PSP/ISOIS
Data Analysis and Plotting Software

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Abstract: This report summarises all the necessary information about the plotting tools that were developed to analyse the data from the official science data host site for the Integrated Science Investigation of the Sun (ISOIS) on board of the Parker Solar Probe (PSP) satellite. The Integrated Science Investigation of the Sun makes observations of energetic electrons, protons and heavy ions that are accelerated to high energies (10s of keV to 100 MeV) in the Sun's atmosphere and inner heliosphere, and these can be correlated with solar wind and coronal structures. This report contains a brief description of PSP and the instruments on board, with more focus on ISOIS, followed by a more detailed description of the PSP/ISOIS database. The functions of the software are described in detail along with all the necessary information about inputs and extra steps one would need in order to use them. The software includes a variety of independent functions. Most of these functions are meant to be used as support functions for the final plot product: the multipanel function. The final plot product includes twelve panels with the most relevant electron and proton measurements for the Low Energy Telescopes (LET) and the High Energy Telescope (HET) data. This includes: 1. Proton flux for direction A (LET), 2. Proton flux for direction A (HET), 3. Count rate of protons for LET as a spectrogram, 4. Count rate of protons for HET as a spectrogram, 5. Count rate of electrons for LET as a spectrogram, 6. Count rate of electrons for HET as a spectrogram, 7. Electron count rate direction A LET, 8. Electron count rate direction A HET, 9. Proton Flux 1.2-1.4 MeV directions A,B,C (LET), 10. Pitch Angle LET directions A,B,C, 11. Proton Flux 11.3-13.5 MeV directions A and B (HET), 12. Pitch Angle directions A and B (HET).

Contents

1 Introduction

The main goal of this project was to create a python-based software containing the necessary tools to download and read the CDF files, analyse and plot the data from the official science data host site for the Integrated Science Investigation of the Sun (ISOIS) instrument on board the Parker Solar Probe (PSP) spacecraft. One of the goals was to create a python-based function that is able read the data from the previously mentioned database and mass produce plots containing all essential proton and electron data. All functions are explained in detail in section 4.1. This report contains general information on Parker Solar Probe and its instruments, as well as a more detailed description of the database and the PSP/ISOIS Data Analysis and Plotting (DAP) Software. Although the PSP/ISOIS database contains Level 2 data from both the EPI-Lo (Energetic Particle Instrument - Low Energy) and EPI-Hi (Energetic Particle Instrument - High Energy) instruments, part of the PSP/ISOIS Data Analysis and Plotting (DAP) Software tools only work on EPI-Hi data. Even more specifically these tools focus on proton and electron data. The decision to focus on EPI-Hi data was made due to the complexity and problems encountered with EPI-Lo data.

2 The Parker Solar Probe satellite

NASA's Parker Solar Probe mission is revolutionizing our understanding of the Sun. Parker Solar Probe travels through the Sun's atmosphere, closer to the surface than any spacecraft before it, facing brutal heat and radiation conditions. [1]

Parker Solar Probe uses Venus' gravity during seven flybys over nearly seven years to gradually bring its orbit closer to the Sun. The spacecraft will fly through the Sun's atmosphere as close as 6.16 million kilometers to the Sun's surface, well within the orbit of Mercury and more than seven times closer than any spacecraft has come before. [2]

Parker Solar Probe employs a combination of in situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. The spacecraft will fly close enough to the Sun to watch the solar wind speed up from subsonic to supersonic, and it will fly though the birthplace of the highest-energy solar particles.[3]

The primary science goals for the mission are to trace how energy and heat move through the solar corona and to explore what accelerates the solar wind as well as solar energetic particles. Parker Solar Probe carries four instrument suites designed to study magnetic fields, plasma and energetic particles, and image the solar wind.[3] [4]

2.1 Instruments

Parker Solar Probe provides a statistical survey of the outer corona. There are four major investigations:

1. **Fields Experiment (FIELDS):** This investigation makes direct measurements of electric and magnetic fields and waves, Poynting flux, absolute plasma density and electron temperature, spacecraft floating potential and density fluctuations, and radio emissions.

2. **Wide-field Imager for Solar PRobe (WISPR):** These telescopes takes images of the solar corona and inner heliosphere. The experiment will also provide images of the solar wind, shocks and other structures as they approach and pass the spacecraft. This investigation complements the other instruments on the spacecraft providing direct measurements by imaging the plasma the other instruments sample.

3. **Solar Wind Electrons Alphas and Protons (SWEAP) Investigation:** This investigation counts the most abundant particles in the solar wind – electrons, protons and helium ions – and measure their properties such as velocity, density, and temperature.

4. **Integrated Science Investigation of the Sun (ISOIS):** This investigation makes observations of energetic electrons, protons and heavy ions that are accelerated to high energies (10s of keV to 100 MeV) in

the Sun's atmosphere and inner heliosphere, and correlates them with solar wind and coronal structures.

[5]

2.2 ISOIS

The Integrated Science Investigation of the Sun (ISOIS) is a complete science investigation on the Parker Solar Probe (PSP) mission. ISOIS comprises a two-instrument suite to measure energetic particles over a very broad energy range, as well as coordinated management, science operations, data processing, and scientific analysis. Together, ISOIS observations allow us to explore the mechanisms of energetic particles dynamics, including their:

1. Origins: defining the seed populations and physical conditions necessary for energetic particle acceleration;
2. Acceleration: determining the roles of shocks, reconnection, waves, and turbulence in accelerating energetic particles;
3. Transport: revealing how energetic particles propagate from the corona out into the heliosphere.

The two ISOIS Energetic Particle Instruments (Figure 1) measure lower (EPI-Lo) and higher (EPI-Hi) energy particles. EPI-Lo (Figure 3) measures ions and ion composition from $\sim$20 keV/nucleon–15 MeV total energy and electrons from $\sim$ 25–1000 keV. EPI-Hi measures ions from $\sim$1–200 MeV/nucleon and electrons from $\sim$0.5–6 MeV. EPI-Lo comprises 80 tiny apertures with fields-of-view (FOVs) that sample over nearly a complete hemisphere, while EPI-Hi (Figure 2) combines three telescopes that together provide five large-FOV apertures. These include a double-ended high energy telescope (HET), a double-ended low energy telescope (LET1) and a single-ended low energy telescope (LET2). ISOIS observes continuously inside of 0.25 AU with a high data collection rate and burst data (EPI-Lo) coordinated with the rest of the PSP payload; outside of 0.25 AU, ISOIS runs in low-rate science mode whenever feasible to capture as complete a record as possible of the solar energetic particle environment and provide calibration and continuity for measurements closer in to the Sun. [6]

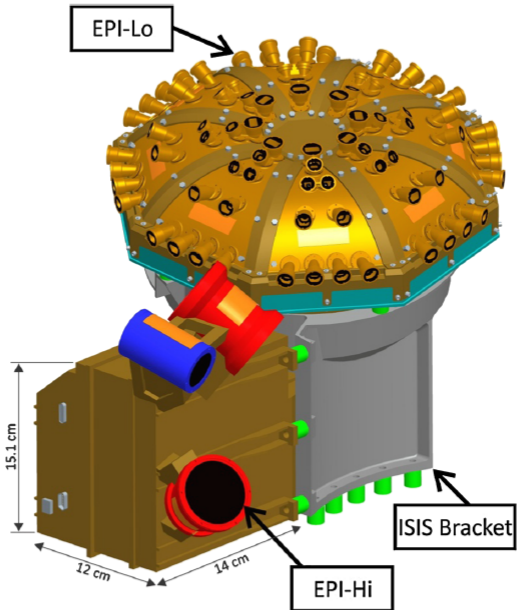

Figure 1: ISOIS suite [7]

