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SunPy: A Python package for Solar Physics

Stuart J. Mumford*[1, 2, 3], Nabil Freij[4], Steven Christe[5], Jack Ireland[5], Florian Mayer[6], V. Keith Hughitt[7], Albert Y. Shih[5], Daniel F. Ryan[8, 5], Simon Liedtke[6], David Pérez-Suárez[9], Pritish Chakraborty[10], Vishnunarayan K I.[6], Andrew Inglis[11], Punyaslok Pattnaik[12], Brigitta Sipőcz[13], Rishabh Sharma[6], Andrew Leonard[3], David Stansby[14], Russell Hewett[15], Alex Hamilton[6], Laura Hayes[5], Asish Panda[6], Matt Earnshaw[6], Nitin Choudhary[16], Ankit Kumar[6], Prateek Chanda[17], Md Akramul Haque[18], Michael S Kirk[11], Michael Mueller[6], Sudarshan Konge[6], Rajul Srivastava[6], Yash Jain[19], Samuel Bennett[6], Ankit Baruah[6], Will Barnes[20], Michael Charlton[6], Shane Maloney[21], Nicky Chorley[22], Himanshu[6], Sanskar Modi[6], James Paul Mason[6], Naman9639[6], Jose Ivan Campos Rozo[23], Larry Manley[6], Agneet Chatterjee[24], John Evans[6], Michael Malocha[6], Monica G. Bobra[25], Sourav Ghosh[24], Airmansmith97[6], Dominik Stańczak[26], Ruben De Visscher[6], Shresth Verma[27], Ankit Agrawal[6], Dumindu Buddhika[6], Swapnil Sharma[6], Jongyeob Park[28], Matt Bates[6], Dhruv Goel[6], Garrison Taylor[29], Goran Cetusic[6], Jacob[6], Mateo Inchaurrandieta[6], Sally Dacie[30], Sanjeev Dubey[6], Deepankar Sharma[6], Erik M. Bray[6], Jai Ram Rideout[31], Serge Zahniy[5], Tomas Meszaros[6], Abhigyan Bose[6], André Chicrala[32], Ankit[6], Chloé Guennou[6], Daniel D'Avella[6], Daniel Williams[33], Jordan Ballew[6], Nick Murphy[34], Priyank Lodha[6], Thomas Robitaille[6], Yash Krishan[6], Andrew Hill[6], Arthur Eigenbrot[35], Benjamin Mampaey[36], Bernhard M. Wiedemann[6], Carlos Molina[6], Duygu Keşkek[6], Ishtyaq Habib[6], Joseph Letts[6], Juanjo Bazán[37], Quinn Arbolante[38], Reid Gomillion[6], Yash Kothari[6], Yash Sharma[6], Abigail L. Stevens[39, 40], Adrian Price-Whelan[41], Ambar Mehrotra[6], Arseniy Kustov[6], Brandon Stone[6], Trung Kien Dang[42], Emmanuel Arias[6], Fionnlagh Mackenzie Dover[1], Freek Verstringe[36], Gulshan Kumar[43], Harsh Mathur[44], Igor Babuschkin[6], Jaylen Wimbish[6], Juan Camilo Buitrago-Casas[6], Kalpesh Krishna[45], Kaustubh Hiware[46], Manas Mangaonkar[6], Matthew Mendero[6], Mickaël Schoentgen[6], Norbert G Gyenge[47], Ole Streicher[48], Rajasekhar Reddy Mekala[6], Rishabh Mishra[6], Shashank Srikanth[43], Sarthak Jain[6], Tannmay Yadav[49], Tessa D. Wilkinson[6], Tiago M. D. Pereira[50, 51], Yudhik Agrawal[12], jamescalixto[6], yasintoda[6], and Sophie A. Murray[52]

1 SP2RC, School of Mathematics and Statistics, The University of Sheffield, UK **2** National Solar Observatory, 3665 Discovery Drive, Boulder, CO 80303 **3** Aperio Software Ltd., Headingley Enterprise and Arts Centre, Bennett Road, Leeds LS6 3HN **4** Institute for Environmental Analytics, University of Reading, Reading RG6 6BX **5** NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA **6** None **7** Center for Cancer Research, National Cancer Institute, Bethesda, MD 20892-9760, USA **8** American University, Washington, DC 20016, USA **9** University College London, Gower Street, London, UK **10** Manav Rachna University **11** Catholic University of America / NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA **12** International Institute of Information

