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LaboratOry for the Behavior of the SloT Region: a small mission doing big radiation science

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This paper outlines the science and basic design choices associated with a mission concept study known as the LaboratOry for the Behavior of the SloT Region (LOBSTR). This mission concept focuses on energetic particles, both electrons and protons, as they impinge upon the slot region in the Van Allen radiation belts around Earth. In particular, it emphasizes the drift dynamics of particles that were not captured by Van Allen Probes. We conceptualize a mission, utilizing state-of-the-art instruments and components, and calculate the mission's orbit, thrust, and radiation requirements using industry-standard methods. The concept uses two SmallSats in a near-equatorial orbit, with precise orbital timing to capture the desired dynamics. The total radiation dose and the details of the orbital dynamics are examined and found to be within the capabilities of current technology.

KEYWORDS

mission concept, radiation belt, drift, radiation, energetic particles

1 Introduction

The Van Allen radiation belts are permanent, although variable, features of Earth's inner magnetosphere. Typically composed of two toroids separated by a low-flux "slot region" (see Figure 1), the radiation belt structure—the energetic particle density, location, and other properties—varies with a variety of inputs, particularly geomagnetic activity. Because of its importance to humanity's assets and presence in near-Earth space, along with the multitude of space weather effects that pass through or are caused by the radiation belts, several missions have been launched to study the region.

The Van Allen Probes (formerly Radiation Belt Storm Probes, or RBSPs) (Fox and Burch, 2014) played a monumental role in our understanding of the radiation belts. RBSPs were operational and collected data on the radiation belts from 2012 to 2019. RBSPs consisted of two identical spacecraft in geotransfer orbits (GTOs), with an orbital period of approximately 9 h. The twin spacecraft (RBSP-A and RBSP-B) followed the same orbital trajectory, traversing the same region but separated in time. This proximity provided spatio-temporal understanding of dynamics, particularly of the outer belt.

Van Allen Probes observations showed that geomagnetic storms, particularly those associated with coronal mass ejections, dramatically increase wave activity, which, in turn, accelerates electrons to relativistic energies. The March 2015 storm produced some of the strongest relativistic electron enhancements during the RBSP era, with an increase in electron fluxes measured from L ~ 2.8 to beyond L ~6.6

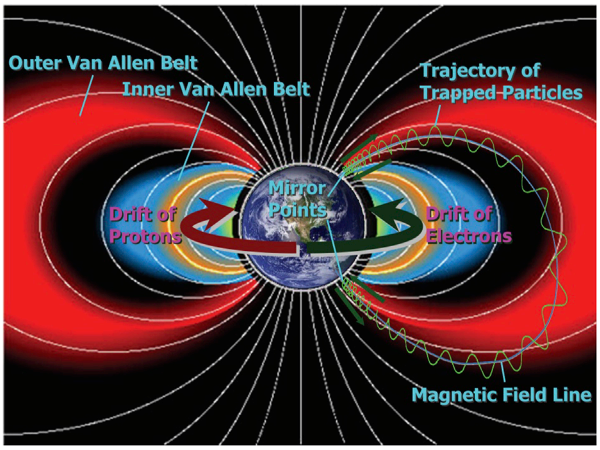

FIGURE 1
Depiction of the radiation belts, showing the drift paths for energetic electrons and protons [modified from Karavaev (2010)].

(Baker et al., 2016; Baker et al., 2019). The interaction between waves and particles is complex and was a focus of the Van Allen Probes science team. For a detailed discussion on important energetic particle results from that mission, see Baker et al. (2021).

One particular area of interest that is closely linked with geomagnetic activity is the slot region. The slot region, nominally between $2 < L < 3$, is a prominent feature of the radiation belts, separating the inner and outer belts. Although often devoid of particles, during a strong geomagnetic storm, the slot region can be filled temporarily, or new belts can form (Reeves et al., 2016; Turner et al., 2017; Pinto et al., 2018). Additionally, there are particle intrusions into the slot region associated with ULF wave activity (Thorne et al., 2007; Sauvaud et al., 2013; Pokhotelov et al., 2016, and others). Plasmaspheric hiss is known to play a key role in the formation of the slot region, with the pitch angle of particles being of particular importance [for a more detailed discussion, please see Lyons and Thorne (1973); Claudepierre et al. (2020)]. The processes involved in the creation of the slot region are fundamentally connected to the decay of a geomagnetic storm. Electrons in the slot region precipitate into the atmosphere via VLF wave-associated pitch-angle scattering. Understanding the evolution of this energetic electron particle population provides a fundamental key to understanding particle dynamics in near-Earth space, which is necessary for space weather forecasting.