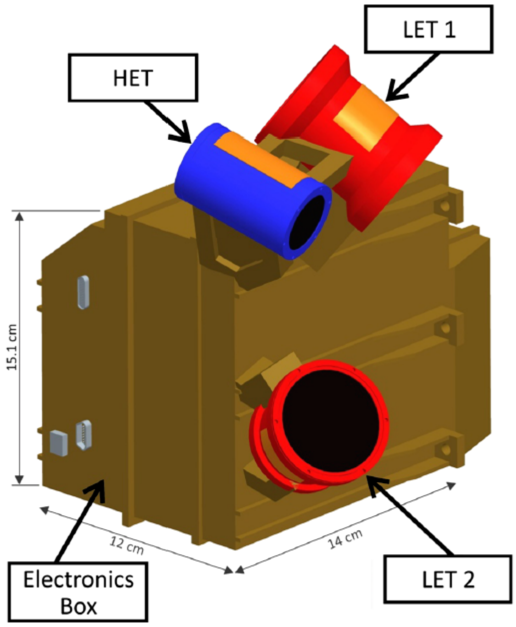

Figure 2: EPI-Hi mechanical design [7]

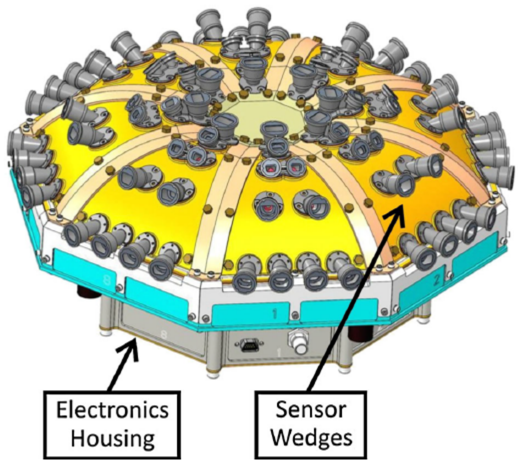

Figure 3: EPI-Lo mechanical design [7]

3 The database

The data used for the project comes from the official science data host site for the Integrated Science Investigation of the Sun (ISOIS) ($https : //spp - isois.sr.unh.edu$). The database consists of multiple folders which contain EPI-Hi and EPI-Lo level 2 data, a data glossary, some publications and quickplots. In this section I have summarized the different types of files that are included in the EPI-Lo and EPI-Hi folders as of May 2022. The EPI-Lo data was barely used during the project, but since it is possible to plot part of this data with the PSP/ISOIS DAP Software it is reasonable to include it in this report.

3.1 EPI-Lo science data

EPI-Lo data is divided into ion composition (psp_isois-epilo_l2-ic) and particle energy (psp_isois-epilo_l2-pe) data. The contents of these files are discussed in further detain in the next sections.

3.1.1 psp_isois-epilo_l2-ic

This file contains the EPI-Lo ion composition (ic) data for various particle species such as C, Fe, H, 3He, 4He, Mg, O and Si. The Columns "Look Direction" and "Energy" imply the available look directions (0 – 79) and energy ranges, respectively, in the data file.

Species	Channel	Size	Count Rate		Counts		Flux	
			Look Direction 80	Energy (keV) (bins)	Look Direction 80	Energy (keV) (bins)	Look Direction 80	Energy (keV) (bins)
C	D	80x48	0 – 79	206 – 17560 (21)	0 – 79	206 – 17560 (21)	0 – 79	206 – 17560 (21)
Fe	C	80x48	0 – 79	466 – 20709 (41)	0 – 79	466 – 20709 (41)	0 – 79	466 – 20709 (41)
H	R	80x48	0 – 79	62 – 83 (41)	0 – 79	62 – 8320 (41)	0 – 79	62 – 8320 (41)
	P	80x48	0 – 79	70 – 8320 (15)	0 – 79	70 – 8320 (15)	0 – 79	70 – 8320 (15)
	T	80x48	0 – 79	30 – 47318 (32)	0 – 79	30 – 47318 (32)	0 – 79	30 – 47318 (32)
He3	D	80x48	0 – 79	87 – 18514 (46)	0 – 79	87 – 18514 (46)	0 – 79	87 – 18514 (46)
He4	C	80x48	0 – 79	73 – 18518 (46)	0 – 79	73 – 18518 (46)	0 – 79	73 – 18518 (46)
Mg	D	80x48	0 – 79	–	0 – 79	–	0 – 79	–
O	C	80x48	0 – 79	233 – 19119 (41)	0 – 79	233 – 19119 (41)	0 – 79	233 – 19119 (41)
Si	D	80x48	0 – 79	594 – 18650 (15)	0 – 79	594 – 18650 (15)	0 – 79	594 – 18650 (15)

Table 1: psp_isois-epilo_l2-ic : The EPI-Lo ion composition (ic) data for C, Fe, H, He3, He4, Mg, O and Si in channels D, C, R, P and T.[7]

3.1.2 psp_isois-epilo_l2-pe

EPI-Lo particle energy (pe) data for different particle species, C, electron, H, 3He, He, and O.

Species	Channel	Size	Count Rate		Counts		Flux	
			Look Direction (bins)	Energy (keV) (bins)	Look Direction (bins)	Energy (keV) (bins)	Look Direction (bins)	Energy (keV) (bins)
C	X	8 x 48	0 – 7 (8)	–	0 – 7 (8)	–	0 – 7 (8)	–
electron	E	8 x 48	0 – 7 (8)	27 – 375 (16)	0 – 7 (8)	27 – 375 (16)	0 – 7 (8)	27 – 375 (16)
	G	80 x 48	0 – 79 (80)	27 – 375 (16)	0 – 79 (80)	27 – 375 (16)	0 – 79 (80)	27 – 375 (16)
	F	8 x 48	0 – 7 (8)	33 – 375 (9)	0 – 7 (8)	33 – 375 (9)	0 – 7 (8)	33 – 375 (9)
H	E	8 x 48	0 – 7 (8)	–	0 – 7 (8)	–	0 – 7 (8)	–
	F	80 x 48	0 – 79 (80)	–	0 – 79 (80)	–	0 – 79 (80)	–
	F	8 x 48	0 – 7 (8)	–	0 – 7 (8)	–	0 – 7 (8)	–
	X	8 x 64	0 – 7 (8)	–	0 – 7 (8)	–	0 – 7 (8)	–
3He	X	8 x 48	0 – 7 (8)	–	0 – 7	–	0 – 7	–
He	X	8 x 48	0 – 7 (8)	–	0 – 7	–	0 – 7	–
O	X	8 x 48	0 – 7 (8)	–	0 – 7 (8)	–	0 – 7 (8)	–

Table 2: psp_isois-epilo_l2-pe: EPI-Lo particle energy (pe) data for different particle species, C, electron, H, 3He, He, and O.[7]

