SSAPy - Space Situational Awareness for Python

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Software

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Summary

SSAPy is a fast and flexible orbit modeling and analysis tool for orbits spanning from low-Earth into the cislunar regime. Orbits can be flexibly specified from common input formats such as Keplerian elements or two-line element (TLE) data files. SSAPy allows users to model satellites and specify parameters such as satellite area, mass, and drag coefficients. SSAPy includes a customizable force-propagation with a range of Earth, Lunar, radiation, atmospheric, and maneuvering models. SSAPy makes use of various community integration methods and can calculate time-evolved orbital quantities, including satellite magnitudes and state vectors. Users can specify various space- and ground-based observation models with support for multiple coordinate and reference frames. SSAPy also supports orbit analysis and propagation methods such as multiple hypothesis tracking and has built-in uncertainty quantification. The majority of SSAPy's methods are vectorized and parallelizable, allowing for effective use of high-performance computer (HPC) systems. Finally, SSAPy has plotting functionality, allowing users to visualize orbits and trajectories. Examples are shown in Figure 1 and Figure 2.

SSAPy has been used for the classification of cislunar (Higgins et al., 2024) and closely-spaced (Pruett et al., 2024) orbits as well as for studying the long-term stability of orbits in cislunar space (Yeager et al., 2023). SSAPy has also been used to build a case study for rare events analysis in the context of satellites passing close to each other in space (Bernstein et al., 2021; Miller et al., 2022).

Statement of need

Cislunar space is a region between Earth out to beyond the Moon's orbit that includes the Lagrange points. This region of space is of growing importance to scientific and other space exploration endeavors (e.g., Duggan et al., 2019). Understanding, mapping, and modeling orbits through cislunar space is critical to all of these endeavors. The challenge for cislunar orbits is that N-body dynamics (e.g., gravitational forces from the Sun, Earth, Moon and other planets) are significant, leading to unpredictable and chaotic orbital motion. In this chaotic regime, orbits cannot be reduced to simple parametric descriptions making scalable orbit simulation and modeling a critical analysis tool (Yeager et al., 2023). Current orbit modeling software tools are predominantly used via graphical user interfaces (e.g., The Systems Tool Kit or the General Mission Analysis Tool, Hughes et al., 2014) and are not optimized for large-scale simulation on HPC systems. Orbital modeling codes that can be run on HPC systems (e.g., REBOUND, Rein & Liu, 2012) lack full observable generation and modeling capabilities with uncertainty quantification. Existing space dynamics libraries such as Orekit (Maisonobe et al., 2024) and Tudat (Dirkx et al., 2022) share many features with SSAPy. However, one point of difference is that they rely on spherical harmonics or model the Moon as a point mass, whereas SSAPy incorporates more comprehensive physical modeling relevant to cislunar dynamics such as Earth (EGM2008, Pavlis et al., 2012) and Lunar (GRGM1200A, Lemoine et al., 2013) surface gravity models. Additionally, SSAPy has utilities for determining—from any location on Earth—on-sky brightness, proper motion, right ascension and declination, and provides conversions between on-sky coordinates, TLEs, the Geocentric Celestial Reference Frame and other commonly used coordinates. There are also built-in observation-linking tools and orbit refinement. SSAPy, with its full-featured modeling framework and scalable, parallelizable functionality, fills the gap in the orbital software landscape.

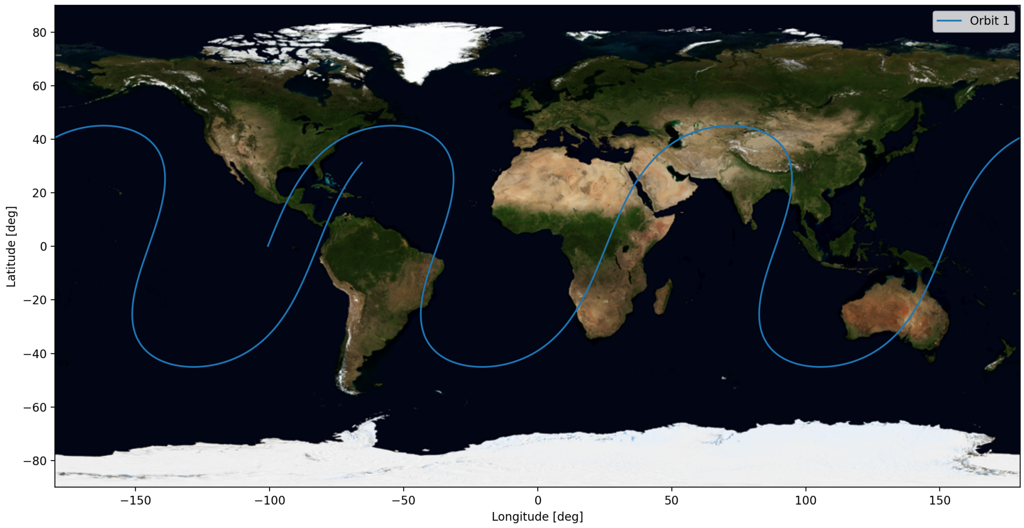

Figure 1: Example SSAPy visualization plot of an orbit ground track over the surface of the Earth. The 12–13 hour orbit has a semi-major axis of 27,000 km, an eccentricity of 0.2 and an inclination of 45 degrees.

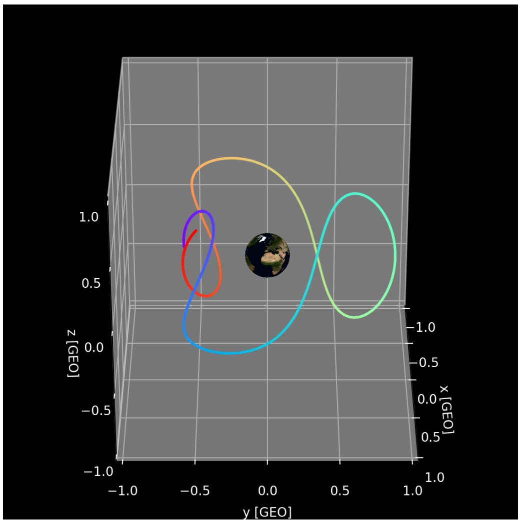

Figure 2: Example SSAPy visualization plot of a cislunar orbit. The color on this plot represents time.

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SSAPy depends on NumPy (Harris et al., 2020), SciPy (Virtanen et al., 2020), Matplotlib (Hunter, 2007), emcee (Foreman-Mackey et al., 2013), Astropy (Astropy Collaboration et al., 2022), PyERFA (Kerkwijk et al., 2023), lmfit (Newville et al., 2024), and SGP4 (Vallado et al., 2006). We would like to thank Robert Armstrong and Iméne Goumiri for valuable contributions to this project. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory (LLNL) under Contract DE-AC52-07NA27344. The document number is LLNL-JRNL-871602 and the code number is LLNL-CODE-862420. SSAPy was developed with support from LLNL's Laboratory Directed Research and Development Program under projects 19-SI-004 and 22-ERD-054.

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