Although the Van Allen Probes far exceeded expectations, no mission can be designed to capture all interesting and important science. The majority of papers about radiation belt particle dynamics have focused on either the inner belt or the outer belt; variations in the slot region, for example, have received much less attention. This is due in part to the lack of simultaneous, azimuthally separated observations in the slot region and along its edges. This could be because the orbit mechanics of a GTO, such as those governing RBSPs, dictate a much shorter dwell time through the inner zone and slot region. Thus, the dynamic evolution is more difficult to capture in rapid samplings. Finally, intrusion of particles into the slot region has been associated with solar maximum, and RBSPs made observations primarily during solar minimum, a period characterized by fewer geomagnetic storms.

Several SmallSat missions have been designed and successfully flown to focus on specific unanswered questions, such as the Colorado Student Space Weather Experiment (CSSWE), Colorado Inner Radiation Belt Experiment (CIRBE), and GTOSat. CSSWE (Blum et al., 2013) was a 3U CubeSat, which housed the Relativistic Electron and Proton Telescope integrated little experiment (REPTile) to measure high-energy particles, in particular electrons in the outer radiation belt. CSSWE was followed at CU Boulder/LASP by CIRBE, which carried the REPTile-2 instrument (Li et al., 2024). The CIRBE mission was focused on the dynamics of electrons in the inner belt. However, no SmallSat has yet flown in a geotransfer orbit that would allow for *in situ* probing of the radiation belts. GTOSat (Blum et al., 2020) is a 6U CubeSat pathfinder mission designed to do just that—demonstrating the capability to collect high-quality science data from a CubeSat operating beyond low Earth orbit (LEO). It is built and awaiting a rideshare to GTO. GTOSat's stated objectives are 1) to study energetic particle dynamics in Earth's radiation belts, 2) to provide low-latency monitoring of the near-Earth radiation environment, and 3) to demonstrate the ability and utility of SmallSats beyond low Earth orbit. GTOSat expands upon the earlier successes of CSSWE and CIRBE by measuring the radiation belts in a geotransfer orbit while carrying more instrumentation. These successful missions highlight the role that SmallSats can play in supplying high-quality science data *in lieu* of large-scale, expensive missions.

Radial transport, or radial diffusion, is a persistent and important topic in magnetospheric research on Earth and beyond (Lejosne and Kollmann, 2020). The physics of radial diffusion, which plays a key role in Earth's radiation belts, is also important in other planetary magnetospheres. The science motivating the LaboratOry for the Behavior of the SloT Region (LOBSTR) mission concept is also relevant for planetary science. The goal is to make the LOBSTR concept a CubeSat/SmallSat that is robust enough to survive the harsh environment of the radiation belts, which could also be of interest to other mission concepts.

In consideration of the science outlined above, the LOBSTR mission has been conceptualized and developed. The concept was initially imagined as large CubeSats, but driven by the science objectives, it may best be described as a SmallSat mission. This development would not have been possible without the support of the NASA Wallops Mission Planning Laboratory. The following sections outline the details of the science objectives of the LOBSTR mission, along with the specifics of engineering and design choices that work together to fulfill those science requirements. In this study, we focus on the instrumentation necessary to meet the requirements and the mission design elements that address the particular challenges related to achieving these science goals. In particular, those challenges are the interplay between orbit selection, radiation dose, and mass limitations.

2 Science rationale and science objectives

The LOBSTR mission is designed to answer the following science objectives: 1) What are the dynamics of high-energy electrons at the lower boundary of the outer radiation belt, including the position of the "impenetrable barrier" (Baker et al., 2014), and how do these parameters change under geomagnetic storm conditions? 2) What are the energetic proton dynamics of the outer boundary of the inner belt, what geomagnetic conditions lead to significant trapping or loss of high-energy protons in this region, and how do these parameters change under geomagnetic storm conditions?

Although RBSPs frequently traversed the slot region, there remain open questions regarding the dynamics on both edges of the slot region. The primary reason these questions remain unanswered is the lack of azimuthally separated measurements in space at the same L-shell. The LOBSTR mission, with two satellites azimuthally separated as they simultaneously traverse the slot region, offers a solution to uncovering these answers. Additional measurements, especially during periods of increased activity, will help us better understand the slot region's response to strong geomagnetic storms.