3.2 EPI-Hi science data

The following tables summarize the science data for the EPI-Hi Instrument. The EPI-Hi instrument consists of three telescopes HET, LET1 and LET2. The HET and LET1 telescopes have two sides (A, B) and LET2 has one side (C). The numerical values following "rates" in the file names represent the cadence in seconds (e.g., rates10, rates300). If no value is present, the cadence is assumed to be 1 second. Listed below are the EPI-Hi data files (Table 3). The 60 s cadence products containing only the engineering singles are excluded from public release. EPI-Hi science rates are accumulated at several cadences. The 10 s and 1 s rates are an encounter–only product. The 60 s rates are also, at a baseline, encounter–only. The 3600 s rates are the main cruise phase product. EPI-Hi produces several engineering rates that overflow their counters when accumulated for 3600 s. For those, a 1/60 sample of the 60 s rates are included in cruise data. The 60 s products are thus produced for the whole mission but those containing no science data are excluded from the public release.[7]

HET	LET1	LET2
psp_isois-epihi_l2-het-rates10	psp_isois-epihi_l2-let1-rates10	psp_isois-epihi_l2-let2-rates10
psp_isois-epihi_l2-het-rates300	psp_isois-epihi_l2-let1-rates300	psp_isois-epihi_l2-let2-rates300
psp_isois-epihi_l2-het-rates3600	psp_isois-epihi_l2-let1-rates3600	psp_isois-epihi_l2-let2-rates3600
psp_isois-epihi_l2-het-rates60	psp_isois-epihi_l2-let1-rates60	psp_isois-epihi_l2-let2-rates60
HET, LET1 & LET2		psp_isois-epihi_l2-second-rates

Table 3: EPI-Hi files[7]

NB: PSP/ISOIS DAP Software focuses on H and electron data. 300s data contains only heavy ion data, thus was not used during the project. The following tables do not contain all the data included in each file (except the 300s tables), but only the data which was used for this project. For more information on the data check the data glossary on the official science data host site ($https://spp-isois.sr.unh.edu$).

3.2.1 psp_isois_epihi_l2-het-rates10

This file contains the 10 s data of energetic particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for electrons, H, He and NEUT_DET for sides A and B, for different ranges (R1 – R7) of HET.

Side	Range	Quantity	Electrons		H		He		NEUT_DET	
			E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)
A/B		Count	16	1 - 9 (16)	11	10 - 59 (11)	12	10 - 70 (12)	35	0 - 495 (35)
		Flux	16	1 - 9 (16)	11	10 - 59 (11)	12	10 - 70 (12)		
		Count Rate	16	1 - 9 (16)	11	10 - 59 (11)	12	10 - 70 (12)	35	0 - 495 (35)
	R1	Count	12	1 - 4 (12)	7	9 - 25 (7)	8	9 - 29 (8)		
		Flux	12	1 - 4 (12)	7	9 - 25 (7)	8	9 - 29 (8)		
		Count Rate	12	1 - 4 (12)	7	9 - 25 (7)	8	9 - 29 (8)		
	R2	Count	12	1 - 4 (12)	7	15 - 42 (7)	8	15 - 50 (8)		
		Flux	12	1 - 4 (12)	7	15 - 42 (7)	8	15 - 50 (8)		
		Count Rate	12	1 - 4 (12)	7	15 - 42 (7)	8	15 - 50 (8)		
	R3	Count	10	1 - 5 (10)	6	21 - 50 (6)	7	21 - 59 (7)		
		Flux	10	1 - 5 (10)	6	21 - 50 (6)	7	21 - 59 (7)		
		Count Rate	10	1 - 5 (10)	6	21 - 50 (6)	7	21 - 59 (7)		
	R4	Count	10	1 - 6 (10)	4	29 - 50 (4)	5	29 - 59 (5)		
		Flux	10	1 - 6 (10)	4	29 - 50 (4)	5	29 - 59 (5)		
		Count Rate	10	1 - 6 (10)	4	29 - 50 (4)	5	29 - 59 (5)		
	R5	Count	9	2 - 7 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
		Flux	9	2 - 7 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
		Count Rate	9	2 - 7 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
	R6	Count	9	2 - 9 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
		Flux	9	2 - 9 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
		Count Rate	9	2 - 9 (9)	4	35 - 59 (4)	5	35 - 70 (5)		
	R7	Count	9	3 - 10 (9)	4	42 - 70 (4)	5	42 - 83 (5)		
		Flux	9	3 - 10 (9)	4	42 - 70 (4)	5	42 - 83 (5)		
		Count Rate	9	3 - 10 (9)	4	42 - 70 (4)	5	42 - 83 (5)		

Table 4: psp_isois_epihi_l2-het-rates10. The 10 s HET data of particle Counts, Flux and Count Rate for electrons, H, He and NEUT_DET for sides A and B, and for ranges R1 – R7.[7]

3.2.2 psp_isois_epihi_l2-het-rates60

This file contains the 60-second cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for Al, Ar, C, Ca, Cr, Electrons, Fe, H, He, Mg, N, Na, Ne, Ni, O, S and Si ions for ranges R1 – R7) of the High Energy Telescope (HET) for sides A and B.

Side	Species	Count			Flux			Count Rate		
		Size (bins)	Range SECT (bins)	Energy (MeV/nuc)	Size (bins)	Range SECT (bins)	Energy (MeV/nuc)	Size (bins)	Range SECT (bins)	Energy (MeV/nuc)
A/B	Al	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236
	Ar	15	–	25 – 280	15	–	25 – 280	15	–	25 – 280
	C	15	–	12 – 140	15	–	12 – 140	15	–	12 – 140
	Ca	15	–	25 – 280	15	–	25 – 280	15	–	25 – 280
	Cr	16	–	25 – 333	16	–	25 – 333	16		25 – 333
	Electrons	19	–	0 – 10	19	–	0 – 10	19	–	0 – 10
	Electron_SECT	2x25 (2 bins)	R17 0 – 8 (9)	2 – 3	2x25	R17 0 – 8 (9)	3 – 3	2x25	R17 0 – 8 (9)	2 – 3
	Fe	15	–	29 – 333	15	–	29 – 333	15	–	29 – 333
	H	15	–	7 – 83	15	–	7 – 83	15	–	7 – 83
	H_SECT	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34
	He	16	–	7 – 99	16	–	7 – 99	16	–	7 – 99
	He_SECT	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34
	Mg	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236
	N	15	–	12 – 140	15	–	12 – 140	15	–	12 – 140
	Na	15	–	18 – 198	15	–	18 – 198	15	–	18 – 198
	Ne	15	–	18 – 198	15	–	18 – 198	15	–	18 – 198
	Ni	15	–	29 – 333	15	–	29 – 333	15	–	29 – 333
	O	15	–	15 – 167	15	–	15 – 167	15	–	15 – 167
	S	16	–	21 – 280	16	–	21 – 280	16	–	21 – 280
	Si	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236

Table 5: psp_isois_epihi_l2-het-rates60: The HET 60 s cadence data for various particle species. R17 implies integration of the measured values over ranges R1 – R7.[7]

3.2.3 psp_isois_epihi_l2-het-rates300

This file provides the 300 s rates of energetic particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for CNO, FeGroup and NetoSi ions for ranges R1 – R7 of the High Energy Telescope (HET) for sides A and B.

Side	Quantity	CNO_SECT			FeGroup_SECT			NetoSi_SECT		
		E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)
A/B	Count	2	36 – 68	0 – 8 (9)	1	81 – 81	0 – 8 (9)	1	57 – 57	0 – 8 (9)
	Flux	2	36 – 68	0 – 8 (9)	1 1	81 – 81	0 – 8 (9)	1 1	57 – 57	0 – 8 (9)
	Count Rate	2	36 – 68	0 – 8 (9)	1 1	81 – 81	0 – 8 (9)	1 1	57 – 57	0 – 8 (9)
	ENB_SECT - measured quantity is Count; Size 1 X 25; E-bins: 1; E-range: 12 - 12; Sectors: 0 -8 (9).									