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Technology, Hyderabad 500 032, India **13** DIRAC Institute, Department of Astronomy, University of Washington, Seattle, WA 98195, USA **14** Mullard Space Science Laboratory, University College London, Surrey, UK **15** Department of Mathematics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0123, USA **16** Department of Mathematics, Indian Institute of Technology, Kharagpur, 721302, India **17** Department of Computer Science & Technology, Indian Institute of Engineering Science & Technology, Shibpur, 711103, India **18** Department of Mechanical Engineering, ZHCET, Aligarh Muslim University, Aligarh, India **19** Indian Institute of Technology, Kharagpur, 721302, India **20** Lockheed Martin Solar and Astrophysics Laboratory / Bay Area Environmental Research Institute **21** Trinity College Dublin / Dublin Institute for Advanced Studies **22** Centre for Fusion, Space and Astrophysics, Physics Department, University of Warwick, Coventry CV4 7AL, United Kingdom **23** Institut für Physik/IGAM - Karl-Franzens University of Graz, Austria **24** Jadavpur University, Kolkata **25** W.W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305, USA **26** University of Warsaw **27** ABV-Indian Institute of Information Technology and Management, Gwalior, MP 474015, India **28** Space Science Division, Korea Astronomy and Space Science Institute, Daejeon 34055, South Korea **29** Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA **30** Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Surrey, RH5 6NT, UK **31** Dogfox Software LLC, Flagstaff, AZ 86001, USA **32** Northumbria University, England **33** SUPA, University of Glasgow, Glasgow G12 8QQ, United Kingdom **34** Center for Astrophysics | Harvard & Smithsonian **35** National Solar Observatory **36** Royal Observatory of Belgium **37** CIEMAT, Astroparticle physics, Madrid, Spain. **38** Lockheed Martin Solar and Astrophysics Laboratory **39** Department of Physics & Astronomy, Michigan State University, 567 Wilson Road, East Lansing, MI 48824, USA **40** Department of Astronomy, University of Michigan, 1085 South University Avenue, Ann Arbor, MI 48109, USA **41** Center for Computational Astrophysics, Flatiron Institute, 162 Fifth Ave, New York, NY 10010, USA **42** Saw Swee Hock School of Public Health, National University Health System, National University of Singapore, Singapore **43** International Institute of Information Technology, Hyderabad **44** Indian Institute of Astrophysics, Bangalore **45** University of Massachusetts, Amherst **46** Indian Institute of Technology, Kharagpur **47** SP2RC, School of Mathematics and Statistics, University of Sheffield, Sheffield, S3 7RH, UK **48** Leibniz Institute for Astrophysics Potsdam, Germany **49** Department of Chemical Engineering, Indian Institute of Technology Kharagpur, 721302, India **50** Rosseland Centre for Solar Physics, University of Oslo, P.O. Box 1029 Blindern, NO-0315 Oslo, Norway **51** Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, NO-0315 Oslo, Norway **52** Trinity College Dublin, Ireland

Summary

The Sun, our nearest star, is a local laboratory for studying universal physical processes. Solar physics as a discipline includes studying the Sun both as a star and as the primary driver of space weather throughout the heliosphere. Due to the Sun's proximity, the temporal and spatial resolution of solar observations are orders of magnitude larger than those of other stars. This leads to significant differences in the data-analysis software needs of solar physicists compared with astrophysicists.

The `sunpy` Python package is a community-developed, free, and open-source solar data analysis environment for Python. It is managed by the SunPy Project, an organization that facilitates and promotes the use of open development and open source packages like `sunpy` through community engagement and tools such as GitHub, mailing lists, and matrix.

The four most significant subpackages of `sunpy` are described below.

The `sunpy.net` subpackage provides a unified interface that simplifies and homogenizes search and retrieval by querying and downloading data from many solar data sources, irrespective of the underlying data-source client. It currently supports sourcing data from 18 different space- and ground-based solar observatories.