3 Spacecraft and payloads

The proposed science objectives flow down to mission requirements, which are realized in the execution of specific instruments and spacecraft requirements. The following sections outline specific selections for the payload and spacecraft arrangement that enable the science objectives. It is noted that these selections may not be the only selections that cover the required science and that availability may change over time.

3.1 Instrumentation

Instruments were selected based on properties (such as energy range measured) that matched the requirements specified by the science questions. The instruments must be able to measure the electrons and protons near the slot region at energies relevant to the local population, and we must be able to understand the local field conditions. A total of three instruments were selected to meet the requirements. Instruments with flight heritage were selected to enhance the mission concept's reliability and reduce overall risk.

Second, although not required, it is beneficial to have instruments that have heritage from Van Allen Probes. In addition to proven capabilities in the same environment, the measurements can be more easily compared with measurements from Van Allen Probes, allowing for additional long-term temporal insights. Furthermore, by providing LOBSTR data products similar to those of the Van Allen Probes, the broader scientific community will be able to access and use the data more quickly and easily.

3.1.1 Particles

As the measurements of energetic particles are linked to both of the stated science objectives, identifying instruments that can effectively measure the energetic electrons and protons that are associated with both edges of the radiation belt slot region is critical. The spacecraft are designed to spin between 3 and 6 RPM, allowing the capture of a full pitch-angle distribution. A wide range of energies must be covered to understand this region. To encompass the full range of energies relevant to the two proposed science questions (see Section 2), we must be able to measure electrons and protons from 200 keV to 5 MeV and 200 keV to 60 MeV, respectively. This requires the use of two instruments in order to cover the energy range of both electrons and protons with the required energy and time resolution. The instrument selected to address the highest energy range is the Proton eLectron Advanced Sensor for Magnetosphere Ionosphere Coupling (PLASMIC). PLASMIC is a small-form solid-state particle detector that measures electrons and protons from 1 to 5 MeV and 7 to 60 MeV, respectively. PLASMIC was built and designed at the University of Iowa and has a flight history on a sounding rocket, LAMP. LAMP, which stands for the Loss through Auroral Microburst Pulsations, was a rocket launched from Poker Flat, Alaska, United States, in March 2022. LAMP has contributed to our understanding of high-energy precipitation and field-aligned currents that occur along with pulsating aurora (Namekawa et al., 2023; Hosokawa et al., 2024; Nosé et al., 2024). PLASMIC has heritage from instruments such as the Relativistic Electron Proton Telescope [REPT, Baker et al. (2021)], which was an energetic particle instrument on the Van Allen Probes and successfully ran the entire mission on both satellites.

Additionally, to capture the entire energetic particle population, we utilize another particle instrument that can reach down to lower energies. The Relativistic Electron Magnetic Spectrometer (REMS) (Gabrielse et al., 2025), designed and built by The Aerospace Corporation, fits the needs of the LOBSTR concept. REMS was designed, built, and delivered for NASA's GTOSat mission (Blum et al., 2020), which is currently awaiting a rideshare opportunity to geostationary orbit GEO. REMS is a miniaturization of MagEIS-Medium (Blake et al., 2013; Claudepierre et al., 2021), which was a key sensor on NASA's Van Allen Probes mission. In addition to electron detectors, REMS also includes proton detectors based on similar designs used in the micro-dosimeter developed by Aerospace and licensed through Teledyne E2V (Lindstrom et al., 2011), and they were previously used on the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument aboard the Lunar Reconnaissance Orbiter (LRO) (Mazur et al., 2011) and in the Responsive Environmental Assessment Commercially Hosted (REACH) Project (Mann et al., 2017). The front-end electronics for both the electron and proton detectors have heritage. The front-end electronics for the electron detector includes the Multi-Amplifier Pulse Peak Energy Readout (MAPPER) device, which was developed for the MagEIS instruments. The front-end electronics for the proton detector includes the Dual Amplifier Pulse Peak Energy Rundown (DAPPER) ASIC, which was developed for the Fly's Eye Energetic Particle Spectrometer (FEEPS) Sensors onboard the Magnetospheric Multiscale (MMS) Mission. The DAPPER was also used onboard AeroCube-10 with the μ CPT particle detector (Turner et al., 2018; Lee et al., 2020; Lee et al., 2024).