Table 6: psp_isois_epihi_l2-het-rates300. The 300 s cadence HET data of particle Counts, Flux and Count Rate for CNO, FeGroup and NetoSi ions for sides A and B, and integrated over ranges R1 – R7.[7]

3.2.4 psp_isois_epihi_l2-het-rates3600

In this file, the 3600 s cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) measured by High Energy Telescope (HET) are available.

Side	Species	Count			Flux			Count Rate		
		Size (bins)	Range SECT (bins)	Energy (MeV/nuc)	Size (bins)	Range SECT (bins)	Energy (MeV/nuc)	Size (bins)	Range SECT (bins)	Energy (MeV/nuc)
A/B	Al	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236
	Ar	15	–	25 – 280	15	–	25 – 280	15	–	25 – 280
	C	15	–	12 – 140	15	–	12 – 140	15	–	12 – 140
	CNO_SECT	2x25 (2 bins)	R17 0 – 8 (9)	36 – 68	2x25	R17 0 – 8 (9)	36 – 68	2x25	R17 0 – 8 (9)	36 – 68
	Ca	15	–	25 – 280	15	–	25 – 280	15	–	25 – 280
	Cr	16	–	25 – 333	16	–	25 – 333	16		25 – 333
	Electrons	19	–	0 – 10	19	–	0 – 10	19	–	0 – 10
	Electron_SECT	2x25 (2 bins)	R17 0 – 8 (9)	2 – 3	2x25	R17 0 – 8 (9)	3 – 3	2x25	R17 0 – 8 (9)	2 – 3
	Fe	15	–	29 - 333	15	–	29 – 333	15	–	29 – 333
	FeGroup_SECT	1x25 (1 bin)	R17 0 – 8 (9)	81 – 81	1x25 (1 bin)	R17 0 – 8 (9)	81 – 81	1x25 (1 bin)	R17 0 – 8 (9)	81 – 81
	H	15	–	7 – 83	15	–	7 – 83	15	–	7 – 83
	H_SECT	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34
	He	16	–	7 – 99	16	–	7 – 99	16	–	7 - 99
	He_SECT	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34	2x25 (2 bins)	R17 0 – 8 (9)	18 – 34
	Mg	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236
	N	15	–	12 – 140	15	–	12 – 140	15	–	12 – 140
	Na	15	–	18 – 198	15	–	18 – 198	15	–	18 – 198
	Ne	15	–	18 – 198	15	–	18 – 198	15	–	18 – 198
	NetoSi_SECT	1x25 (1 bin)	R17 0 – 8 (9)	57 – 57	1x25 (1 bin)	R17 0 – 8 (9)	57 – 57	1x25 (1 bin)	R17 0 – 8 (9)	57 – 57
	Ni	15	–	29 - 333	15	–	29 – 333	15	–	29 – 333
	O	15	–	15 - 167	15	–	15 – 167	15	–	15 – 167
	S	16	–	21 – 280	16	–	21 – 280	16	–	21 – 280
	Si	15	–	21 – 236	15	–	21 – 236	15	–	21 – 236
	NEUT1	35x21	–	0 – 495	–	–	–	35x21	–	0 – 495
	NEUT2_DET	35x6	–	0 – 495	–	–	–	35x6	–	0 – 495

Table 7: psp_isois_epihi_l2-het-rates3600: The 3600 s cadence HET data of the particle Counts, Flux and Count Rates for different particle species for sides A and B and ranges R1 – R7. R17 implies integration of the measured values over ranges R1 – R7.[7]

3.2.5 psp_isois_epihi_l2-let1-rates10

This file contains the 10-second cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for Electrons, H and He ions for various ranges (R1 – R7) of the Low Energy Telescope (LET1), for sides A and B.

Side	Range	Quantity	Electrons		H		He	
			E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)
A/B		Count			16	1 - 12 (16)	20	1 - 25 (20)
		Flux			16	1 - 12 (16)	20	1 - 25 (20)
		Count Rate			16	1 - 12 (16)	20	1 - 25 (20)
	R1	Count			8	1 - 3 (8)	8	1 - 3 (8)
		Flux			8	1 - 3 (8)	8	1 - 3 (8)
		Count Rate			8	1 - 3 (8)	8	1 - 3 (8)
	R2	Count			13	2 - 12 (13)	13	2 - 15 (13)
		Flux			13	2 - 12 (13)	13	2 - 15 (13)
		Count Rate			13	2 - 12 (13)	13	2 - 15 (13)
	R3	Count	10	1 - 3 (10)				
		Flux						
		Count Rate	10	1 - 3 (10)				
	R4	Count	10	1 - 4 (10)				
		Flux						
		Count Rate	10	1 - 4 (10)				
	R5	Count	9	1 - 4 (9)				
		Flux						
		Count Rate	9	1 - 4 (9)				
	R6	Count	8	2 - 5 (8)			3	21 - 29 (3)
		Flux					3	21 - 29 (3)
		Count Rate	8	2 - 5 (8)			3	21 - 29 (3)
	R7	Count						
		Flux						
		Count Rate						

Table 8: psp_isois_epihi_l2-let1-rates10: The LET1 10 s data of various energetic particle species.[7]

3.2.6 psp_isois_epihi_l2-let1-rates60

This file contains the LET1 (Low Energy Telescope) 60 s cadence measurements of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) of Al, Ar, C, Ca, Cr, Fe, H, He, Mg, N, Na, Ne, Ni, O, S and Si for sides A and B.

Side	Species	Counts		Flux		Count Rate	
		Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)
A/B	Al	28	1 – 118	28	1 – 118	28	1 – 118
	Ar	29	1 – 140	29	1 – 140	29	1 – 140
	C	27	1 – 99	27	1 – 99	27	1 – 99
	Ca	30	1 – 140	30	1 – 140	30	1 – 140
	Cr	31	1 – 140	31	1 – 140	31	1 – 140
	Fe	32	1 – 167	32	1 – 167	32	1 – 167
	H	25	1 – 42	25	1 – 42	25	1 – 42
	He	26	1 – 50	26	1 – 50	26	1 – 50
	Mg	28	1 – 118	28	1 – 118	28	1 – 118
	N	27	1 – 99	27	1 – 99	27	1 – 99
	Na	28	1 – 118	28	1 – 118	28	1 – 118
	Ne	28	1 – 118	28	1 – 118	28	1 – 118
	Ni	33	1 – 198	33	1 – 198	33	1 – 198
	O	28	1 – 118	28	2 – 118	28	1 – 118
	S	29	1 – 140	29	1 – 140	29	1 – 140
	Si	29	1 – 140	29	1 – 140	29	1 – 140

Table 9: psp_isois_epihi_l2-let1-rates60: The LET1 measurements of different particle species at a cadence of 60 s for sides A and B.[7]

3.2.7 psp_isois_epihi_l2-let1-rates300

This file contains the 300 s cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for various particle species for ranges R1 - R26 (integrated over ranges R2 to R6) measured by the Low Energy Telescope (LET1), for sides A and B.

