-probe Swarm Landing Capabilities

With an orbital period of 92 minutes at 400 km altitude, continuous global coverage with a Δv=400 m/s is possible with a worst-case response time of 132 minutes (1 orbital period plus maximum EDL time) using 30 carriers positioned equally along 30 orbital planes spaced 6° in longitude apart. For 300 m/s and 200 m/s ejections this increases to 45 and 82 carriers spaced 4° and 2.2° in longitude apart. Maximum EDL time corresponds to the maximum attainable longitude per orbit for each Δv.

Due to the rotation of the Earth (at this altitude approximately 23° per orbit), as few as 4 satellites could enable full coverage of Earth within 12 hours if deployed with a Δv=400 m/s. Equivalently, 6 or 11 carriers spaced 4° or 2.2° apart for a Δv of 300 m/s or 200 m/s could achieve the same.

Figure 3 shows the worst-case response time between deployment and landing as a function of the number of satellite carriers for the swarm in orbit for a polar constellation. This is shown for the three Δv values modelled. Past the line of continuous global coverage for each Δv, multiple satellites sharing one orbital plane can reduce the response time further to (T/n + 40) minutes, where T is the orbital period and n is the number of carriers spaced equally on the same orbital plane.

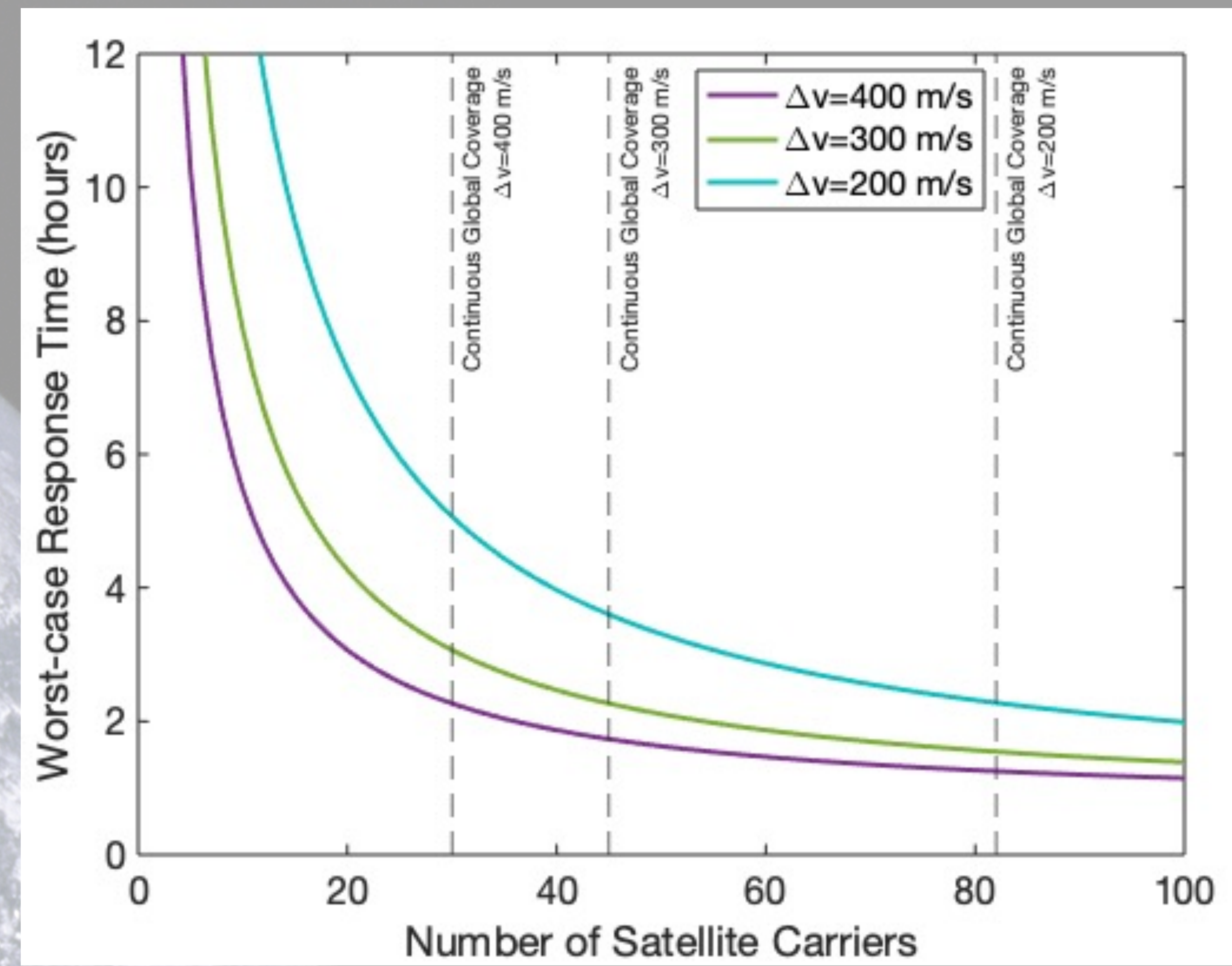

Figure 3: Femto-probe Response Time Vs. No. of Carriers

Conclusions

The analysis of this exciting mission concept demonstrates not only the potential for femto-probe swarms to augment remote orbiter data with in-situ, distributed simultaneous sensor points. Not only could this technology enhance for Earth based applications, but also assist in exploring harsh interplanetary environments in the future.

We have shown that in-situ sensing can be achieved on Earth for global coverage within 12 hours with as few as 4 polar orbiters using a femto-probe swarm based deployment concept, or within 2 hours with up to 30 orbiters, with a concept that could augment existing remote-sensing satellite technologies.

Future work will investigate ejection methodologies and enhanced thermal protection systems for femto-probes deployed at high velocity.

Acknowledgements

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References

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