The GTOSat REMS measures 136–1,088 keV across 9 main electron energy channels with a median $\Delta E/E$ of 33.5%. The MAPPER allows for an energy range that spans a decade, e.g., 30–300 keV or 100–1,000 keV. The REMS magnet material is a samarium–cobalt alloy, which is partially magnetized to provide the magnetic field needed to focus a specific electron energy range onto the detectors. The samarium–cobalt alloy saturates at approximately 1900 G, suggesting that, with thicker detectors, REMS could measure from 150 keV up to 1500 keV. Each of the main energy channels is subdivided into 32 histogram channels, which provide fine energy resolution with a median Δ E/E of 4.7% and an average of 10.3%. These histograms

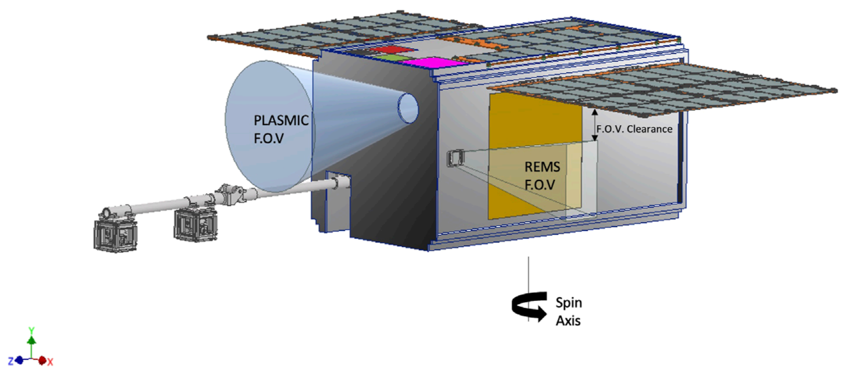

FIGURE 2
Mechanical model of a possible layout of the instrument field of views inside the 16-U structure.

were used to remove background from MagEIS measurements (Claudepierre et al., 2015; Claudepierre et al., 2021).

The Aerospace Corporation funded the addition of the proton detectors on REMS; they were neither originally proposed nor required for GTOSat. As a result, their calibration was secondary to the electron detectors. Aerospace does not have a proton accelerator that covers the energy range required for calibrations, and the team was unable to use a proton accelerator elsewhere. However, Aerospace calibrated the detectors using a calibrated pulser through a precision capacitor into the DAPPER chip. Those calibrations showed that the two proton detectors, each with 12 energy channels, measure ions with energies from 384 to 9,066 keV with energy resolution Δ E/E $\leq$ 20% on average (9.7% median). A spot check was performed using an Am241 source placed at the REMS aperture. Most of the counts landed in the expected channel, providing some assurance in the pulser calibration. For LOBSTR, a more thorough calibration of the proton detectors would be performed (Gabrielse et al., 2025).

3.1.2 Fields and waves

In addition to measuring particles, it is necessary to characterize the local magnetic field. Additional measurements, such as those of relevant wave frequencies, may also enhance the science; however, these were considered of secondary importance and were therefore not prioritized in the concept study.

There are a number of magnetometer options available for CubeSat and SmallSat platforms; some are commercial off-the-shelf (COTS) devices, while others are specifically designed for the high-resolution science we are interested in. One consideration in selecting a magnetometer that fits the needs of this mission was the ability to deal with the lack of magnetic cleanliness. Enforcing magnetic cleanliness on SmallSats and CubeSats can be a difficult and costly endeavor because many COTS parts are not designed with this in mind. The selection of a magnetometer that can act as a gradiometer then becomes important. This is achieved by using multiple (minimum two) magnetometers, positioned at different distances from the spacecraft body. The sensors are separated using a deployable rigid boom.

The magnetometer selected for the concept study of LOBSTR was designed and built at the University of Iowa. The miniature sensor is enabled by recent advances in low-noise custom fluxgate cores (Miles et al., 2019), allowing the manufacture of bespoke 1 cm low-noise fluxgate cores. The feedback windings are tuned with the electronics to provide real-time analog temperature compensation (Miles et al., 2017), enabling a compact sensor that provides high magnetic stability. An earlier version (Miles et al., 2016) of the same sensor was flown on the Ex-Alta 1 CubeSat (Mann et al., 2020), and the current version was demonstrated on the ICI-5 sounding rocket in 2019. This instrument will be paired with the Boom for Lunar Applications Miniaturized Experiment (BLAZE). BLAZE uses non-magnetic materials, primarily titanium and carbon-fiber, and deploys using phosphor-bronze springs. A ramp pin detent system provides positional accuracy and repeatability, controls deployment speed, and locks the boom once it reaches 180° deployment. BLAZE was test-flown in April 2020 during NASA-funded micro-g parabolic flights.