Side	Range	Quantity	CNO_SECT			FeGroup_SECT			NetoSi_SECT		
			E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)
A/B	R1	Count	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Flux	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Count Rate	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
A/B	R26	Count	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Flux	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Count Rate	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
	R1 ENB_SECT - measured quantity is Counts; Size 3 x 9; E-bins: 3; E-range: 1 - 2 (MeV/nuc); Sectors: 0 - 8 (9).										
	R26 ENB_SECT - measured quantity is Counts; Size 4 x 25; E-bins: 4; E-range: 2 - 12 (MeV/nuc); Sectors: 0 - 24 (25).										

Table 10: psp_isois_epihi_l2-let1-rates300: The LET1 300 s cadence measurements of various energetic particle species for ranges R1 and integrated over ranges R2 – R6 (R26).[7]

3.2.8 psp_isois_epihi_l2-let1-rates3600

This file contains the 3600 s cadence measurements of particle Counts, Count Rate (counts/sec) and Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) for Al, Ar, C, Ca, Cr, Fe, H, He, Mg, N, Na, Ne, Ni, O, S and Si by the Low Energy Telescope (LET1), for sides A and B for different ranges (R1 – R6).

Side	Species	Count		Flux		Count Rate	
		Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)
A/B	Al	28	1 – 118	28	1 – 118	28	1 – 118
	Ar	29	1 – 140	29	1 – 140	29	1 – 140
	C	27	1 – 99	27	1 – 99	27	1 – 99
	Ca	30	1 – 140	30	1 – 140	30	1 – 140
	Cr	31	1 – 140	31	1 – 140	31	1 – 140
	Fe	32	1 – 167	32	1 – 167	32	1 – 167
	H	25	1 – 42	25	1 – 42	25	1 – 42
	He	26	1 – 50	26	1 – 50	26	1 – 50
	Mg	28	1 – 118	28	1 – 118	28	1 – 118
	N	27	1 – 99	27	1 – 99	27	1 – 118
	Na	28	1 – 118	28	1 – 118	28	1 – 118
	Ne	28	1 – 118	28	1 – 118	28	1 – 118
	Ni	33	1 – 198	33	1 – 198	33	1 – 198
	O	28	1 – 118	28	1 – 118	33	1 – 118
	S	29	1 – 140	29	1 – 140	29	1 – 140
	Si	29	1 – 140	29	1 – 140	29	1 – 140

Table 11: psp_isois_epihi_l2-let1-rates3600: The 3600 s cadence LET1 data for various particle species for sides A and B.[7]

Side	Species	Count		Count Rate	
		Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)
A/B	Electrons_xxx	16	0 – 7	16	0 – 7

Table 12: Electron measurements.

3.2.9 psp_isois_epihi_l2-let2-rates10

This file contains the 10-second cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for Electrons, H and He ions for various ranges (R1 – R7) of the single–sided (depicted as C) Low Energy Telescope (LET2).

Side	Range	Quantity	Electrons		H		He	
			E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)
C		Count			16	1 - 12 (16)	20	1 - 25 (20)
		Flux			16	1 - 12 (16)	20	1 - 25 (20)
		Count Rate			16	1 - 12 (16)	20	1 - 25 (20)
	R1	Count			8	1 - 3 (8)	8	1 - 3 (8)
		Flux			8	1 - 3 (8)	8	1 - 3 (8)
		Count Rate			8	1 - 3 (8)	8	1 - 3 (8)
	R2	Count			13	2 - 12 (13)	13	2 - 15 (13)
		Flux			13	2 - 12 (13)	13	2 - 15 (13)
		Count Rate			13	2 - 12 (13)	13	2 - 15 (13)
	R35	Count			5	7 - 15 (5)	9	7 - 29 (9)
		Flux			5	7 - 15 (5)	9	7 - 29 (9)
		Count Rate			5	7 - 15 (5)	9	7 - 29 (9)
	R3	Count	10	1 - 3 (10)				
		Flux						
		Count Rate	10	1 - 3 (10)				
	R4	Count	10	1 - 4 (10)				
		Flux						
		Count Rate	10	1 - 4 (10)				
	R5	Count	9	1 - 4 (9)				
		Flux						
		Count Rate	9	1 - 4 (9)				

Table 13: The 10 s cadence data of LET2 for various energetic particle species.[7]

3.2.10 psp_isois_epihi_l2-let2-rates60

This file contains the 60 s cadence measurements of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) of Al, Ar, C, Ca, Cr, Fe, H, He, Mg, N, Na, Ne, Ni, O, S and Si coming from the single-sided (side C) Low Energy Telescope (LET2).

Side	Species	Counts		Flux		Count Rate	
		Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)
C	Al	27	1 – 99	27	1 – 99	27	1 – 99
	Ar	28	1 – 118	28	1 – 118	28	1 – 118
	C	25	1 – 70	25	1 – 70	25	1 – 70
	Ca	30	1 – 140	30	1 – 140	30	1 – 140
	Cr	31	1 – 140	31	1 – 140	31	1 – 140
	Fe	31	1 – 140	31	1 – 140	31	1 – 140
	H	24	1 – 35	24	1 – 35	24	1 – 35
	He	25	1 – 42	25	1 – 42	25	1 – 42
	Mg	27	1 – 99	27	1 – 99	27	1 – 99
	N	25	1 – 70	25	1 – 70	25	1 – 70
	Na	27	1 – 99	27	1 – 99	27	1 – 99
	Ne	27	1 – 99	27	1 – 99	27	1 – 99
	Ni	32	1 – 167	32	1 – 167	32	1 – 167
	O	26	1 – 83	26	2 – 83	26	1 – 83
	S	28	1 – 118	28	1 – 118	28	1 – 118
	Si	28	1 – 118	28	1 – 118	28	1 – 118

Table 14: psp_isois_epihi_l2-let2-rates60: The 60 s cadence measurements of the single–sided (side C) telescope LET2 for different particle species.[7]

3.2.11 psp_isois_epihi_l2-let2-rates300

This file contains the 300 s cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for various particle species for ranges R1 and R26 (integrated over Ranges 2 – 6) measured by the single–sided (named C) Low Energy Telescope (LET2).

Side	Range	Quantity	CNO_SECT			FeGroup_SECT			NetoSi_SECT		
			E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)
C	R1	Count	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Flux	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Count Rate	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
C	R26	Count	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Flux	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Count Rate	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
R1 ENB_SECT – measured quantity is Counts; Size 3 x 9; E-bins: 3; E-range: 1 - 2 (MeV/nuc); Sectors: 0 - 8 (9).											
R26 ENB_SECT – measured quantity is Counts; Size 4 x 25; E-bins: 4; E-range: 2 - 12 (MeV/nuc); Sectors: 0 - 24 (25).											

Table 15: psp_isois_epihi_l2-let2-rates300: The LET2 300 s cadence measurements of various energetic particle species for ranges R1 and integrated over ranges R2 – R6 (R26).[7]

3.2.12 psp_isois_epihi_l2-let2-rates3600

This file contains the 3600 s cadence data of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) for Al, Ar, C, Ca, Cr, Fe, H, He, Mg, N, Na, Ne, Ni, O, S and Si by the single sided (depicted as C) Low Energy Telescope (LET2).

