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Editorial: Active Experiments in Space: Past, Present, and Future

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Editorial on the Research Topic

Active Experiments in Space: Past, Present, and Future

Between 1958 and 1962 the United States and the Soviet Union performed several nuclear detonation tests in the atmosphere, including the Starfish Prime event which involved a 1.4 Mt explosion at 400 km altitude over Johnston island on July 9, 1962 (Gombosi et al., 2017). These tests can be considered as the beginning of active experiments in space (i.e., experiments that deliberately perturb the local environment). They demonstrated the potential destructive power of high-altitude nuclear explosions, both in terms of the resulting electromagnetic pulse as well as for the creation of a potentially long-lasting artificial radiation belt from the radioactive fission debris. For instance, one of the unintended consequences of Starfish Prime was to cripple at least seven spacecraft in low-Earth orbit (LEO), about a third of the LEO spacecraft of the time (Gombosi et al., 2017).

At about the same time, the fundamental discovery of the Earth's radiation belts by Van Allen and his team (Van Allen and Frank, 1959 and references therein) indicated how harsh the space environment could be for spacecraft and astronauts as well as how little we knew about it. Following the impetus of the Space Age, active space experiments flourished with the goals of (1) probing basic plasma physics phenomena, (2) elucidating aspects of magnetospheric and ionospheric physics, and (3) understanding how to control the effects of the environment on space assets. Bombs, beams, heaters, releases, chemical dumps, plasma plumes, tethers, antennas, voltages are examples of active experiments spanning several decades of research.

Six decades later the US active space experiment program has changed dramatically. The number of space-based experiments has seen a steep decline, supplanted by ground-based experiments that study the heating and modification of the ionosphere induced by powerful transmitters, such as the facilities of the High-Frequency Active Auroral Research Program (HAARP) and at Arecibo. This decline can be attributed to several reasons, summarized by the fact that the "low-hanging fruits" had already been collected and much more is known today about the space environment, that space flight became more bureaucratic and more risk-adverse, and budgetary pressures (Delzanno and Borovsky, 2018).

Yet, there are many reasons to be optimistic about the future of active experiments in space. There are new scientific and national-security drivers that demand new active space experiments. One example involves magnetosphere-ionosphere coupling, where a high-power electron beam could be used for magnetic field line mapping and connect phenomena occurring in the distant magnetosphere with their image in the ionosphere (National Research Council, 2012). Another example concerns radiation belt remediation, where the fluxes of an artificial radiation belt created by a high-altitude nuclear explosion could be substantially reduced by space-based injection of electromagnetic plasma waves with the objective of protecting critical space assets. Furthermore, there are new maturing technologies (metamaterials, compact relativistic

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accelerators, antennas constructed of superparamagnetic nanoparticles, cube-satellites, . . .), ever better diagnostics and data-gathering capabilities, and new computational tools that can support the design and interpretation of active experiments like never before. Indeed, this optimism was conveyed by the 65 participants of the Workshop "Active Experiments in Space: Past, Present and Future" who gathered in Santa Fe, New Mexico, in September 2017 (see the link http://www.cvent.com/events/active-experiments-in-space-past-present-and-future/event-summary-73675ac6ba5745d48d181933c4783454.aspx?dvce=1 for a list of talks presented at the workshop) and is echoed in this Frontiers special issue with the same name.

This special issue was designed to connect the past, the present, and the future of active experiments in space and serve as a reference for the community. It involves several review articles of past active experiments discussing chemical releases (Haerendel) and diamagnetic cavities (Winske et al.), artificial aurora experiments (Mishin), the APEX electron-beam experiments (Prech et al.), and an overview of active experiments involving the Los Alamos National Laboratory (Pongratz). A review of more recent active experiments focusing on electromagnetic wave injection and wave-particle interaction physics is given by Gołkowski et al.. A review on the potential use of electron beams to solve outstanding problems in space physics is presented by Sanchez et al., while a review on the future of active experiments is presented by Borovsky and Delzanno. The special issue also contains several "Original Research" articles. A major focus is on the research associated with the use of high-power electron beams for space applications. These articles include a discussion of the development of new, compact, relativistic electron accelerators (Lewellen et al.), a tether-based spacecraft charging mitigation scheme (Marchand and Delzanno), the evolution of a relativistic electron beam for magnetic-field line mapping in near-Earth space (Powis et al.) and how magnetic-field-line curvature affects the ionospheric accessibility of the electron beam (Willard et al.), a method for measuring the local magnetic-field-line curvature in the inner magnetosphere with a variable-energy electron beam (Willard et al.), and the atmospheric signatures created by relativistic electron beams (Marshall et al.). New ionospheric experiments involving very-long-distance propagation of high-frequency waves are discussed by Yampolski et al. A simulation study of the effect of plasma releases on the equatorial spread F is presented by Zawdie et al., while the use of plasma releases to enhance energetic neutral atom imaging is discussed by Scime and Keesee. Active experiments for planetary missions are discussed by Gilet et al. for active probes and by Voshchepynets et al. for sounding radar operations.

In the words of Nobel laureate Hannes Alfvén (Alfvén, 1970): "The center of gravity of the physical sciences is always moving. Every new discovery displaces the interest and the emphasis. Equally important is that new technological developments open new fields for scientific investigation. To a considerable extent the way science takes depends on the construction of new instruments as is evident from the history of science." This is certainly true for active experiments and an exciting new season of active experiments in space awaits. Ad maiora!

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All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The 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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