3.2 Payload and mission requirements

One of the mission's key requirements is operation on a spinning platform to capture the full pitch-angle distribution of the relevant particles. The orbit required to make the necessary measurements to achieve the science objectives is near the equatorial region as we aim to capture the full particle population (so within the mirror point of all particles). There is some allowance for inclination (approximately 20°) as the core of the particle distribution can still be measured within a certain amount of magnetic latitude.

The nominal size of the mission is a 16-U spacecraft, which accommodates all three described instruments, along with solar panels and all necessary subsystems as shown in Figure 2. Importantly, this includes a propulsion system, which, in the case of orbit scenario 1, takes up approximately 4U of the total volume. This spacecraft's size allows for a standard amount of radiation shielding. Depending on specific subsystem selection, this size may be too small, particularly if more radiation shielding is necessary. Moreover, this configuration leaves very little mass margin, so a body shape conforming to standard CubeSat or SmallSat form factors could be necessary. The necessary body size and spacecraft mass are considered achievable—factors that could rapidly evolve in the coming years as developments in small spacecraft continue to accelerate.

4 Orbit possibilities and difficulties

One of the biggest challenges of this study is defining the optimal orbit for this mission concept. There are several challenges in defining the orbit; first, to make the required measurements, LOBSTR must pass through the inner radiation belt—and certainly some, if not all, of the outer belt—to capture the full extent of the slot region. Missions of this size and scope have typically utilized rideshares, taking up available mass on a rocket headed to a specific location driven by the primary payload. One of the challenges this mission concept faces is that many launches are currently headed to low Earth orbit, which is not suitable for the proposed science. An ideal scenario for LOBSTR would be a rideshare to a geotransfer orbit or some form of medium Earth orbit (MEO), but opportunities for rideshares to these locations are infrequent. Relying on rideshares to these locations may leave a mission grounded for long periods of time, missing important phases of the solar cycle and increasing the risk of degradation of spacecraft parts.

One of the challenges, regardless of the final orbit configuration, is executing the necessary spacecraft separation. It could be possible to launch on two separate rideshares but, with the small number of rideshare options beyond LEO, this is not considered a favorable option. This is because if one of the launches is delayed, there is no guarantee that the second SmallSat will launch on time afterward, which could drastically increase the overall radiation dose for the first-launched SmallSat.

To fulfill the proposed science objectives, LOBSTR needs to be able to measure populations of energetic electrons as they evolve. Specifically, we need to capture how these populations are evolving as they drift through the system. RBSP was able to measure differences in electron dynamics at the same L-shell from the time the first spacecraft traversed it to the time the second traversed it. During that time period from one spacecraft's traversal to the second spacecraft's traversal, there was some drift of the particles around the magnetosphere; therefore, although RBSP caught the spatial–temporal dynamics of a specific radius, it was not able to measure drift-associated changes. To measure these drift-associated changes in the particles, the orbits must be synchronized. The timing between satellites A and B is determined by the amount of time it would take an electron well within the energy range determined by the science to drift from one spacecraft location to the next. Considering an energy range of 200 keV–5 MeV, this suggests a delay in satellite B's location ranging between 21 and 250 s. This synchronicity of the orbit must be located within the slot region, or approximately 3.5–4.5 Re. To maintain this time synchronization during the science phase, LOBSTR needs to be able to execute burns, with a total maintenance budget of 20 m/s of dV.

One explored orbit focuses on sampling the entire magnetosphere by prioritizing the precession of spacecraft through all magnetic local times. This orbit utilizes a geosynchronous transfer orbit. Since the spacecraft will need to be launched on the same rideshare and then separated, there is a significant commissioning phase prior to the science phase. A 4.5-month commissioning period is required to get a 30° angular separation of the satellites, as shown in Figure 3. This orbit would set the nominal mission length at 1.7 years to precess around the entire magnetosphere. This orbit would require an apogee at 6.5 Re; an apogee point below this significantly lengthens the precession time. Precessing around the entire magnetosphere would allow the team to measure local features of the slot region, which may be related to wave activity or other factors. The downside of this orbit is that, due to the orbital mechanics, there will not be a long dwell time in the slot region, similar to RBSP.