Side	Species	Count		Flux		Count Rate	
		Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)	Size (bins)	Energy (MeV/nuc)
C	Al	27	1 – 99	27	1 – 99	27	1 – 99
	Ar	29	1 – 118	28	1 – 118	28	1 – 118
	C	25	1 – 70	25	1 – 70	25	1 – 70
	Ca	30	1 – 140	30	1 – 140	30	1 – 140
	Cr	31	1 – 140	31	1 – 140	31	1 – 140
	Fe	31	1 – 140	31	1 – 140	31	1 – 140
	H	24	1 – 35	24	1 – 35	24	1 – 35
	He	25	1 – 42	25	1 – 42	25	1 – 42
	Mg	27	1 – 99	27	1 – 99	27	1 – 99
	N	25	1 – 70	25	1 – 70	25	1 – 70
	Na	27	1 – 99	27	1 – 99	27	1 – 99
	Ne	27	1 – 99	27	1 – 99	27	1 – 99
	Ni	32	1 – 167	32	1 – 167	32	1 – 167
	O	26	1 – 83	26	1 – 83	26	1 – 83
	S	28	1 – 118	28	1 – 118	28	1 – 118
	Si	28	1 – 117	28	1 – 118	28	1 – 118

Table 16: psp_isois_epihi_l2-let2-rates3600: The 3600 s cadence data for various particle species for the single–sided (side C) telescope LET2.[7]

Side	Range	Quantity	CNO_SECT			FeGroup_SECT			NetoSi_SECT		
			E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)	E-bins	E-range (MeV/nuc)	Sectors (bins)
C	R1	Count	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Flux	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
		Count Rate	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)	1	3 - 3	0 - 8 (9)
C	R26	Count	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Flux	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
		Count Rate	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)	3	6 - 24	0 - 24 (25)
R1 ENB_SECT – measured quantity is Counts; Size 3 x 9; E-bins: 3; E-range: 1 - 2 (MeV/nuc); Sectors: 0 - 8 (9).											
R26 ENB_SECT – measured quantity is Counts; Size 4 x 25; E-bins: 4; E-range: 2 - 12 (MeV/nuc); Sectors: 0 - 24 (25).											

Table 17: Electron measurements.

3.2.13 psp_isois_epihi_l2-second-rates

This file contains the 1 s cadence measurements of particle Counts, Flux (cm^{-2} sr^{-1} sec^{-1} MeV^{-1}) and Count Rate (counts/s) of Electrons and H for sides A and B for the double–sided High Energy Telescope (HET) and the Low Energy Telescopes (LET1), and the single–sided Low Energy Telescope (LET2).

Side	Range	Quantity	Electrons		H	
			E-bins	E-range (MeV/nuc) (bins)	E-bins	E-range (MeV/nuc) (bins)
C	HET_A	Count	3	1 – 3	2	13 – 24
		Flux	3	1 – 3	2	13 – 24
		Count Rate	3	1 – 3	2	13 – 24
	HET_B	Count	3	1 – 3	2	13 – 24
		Flux	3	1 – 3	2	13 – 24
		Count Rate	3	1 – 3	2	13 – 24
	LET1_A	Count	2	1 – 2	3	2 – 11
		Flux	2	1 – 2	3	2 – 11
		Count Rate	2	1 – 2	3	2 – 11
	LET1_B	Count	2	1 – 2	3	2 – 11
		Flux	2	1 – 2	3	2 – 11
		Count Rate	2	1 – 2	3	2 – 11
	LET2_C	Count	2	1 – 2	3	2 – 11
		Flux	2	1 – 2	3	2 – 11
		Count Rate	2	1 – 2	3	2 – 11

Table 18: psp_isois_epihi_l2-second-rates: The EPI-Hi 1 s data of Electrons and H for HET, LET1 and LET2.[7]

4 The software

This sotfware is designed to analyse Parker Solar Probes's data from the PSP database: $https://spp-isois.sr.unh.edu$. Most of the functions in the software work only for EPI-Hi data, since that is this software's main focus.
The software can be found at :
$https://github.com/AnnamariaFedeli/PSP-ISOIS-DataAnalysisAndPlottingSoftware.g$

4.1 Functions and general description

The software consists of multiple functions that enable you to retrieve, analyse and plot PSP data. Below I have listed all the functions, their necessary inputs and their functionality. Some of the functions require the data to be downloaded beforehand. The data can be retrieved from the database using the **retrieve_data** function. You do not need to retrieve the data separately for the **mulipanel** function. Part of the functions in the software are meant to be used primarily inside other functions. These functions can of course be used separately, but it will require a few extra steps than just retrieving the data.

4.1.1 info_software

info_software(path_to_software_infotxt)
This functions opens the info.txt file that contains all the necessary information about the software.

Inputs:

path_to_software_infotxt	: path to the info.txt file. Remember to use the r before the quotation marks if you're using the back slash in the path name. This cancels special python characters. Or use / instead.

4.1.2 retrieve_data

retrieve_data(path_to_folder, date, instrument, data = "", rate = "")
This function retrieves the data from the PSP database for a chosen date, instrument and resolution (rate). The database has 3 main folders EPI-Hi, EPI-Lo, ISOIS:

1. EPI-Hi: the data is separated into LET1, LET2 and HET. With rate: 10s, 60s, 300s, 3600s and one second rate.

2. EPI-Lo: the data is separated into pe (particle energy) and ic (ion composition). The resolution varies and cannot be chosen separately.

3. ISOIS: contains a summary of the data.

Inputs:

1. path_to_folder:	Choose a folder in your computer where you want to save the data. The data will be automatically saved in the chosen folder as a cdf file. The files will be named as in the database. Remember to use the r before the quotation marks if you're using the back slash in the path name. This cancels special python characters. Or use / instead.
2. date:	Input the date as a string in the form: "YYYYMMDD"
3. instrument:	Input (as a string) either "epihi", "epilo" or "isois"
4. data:	input (as a string): For EPI-Hi: "let1", "let2" or "het" (if you wish to retreive 1s data no input needed). For EPI-Lo: "ic" or "pe". For ISOIS: no input needed
5. rate (resolution):	For EPI-Hi: "rates10", "rates60", "rates300", "rates3600" or just "rates" for 1s. For EPI-Lo: no input needed. For ISOIS: no input needed.

4.1.3 get_zvariables

get_zvariables(name_of_cdf)

This function outputs all the zVariables in the opened cdf along with some basic information. For more metadata use the get_info function.

Inputs:

name_of_cdf	the name given to the cdf when opened in a notebook (or command (cmd) line) e.g. name_of_cdf = cdflib.CDF(r"path_to_folder"). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.

4.1.4 get_info

get_info(name_of_cdf, variable = "all")
This function outputs the information (the metadata) for a chosen variable from the CDF file.

Inputs:

1. name_of_cdf: The name given to the cdf when opened in a notebook e.g. name_of_cdf = cdflib.CDF(r"path_to_folder") The path_to_folder is output when retrieving the data from the database using the retrieve_data function.
2. variable: If you wish to retrieve the information for all the variables contained in the cdf file, no second input needed. Otherwise, input the name of the variable you are interested in getting the information about. To check the variable names use the get_zvariables function.

4.1.5 get_data

get_data(name_of_cdf, variable = "all")
This function prints the data for a chosen variable.

Inputs:

1. name_of_cdf:	The name given to the cdf when opened in a notebook e.g. name_of_cdf = cdflib.CDF(r"path_to_folder"). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.
2. variable:	If you wish to retrieve the data for all the variables, no second input needed. Otherwise, input the name of the variable you are intrested in getting the data of. To check the variable names use the get_zvariables function.

4.1.6 energy_channels

energy_channels(name_of_cdf)
This function prints out the energy channels for each particle species in the cdf file.
Currently works only for EPI-Hi data.

Inputs:

cdf_name:	The name given to the cdf when opened in a notebook e.g. name_of_cdf = cdflib.CDF(r"path_to_folder"). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.