The `sunpy.map` and `sunpy.timeseries` subpackages provide core data types (`Map` and `TimeSeries`, respectively) that are designed to provide a general, standard, and consistent interface

*The author list in this paper is sorted by number of commits to the core SunPy repository.

for loading and representing solar data across different instruments and missions. These classes load data which conform to solar physics standards and conventions such as FITS (Wells, Greisen, & Harten, 1981), FITS World Coordinate Systems (WCS) (Greisen & Calabretta, 2002), and solar-specific FITS headers (Thompson, 2006), while allowing customization to account for differences in specific instruments. Visualization methods are also provided to inspect and plot those data. Example visulizations of both `TimeSeries` and `Map` are shown in Figure 1.

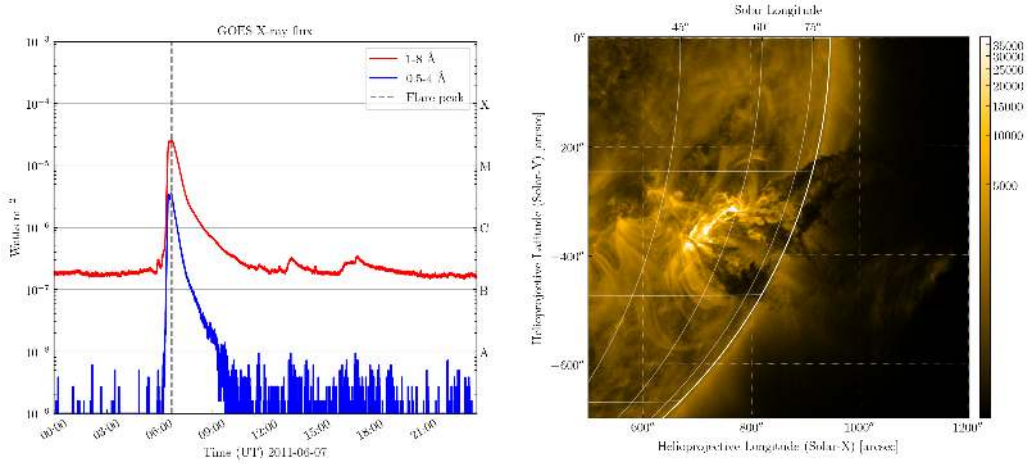

Figure 1: Left: An example of `TimeSeries` for the GOES X-ray Sensor in two broadband channels. Right: A `Map` of the extreme ultraviolet 171 $\AA$ channel of AIA corresponding to the time of a solar flare depicted by the vertical dashed line in the left-hand panel.

The `sunpy.coordinates` subpackage provides support for representing and transforming coordinates used in solar physics and astrophysics. These coordinates may represent events (e.g., flares), features on or above the Sun (e.g., magnetic loops), or the position of structures traveling throughout the heliosphere (e.g., coronal mass ejections). The package currently implements the most widely used Sun-centered coordinate frames, and extends `astropy.coordinates`.

Other functionality provided by `sunpy` includes physical models of solar behavior, such as differential rotation, color maps for certain data sources, image-processing routines integrated with `Map`, and useful physical parameters such as constants.

The `sunpy` package is designed to be extensible, which means that it is easy to add support for additional instruments or data sources. It relies heavily on the `astropy` (The Astropy Collaboration et al., 2018) Python package as well as the scientific python stack (e.g. `numpy` (van der Walt, Colbert, & Varoquaux, 2011), `scipy` (Jones, Oliphant, Peterson, & others, n.d.), `matplotlib` (Hunter, 2007) and `pandas` (McKinney, 2010)).

A more complete description of the SunPy Project and the `sunpy` package, including the methodology, development model, and implementation, as well as a comparison with other commonly-used packages in solar physics, can be found in (Barnes et al., 2020).

The SunPy Project supports affiliated packages, which build upon or extend the functionality of `sunpy`. The current affiliated packages are `drms` (Glogowski, Bobra, Choudhary, Amezcua, & Mumford, 2019), `ndcube`, `radiospectra` and `IRISPy`. The Project is also a member of the Python in Heliophysics community (PyHC, Annex et al., 2018), whose mission is to enable interdisciplinary analysis across all sub-disciplines of heliophysics by adhering to standards for code development and interoperability.

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