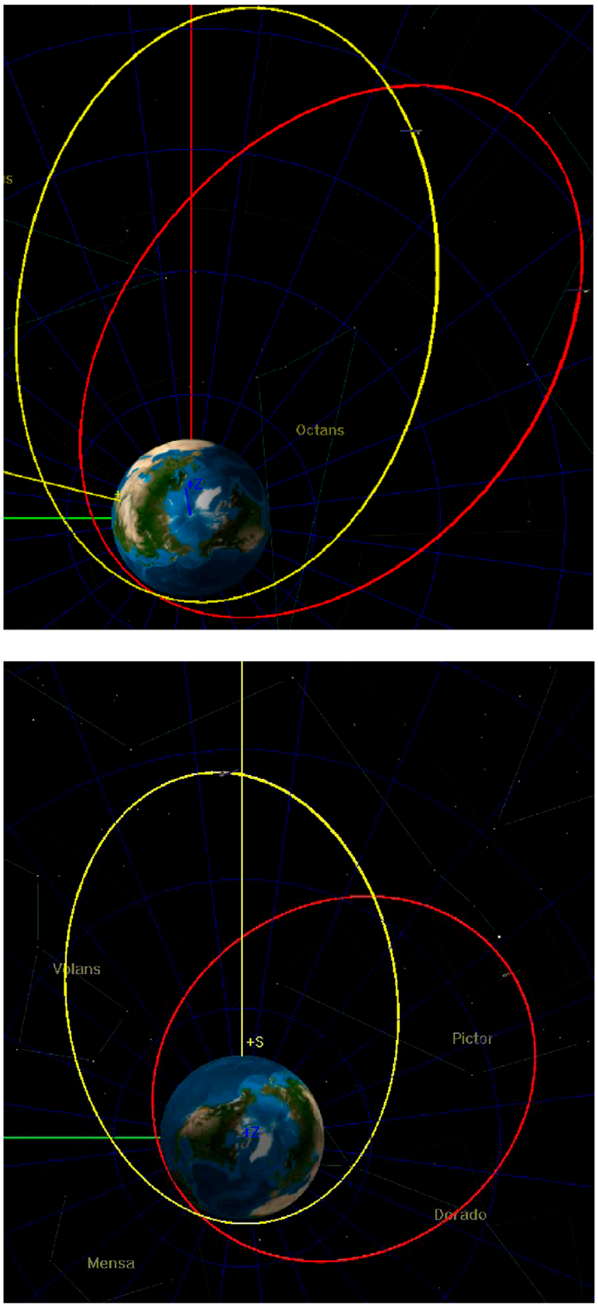

FIGURE 3
Images depicting the initial orbit configuration for the two possibilities described in this study. (Top panel) This orbit is separated by 30°, with an apogee near 6 Re, and maintains this separation for an entire precession. (Bottom panel) This orbit is separated by 30° 4 months after launch and 60°, the maximum separation, at 8 months.

Another possible orbit prioritizes measuring the dayside of the magnetosphere, which will likely feel the most extreme effects of the initiation of a geomagnetic storm as the magnetosphere is compressed. These geomagnetic storms occur most frequently near

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solar maximum, which is the time period we would target. When prioritizing this location, it is not as advantageous to extend the orbit to or beyond 6 Re. A lower apogee, which provides a faster revisit time to the slot region, at approximately 4.5 Re, could then be utilized. This orbit would require a 6–8-month commissioning phase (depending on whether orbit resonance can be used), and since the mission is not constrained by the time it takes to precess around the Earth, its timeline is instead driven by the frequency of geomagnetic storm occurrences; if we consider a launch during solar max, a 6-month science phase would be considered sufficient. There are also radiation considerations, which are discussed further in Section 5.