4.1.7 average_data

average_data(cdf_name, variable, wanted_resolution, data_resolution , particle= "")
This function creates an averaged dataframe for a chosen variable from the

cdf file. The averaged variable is epoch (time). This function works for all data (Flux, Rate, Pitch Angle and RTN/HGC/HCI data).

Inputs:

1. cdf_name:	The name given to the cdf when opened in a notebook e.g. name_of_cdf = cdflib.CDF(r"path_to_folder"). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.
2. variable:	The variable you wish to average, for exemple "C_H_Flux". It is possible to check all the variables in the cdf using the get_zvariables function.
3. wanted_resolution:	Input the wanted resolution in seconds as an integer e.g 300, 3600 etc.
4. data_resolution:	Input the resolution of the data in seconds as an integer. For EPI-Hi could be 10s, 60s, 300s, 3600s or one second.
5. particle:	If you are NOT averaging Flux or Count Rate data, no input needed. Otherwise input the particle as a string: For EPI-Hi data: let1 and let2 : "H", "He" or "electrons" het: "H", "He" or "electrons"

4.1.8 average_data_dataframe

average_data_dataframe(dataframe, wanted_resolution, data_resolution)
This function creates an averaged pandas dataframe from a ready made dataframe. This function works for all kinds of dataframe, but the first column shouold be an epoch column.

Inputs:

1. dataframe:	The name of the dataframe you wish to average.
2. wanted_resolution:	Input the wanted resolution in seconds as an integer e.g 300, 3600 etc.
3. data_resolution:	input the resolution of the data as an integer in seconds. For EPI-Hi could be 10s, 60s, 300s, 3600s or one second.

4.1.9 average_list

average_list(lista, wanted_resolution, data_resolution)
This function is primarily made for averaging an epoch (time) list used in some other functions in the software.

Inputs:

1. lista:	The name of the list you wish to average.
2. wanted_resolution:	Input the wanted resolution in seconds e.g 300, 3600 etc. as an integer.
3. data_resolution:	Input the resolution of the data as an integer in seconds. For EPI-Hi could be 10s, 60s, 300s, 3600s or one second.

4.1.10 join_dataframes

join_dataframes(dataframe_one, dataframe_two)
This function is primarily made for being used in other functions in the software. This functions concatenates two dataframes. The dataframe columns must be of the same length. This function can be used to create an averaged dataframe for the pa_flux and multipanel functions. This function is mainly used to concatenate data from separate files.

Inputs:

1. dataframe_one:	The name of the first dataframe. e.g dataframe containing the pitch angle. dataframe_one must constain an epoch column.
2. dataframe_two:	The name of the second dataframe e.g. dataframe containing the fluxes corresponding to the pitch angle of the first dataframe.

4.1.11 pa_dataframe

pa_dataframe(cdf_name, particle, direction= "")

This function creates a dataframe that includes the cdf file's epoch, pitch angle and flux for a chosen direction and particle species. This dataframe can be used in the pa_fluxes function and is also used in the multipanel function.

Inputs:

1. cdf_name: The name given to the cdf when opened in a notebook. e.g. cdf_name = cdflib.CDF(r"path_to_folder2). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.
2. particle: The particle species you want the fluxes of in the dataframe.
   For HET: "H", "He" or "Electrons"
   For LET: "H" or "He" (as LET does not have flux data for electrons)
3. direction: LET and HET have different viewing directons.
   HET: "A" or "B"
   LET1: "A" or "B"
   LET2: "C" (no input necessary)
   direction A is the main looking direction for both LET and HET. This is along the nominal Parker spiral towards the Sun.

4.1.12 plot

plot(cdf_name, variable, title = "", ylabel = "")

This function plots the data for any chosen variable from the cdf. The data will be plotted in the same panel (in case of matrixlike format of the variable data e.g. flux or count rate).

Inputs:

1. cdf_name: The name given to the cdf when opened in a notebook e.g. name_of_cdf = cdflib.CDF(r"path_to_folder"). The path_to_folder is output when retrieving the data from the database using the retrieve_data function.
2. variable: Input the name of the variable you wish to plot from the cdf file. It is possible to check the variable names by using the get_zvariables function.
3. title: choose a title for the plot (input not necessary).
4. ylabel: chose a label for the y-axis (input not necessary)

4.1.13 plot_pa_flux

plot_pa_flux(let1 = "", let2 = "", het = "", title = "" , e_bins = [] , wanted_resolution = "", data_resolution = "")

This function plots the pitch angles of either LET or HET and the fluxes corresponding to the chosen e-bins of each pitch angle. The fluxes of each energy channel will be plotted in a different panel. The colors of the plots correspond to the pitch angles. let1 files contain data for the A and B viewing directions of LET and let2 files contain data for the C viewing direction of LET. HET has A and B viewing directions. LET1 and LET2 data should be plotted together to have all three let viewing directions (A, B and C).

After using the retrieve_data function to retrieve the data for let1, let2 and/or het for a certain date and resolution, e.g.:

retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" , data = "let1", rate = "rates10")

retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" , data = "let2", rate = "rates10")

retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" ,

data = "het", rate = "rates10")
(check the documentation of the retrieve_data function to see how to choose the inputs)
After this step, the data should be opened. e.g: let1 = cdflib.CDF(r"path_to_cdf")
let2 = cdflib.CDF(r"path_to_cdf")
het = cdflib.CDF(r"path_to_cdf")

Inputs:	Either input both let1 and let2 or just het
1. let1:	The name given to the let1 cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste the path to open the file in the notebook or cmd line.
2. let2:	The name given to the let2 cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste the path to open the file in the notebook or cmd line.
3. het:	The name given to the het cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste th path to open the file in the notebook or cmd line.
4. title:	title of the plot as a string.
5. e_bins:	This input should be a list of numbers corresponding to the energy bins you wish to plot. To check which number corresponds to which energy channel use the energy_channels function. This Input should be a list even if you wish to plot just one energy channel. e.g [3] or [0,4,7,10].

6. wanted_resolution: If you DO NOT wish to average the data NO input is necessary. Otherwise: input the wanted resolution in seconds as an integer e.g 300, 3600 etc.
7. data_resolution: If you DO NOT wish to average the data NO input is necessary. Otherwise: input the resolution of the used data in seconds as an integer. For EPI-Hi could be 10s, 60s, 300s, 3600s or one second.

4.1.14 spec_plot_pa

spec_plot_pa(let1 = "", let2 = "", het = "", title="", colorbar = True, ylabel = "Pitch Angle ("+r"°"+")', colbar_orientation = "horizontal", even_limits = False, colorbar_label = True, colormap = cm.inferno)

This function creates a spectrogram of the flux for each pitch angle of either LET or HET. let1 files contain data for the A and B viewing directions of LET and let2 files contain data for the C viewing direction of LET. het has A and B viewing directions. let1 and let2 data should be plotted together to have all three let viewing directions (A, B and C). So if you are plotting let data you should have an input for both let1 and let2. The input variables are explained below. After using the retrieve_data function to retrieve the data for let1, let2 and/or het for a certain date and resolution, e.g.:
retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" , data = "let1", rate = "rates10")
retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" , data = "let2", rate = "rates10")
retrieve_data(path_to_folder, date = "20190404", instrument = "epihi" , data = "het", rate = "rates10")
(check the documentation of the retrieve_data function to see how to choose the inputs)
After this step, the data should be opened. e.g: let1 = cdflib.CDF(r"path_to_cdf")
let2 = cdflib.CDF(r"path_to_cdf")

het = cdflib.CDF(r"path_to_cdf")

Inputs:	Either input both let1 and let2 or just het.
1. let1:	The name given to the let1 cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste it to open the file in the notebook or cmd line.
2. let2:	The name given to the let2 cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste it to open the file in the notebook or cmd line.
3. het:	The name given to the het cdf when opened in a notebook e.g. See above. The path_to_folder is output when retrieving the data from the database using the retrieve_data function. You can copy paste it to open the file in the notebook or cmd line.
4. title:	Title of the plot as a string (if colorbar_orientation = horizontal it will cover the title)
5. colorbar:	True or False.
6. ylabel:	Should be a string. No need to change it. It's the flux unists by default.
7. colbar_orientation:	"horizontal" or "vertical" .
8. even_limits:	True or False. (Leave to False)

9. colorbar_label: True if you want to label the colorbar (name filled automatically) or False otherwise.

