

¹ SolarWindPy: A Heliophysics Data Analysis Tool Set

² B. L. Altermann 

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³ Summary

⁴ The region of space within the Sun's envelope of influence is called the heliosphere. The field
⁵ of heliophysics starts in the solar interior and extends out to the very local interstellar medium,
⁶ just beyond the heliosphere. The solar wind is a stream of charged particles that continuously
⁷ flows away from the Sun, carrying mass, energy, and momentum along with an embedded
⁸ magnetic field. In short, it mediates the interaction of the Sun with the heliosphere and this is
⁹ a feature shared by stars and their astrospheres more broadly. Changes in the solar wind are
¹⁰ one source of space weather, which is a critical threat to our technological infrastructure on
¹¹ Earth and in space. SolarWindPy provides a unified framework for analyzing the solar wind
¹² and related space weather data, filling the gap between packages targeting astronomy, remote
¹³ observations of the Sun, and general timeseries analysis of spacecraft based data. The package
¹⁴ is available via PyPI¹ and conda-forge² and can be installed using pip install solarwindpy
¹⁵ or conda install -c conda-forge solarwindpy.
¹⁶

Statement of Need

¹⁷ There is a growing ecosystem of python libraries to enable astrophysics, solar physics, plasma
¹⁸ physics, and space physics. The table below cites key examples. Notably, there are several
¹⁹ packages that support different elements of space physics, including magnetospheric data
²⁰ analysis (Pysat), integration of magnetospheric observations (SpacePy), and the retrieval
²¹ and analysis of heliophysics timeseries data (pySpedas and PyTplot). Tools for the dedicated
²² analysis of solar wind observations are noticeably absent. SolarWindPy fills this gap by
²³ providing a unified framework for analyzing solar wind observations in combination with
²⁴ relevant information about the spacecraft from which the observations were made.

| Library | Purpose | Citation |
|----------|--|---|
| AstroPy | Astronomical observations. | Astropy Collaboration et al. (2022) |
| SunPy | Remote sensing observations of the Sun. | Barnes et al. (2020) (PlasmaPy Community , 2025) |
| PlasmaPy | Theoretical plasma physics. | (PlasmaPy Community , 2025) |
| SpacePy | Timeseries analysis and magnetospheric modeling. | Morley et al. (n.d.) |
| Pysat | Magnetospheric mission data analysis. | Stoneback et al. (2023) |

¹<https://pypi.org/project/solarwindpy/>

²<https://anaconda.org/conda-forge/solarwindpy>

| Library | Purpose | Citation |
|----------|--|--------------------------------|
| pySpedas | Retrieval and plotting of heliophysics timeseries. | (Grimes et al., 2022) |
| PyTplot | Timeseries and spectrograph data visualization. | (Harter & MAVENSDC Team, 2019) |

25 The SolarWindPy framework utilizes a pythonic, class-based architecture that combines ion
 26 and magnetic field objects into a single, unified plasma. It is designed for both experienced
 27 researchers and to provide an intuitive scaffold for students learning to analyze spacecraft
 28 data. SolarWindPy's primary functionality (core, fitfunctions, plotting, instabilities, and
 29 solar_activity submodules) was written by the author and developed or utilized in support
 30 of multiple publications B. L. Alterman, Rivera, Lepri, & Raines (2025). The transformation
 31 from thesis research code to a production package deployable via PyPI and conda-forge was
 32 accomplished using AI-assisted development with specialized quality assurance infrastructure
 33 for the supporting infrastructure (test suites, documentation, and deployment workflows), while
 34 the core scientific functionality remains human-authored.

35 The package builds on well-established libraries including NumPy van der Walt et al. (2011),
 36 SciPy (Virtanen et al., 2020), Matplotlib (Hunter, 2007), and Pandas Mckinney (2013) to
 37 ensure that the dependencies are stable. The plotting functionality retains the mapping
 38 between timeseries and aggregated observations to enable researchers to easily extract subsets
 39 of their observations for detailed analysis. The plot labeling functionality maps the quantities
 40 plotted to their file names, improving the mapping from the user's analysis to the saved
 41 output. The non-linear fitting libraries (utilizing scipy optimize) are designed for multi-step
 42 fitting in which the user performs nested regression of one variable on parameters derived
 43 from fitting other quantities. Submodules for the analysis of magnetohydrodynamic turbulence
 44 parameters and kinetic instabilities are also provided. The solar_activity submodule provides
 45 the user with seamless access to solar activity indicators provided by the LASP Interactive
 46 Solar IRradiance Datacenter (LISIRD) (Leise et al., 2019) and the Solar Information Data
 47 Center (SIDC) at the Royal Observatory of Belgium (?). This tool enables easy comparison
 48 of solar wind parameters across different phases of the solar cycle and different solar cycles,
 49 which is an essential component of solar wind data analysis. SolarWindPy currently stores data
 50 in pandas DataFrames and Timeseries objects. However, there is a clear separation between
 51 the two libraries such that future development could transition to using more nuanced and
 52 scientifically-targeted data structures, for example those provided by xarray (Hoyer & Hamman,
 53 2017), SunPy, or AstroPy.

54 AI-Assisted Development Workflow

55 SolarWindPy's evolution from thesis research code (B. L. Alterman et al., 2018; Benjamin L.
 56 Alterman, 2019; B. L. Alterman & Kasper, 2019) to a production software package required
 57 comprehensive testing, documentation, and deployment infrastructure. To be explicit about
 58 the scope of AI assistance: the core scientific modules (core/, fitfunctions/, plotting/,
 59 instabilities/, solar_activity/) containing the physics algorithms and analysis methods
 60 were developed by the author without AI assistance and represent the scholarly contribution of
 61 this work, validated through eight peer-reviewed publications B. L. Alterman, Rivera, Lepri,
 62 & Raines (2025). AI-assisted development was used exclusively for supporting infrastructure:
 63 test suites, continuous integration pipelines, package deployment workflows, and completion of
 64 docstring documentation.

65 This was accomplished using Claude Code (Anthropic, 2024) with custom AI development
 66 infrastructure designed for scientific computing quality assurance.

67 The implementation includes specialized domain-specific agents and automated validation
68 workflows using pre-commit hooks for physics validation, test execution, and coverage monitoring.
69 This systematic approach enabled rapid development of test suites for modules outside
70 the original core implementation, completion of documentation including missing docstrings,
71 and creation of continuous integration and deployment pipelines for PyPI, conda-forge, and
72 ReadTheDocs. The current agent system contains 7 specialized agents with an extensible
73 architecture designed for integration with Claude Code's skills system. The infrastructure
74 incorporates git commit integration, GitHub Issues planning workflows, and comprehensive
75 audit trails to ensure traceability of all AI-generated modifications, establishing an infrastructure
76 for trustworthy AI-assisted scientific software.

77 The project targets 95% test coverage, with core physics and plasma functionality currently
78 achieving comprehensive coverage (95%), while tests for advanced features such as fitfunctions
79 and plotting capabilities remain in active development, bringing overall coverage to 78%. All
80 code generated or modified by AI in the supporting infrastructure (representing the test suites,
81 CI/CD pipelines, and packaging tooling) undergoes expert review to ensure correctness, while
82 the scientific algorithms themselves remain entirely human-authored as evidenced by their
83 multi-year publication history. The complete AI-assisted development infrastructure, including
84 agent specifications, validation hooks, and workflow automation, is publicly available in the
85 .claude/ directory of the repository.

86 References

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97 2017)

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