To achieve either orbit, particularly their longitudinal spacing, and maintain orbit synchronicity, there must be a significant amount of onboard propulsion. The GTO-like orbit needs 255 m/s total dV for commissioning, maintenance, and de-orbit. This is based on the assumption of a 35-kg total spacecraft wet mass (which includes 5 mm of aluminum shielding), 1 N total effective thrust, and 200 s specific impulse. This works off the assumption that the spacecraft can ride share to a GTO orbit. For the second orbit, the dV required is 248 m/s total for commissioning, maintenance, and de-orbit. This is in consideration of the same wet mass, thrust, and impulse. The de-orbit time is within current standards, but the exact time is dependent on which surface of the satellite is experiencing the drag. There are a variety of options to execute an amount of propulsion on a SmallSat or using a CubeSat form factor. The possible propulsion options are rapidly expanding as the market for small spacecraft, particularly those associated with constellations in the private sector, increases.

The first orbit in reality necessitates a ride-share as a rocket large enough to achieve this orbit would be (at least as of this writing) outside the budget associated with this size of mission. The second orbit could be part of a rocket purchase as the lower apogee is possible for small-launch vehicles and could be within the budget. Additionally, a purchase of a rocket has distinct advantages over a ride-share. A ride-share would most likely require the two satellites to create all of their own separation, which is costly on deltaV.

There has been consideration of whether LOBSTR science objectives could be achieved by being a ride-along instrument on a dedicated mission to some sort of geosynchronous or middle Earth transfer orbit. There are a few challenges to this; first is the requirement to measure the full energetic particle population, which drives the need for a spinning and equatorial platform—severely limiting the type of ride-along opportunities capable of fulfilling the science goals. These restrictions do not eliminate this possibility entirely, but modifications to sensor structure would have to be considered. A few of these opportunities are appearing in the commercial space sector. It is worth consideration, for any mission concept, whether it could fit within the parameters of one of these ride-along options.

5 Radiation analysis

Any mission concept focusing on the radiation belts would not be complete without a discussion on the total ionizing dose (TID) it will be exposed to. One of the remaining variables is final orbit, as discussed in the previous section. This suggests that a range of TIDs must be planned for, potentially with additional shielding being added. Below, we examine the two previously described orbit options for total TID and necessary shielding.

The GTO orbit presents a challenge in terms of radiation; for a 1.7-year mission, which would include the commissioning and science phases, the mission would expect approximately 171.9 krad (Si). From the total dose, 23.9 krad comes from the commissioning phase, while the spacecraft are achieving necessary separation. This is the dose under 5.08 mm of aluminum, which has a 95 percent probability of not being exceeded. The trapped electrons are the primary source of this radiation, with 114 rads coming from trapped electrons. The TID for this orbit is high, which is a concern for the success of the mission. This risk could be lowered by increasing the overall shielding, which would increase the mass. COTS parts with a high radiation tolerance are often available, but unless they are available for all parts, the risk remains concerning. COTS parts with increasing radiation tolerance are becoming more readily available over time, although often at an increased price point.

Another strategy is to put the most radiation-sensitive parts in the center of the SmallSat, using strategic placement of parts to act as additional shielding for those with lower tolerance. Analyzing a simple box, using an aluminum cube with 5 mm walls but that is otherwise empty, shows a TID of 64.6 krad (Si); therefore, with the additional shielding of more parts, this could be a viable strategy. Despite the potential mitigation strategies, this is considered a large risk and, so, the choice of an orbit with less radiation might be advantageous.

The secondary orbit has a higher TID, between 32.1 and 42.3 krad during commissioning, and then 38.3 krad during the science phase (total 80 krad). Although this TID is lower on the surface than the previously described configuration, this is because this orbit has a science phase of 6 months compared to well over a year. This mission has the highest radiation accumulation daily because, although this orbit avoids the bulk of the outer radiation belt, the orbital dynamics dictate a higher dwell time in the heart of the radiation belt.

5.1 Orbit maintenance

To maintain the timing of the spacecraft, in particular, the delay of one spacecraft reaching the region of interest based on the drift period of the electrons, orbit maintenance must be performed. This requires a spin-down of the satellite that will perform the correction burn, followed by a subsequent spin-up. Analysis shows that these orbit corrections must occur fairly frequently to maintain the time range described. Figure 4 (top) shows the 14-day maintenance cadence to maintain an apogee time difference goal of 21–250 s. As shown in Figure 4 (top), using this time cadence shows approximately three excursions outside that time window within the first 350 days of the mission. Similar calculations can be carried out for a 7-day orbit maintenance cadence, which keeps the orbit window within the specified time separation and has smaller departures from a single-valued apogee time difference. One difference to highlight between the 7-day and 14-day cadences is that it requires an average monthly dV cost of 0.1321 m/s compared to 0.1187 m/s, respectively. Additional analysis was performed to observe whether the total needed deltaV could be further reduced by only doing orbit maintenance when needed, instead of on a regular interval, as shown in Figure 4 (bottom). A variable maintenance cadence results in a minimum time between burns of 10.8 days, with a maximum of 53.5 days and a mean of 25.7 days, and has an average monthly dV cost of 0.1591 m/s. Either a variable maintenance cadence or a 14-day scheduled maintenance

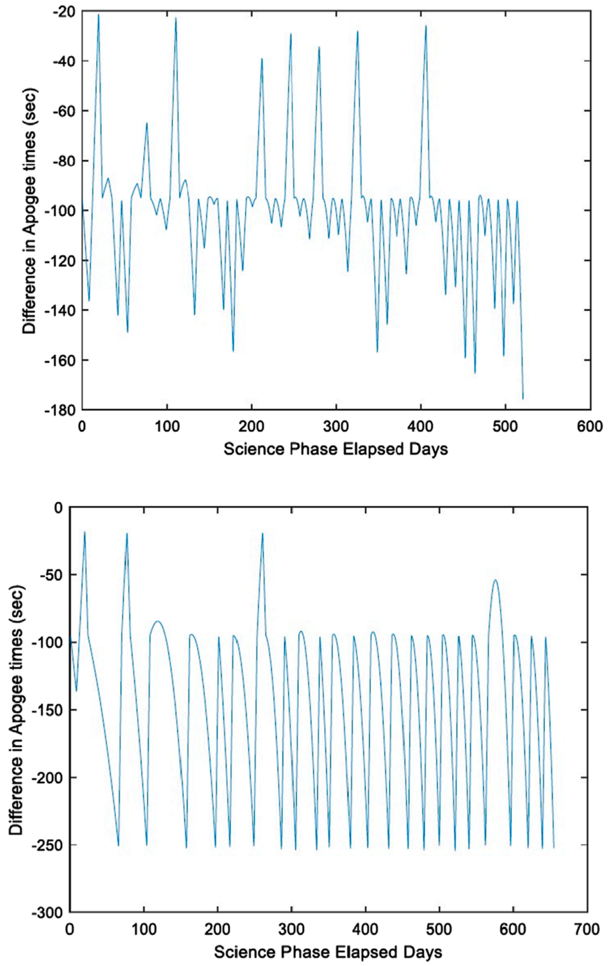

FIGURE 4
Difference in apogee in seconds for the two spacecraft. (Top panel) A 7-day maintenance cadence, which results in a time difference between 21 and 250 s, with a monthly dV cost of 0.1321 m/s. (Bottom panel) A variable maintenance cadence, which results in a monthly dV cost of 0.1591 m/s.

is considered feasible, with more frequent maintenance considered an additional risk with the spin-up–spin-down maneuver. Additionally, it appears that, at a 14-day cadence, we are minimizing our dV, which is a priority. Although it is difficult to keep the spacecraft lag stable, this is viewed as a positive as the instruments will capture the dynamics of the electrons of most interest across the slot region throughout the mission.

6 Summary and conclusion

The mission concept known as LOBSTR works to understand the dynamics of particles at the edge of the region known as the slot region. The scientific objectives of the LOBSTR mission address the remaining gaps left by the Van Allen Probes mission. By prioritizing a launch during solar maximum and offering multiple possible orbit options, LOBSTR allows flexibility in accomplishing its goals, despite a modest projected budget. By using instruments with flight heritage and those similar to RBSPs, the mission reduces risk while ensuring data comparability with the RBSP dataset. The use of radiation-tolerant spacecraft components as shielding minimizes the additional mass required. Although the orbital requirements introduce many challenging factors, particularly for a SmallSat mission, the mission concept is feasible with current technology.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

RF: Writing – review and editing, Funding acquisition, Investigation, Supervision, Validation, Writing – original draft, Visualization, Data curation, Project administration, Conceptualization, Resources, Formal Analysis, Methodology. DM: Visualization, Funding acquisition, Resources, Investigation, Writing – original draft, Conceptualization. AJ: Resources, Funding acquisition, Conceptualization, Writing – review and editing, Formal Analysis, Methodology. CG: Writing – review and editing, Formal Analysis, Writing – original draft, Methodology, Investigation.

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Conflict of interest

Author CG was employed by Aerospace Corporation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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