10. colormap: This can be any of the matplotlib colormaps (matplotlib.cm package) e.g. cm.inferno, cm.jet etc. link: https://matplotlib.org/stable/tutorials/colors/colormaps.html

4.1.15 spec_plot

spec_plot(fig, ax, epoch, energy_channels, intensity, ylabel = "", title="", colorbar = True, colbar_orientation = 'vertical', even_limits = False, colorbar_label = True, colormap = cm.inferno)

This function creates a spectrogram of the flux or rate for each energy channel. This function is primarily used in the multipanel plot function, but can be called from another plotting function.

Inputs:

0: fig, ax How the figure and the axes are defined in the multiplot funtion.

1. epoch: The datetime list. The epoch of the cfd in encoded in J2000. You can use the following code to convert it to a readable form:
e.g. LET 1
t = name_of_the_file.varget("Epoch")
t1 = []
Changing Epoch to readable UTC u.ns where ns = nanoseconds and u is the units package.
for i in time1:
—date_time_str = (Time(2000, format="jyear") + TimeDelta(i*u.ns)).iso
t1.append(datetime.strptime(date_time_str, "%Y-%m-%d %H:%M:%S.%f"))

2. energy_channels:	The list of the energy channels for the chosen flux or rate.
3. intensity:	Rate count of the particle (can be also the flux).
4. ylabel:	Input string. No need to change it for count rate data. It's the counts/s by default. Should be changed if the function is used to plot flux data.
5. title:	Title of the plot as a string (if colorbar_orientation = horizontal it will cover the title)
6. colorbar:	True or False (leave to True).
7. colbar_orientation:	Input as string: 'horizontal' or 'vertical'
8. even_limits:	True or False.
9. colorbar_label:	True if you want to label the colorbar or False. If True the label will be labelled automatically.
10. colormap:	Can be any of the matplotlib colormaps e.g. cm.inferno, cm.jet link: https://matplotlib.org/stable/tutorials/colors/colormaps.html

4.1.16 multipanel

multipanel(path_to_folder, date, days, data_resolution = "auto", plot_resolution = "original")
This function creates a multipanel plot that includes:

1. Proton flux for direction A (LET)
2. Proton flux for direction A (HET)
3. Count rate of protons for LET as a spectrogram
4. Count rate of protons for HET as a spectrogram
5. Count rate of electrons for LET as a spectrogram
6. Count rate of electrons for HET as a spectrogram
7. Electron count rate direction A LET
8. Electron count rate direction A HET
9. Proton Flux 1.2-1.4 MeV directions A,B,C (LET)
10. Pitch Angle LET directions A,B,C
11. Proton Flux 11.3-13.5 MeV directions A and B (HET)
12. Pitch Angle directions A and B (HET)

(Figure 4)

Inputs:

1. path_to_folder:	Choose a folder in your computer where you want to save the data. The data will be automatically saved in the chosen folder as a cdf file. The files will be named with the exact name they have in the database. Remember to use the r before the quotation marks if you're using the back slash in the path name. This cancels special python characters. Or use / instead.
2. date:	Input the date as a string in the form: "YYYYMMDD". This is the start date of the plot. It is possible to plot multiple days by specifying the number of consecutive days you wish to plot.
3. days:	Number of consecutive days you wish to plot
4. data_resolution:	No input is necessary. The function will automatically download the data for the chosen resolution. For EPI-Hi there are three possible choices of resolution: 10 seconds, 60 seconds and 3600 seconds. The input should be a string: e.g. "rates10", "rates60" or "rates3600". "rates10": If the 10s resolution data is not available, the function will automatically download 60s resolution files. If this is not available either, 3600s data will be downloaded. "rates60": If the 60s resolution data is not available, the function will automatically download 10s resolution files. If this is not available either, 3600s data will be downloaded.

"rates3600": If the 3600s resolution is not available, the function will automatically download 60s resolution files. If this is not available either, 10s data will be downloaded. If no input is provided, depending on the number of consecutive days you choose to plot, the function will automatically choose the most appropriate resolution. For 1-3 days it will be 60 seconds. If however the 60 second data is not available, the function will download 10 second data and if this is not available it will download 3600 second data. For 4+ days it will be 3600 seconds. If however the 3600 second data is not available, the function will download 60 second data and if this is not available it will download 10 second data.

5. plot_resolution: No input is necessary. You can also choose to average the data of the plot. The input should be a string. For example: "S", "30S", "min", "10min", "H", "3H","d", "3d", "W"
Keywords:
seconds: "S"
minutes: "min"
hours: "H"
days: "d"
weeks: "W"

4.1.17 loop_plot

loop_plot(path_to_folder, start_date, end_date, frequency)
This function plots and saves in loop of n days the plots between the start and end date (+n days, if the data is available). The function uses directly the multipanel function's default inputs for data resolution.

Inputs:

1. path_to_folder:	Choose a folder in your computer where you want to save the data. The data will be automatically saved in the chosen folder as a cdf file. The files will be named with the exact name they have in the database. Remember to use the r before the quotation marks if you're using the back slash in the path name. This cancels any special python characters. Or use / instead.
2. start_date:	First date of the plots. Input a string in the form "YYYYMMDD".
3. end_date:	Last date to be plotted. Input a string in the form "YYYYMMDD".
4. frequency:	Number of days in each plot. The input should be an integer.

4.2 The final plot product

Although the software includes a variety of useful and independent functions, most of these functions were created with the intention of being used as support functions for the final plot product: the multipanel function. This function produces a plot with twelve panels that includes all the most relevant electron and proton measurements for LET and HET data. The plot (Figure 4) includes:

1. Proton flux for direction A (LET)
2. Proton flux for direction A (HET)

3. Count rate of protons for LET as a spectrogram
4. Count rate of protons for HET as a spectrogram
5. Count rate of electrons for LET as a spectrogram
6. Count rate of electrons for HET as a spectrogram
7. Electron count rate direction A LET
8. Electron count rate direction A HET
9. Proton Flux 1.2-1.4 MeV directions A,B,C (LET)
10. Pitch Angle LET directions A,B,C
11. Proton Flux 11.3-13.5 MeV directions A and B (HET)
12. Pitch Angle directions A and B (HET)

5 Results

The goal of this project was to create python-based tools that could be used to plot and analyse the data from the official science data host site for the Integrated Science Investigation of the Sun (ISOIS) of the Parker Solar Probe spacecraft ($https://spp-isois.sr.unh.edu$). The focus of the project and the software was mainly EPI-Hi data. As a result of creating these plotting tools, we were able to plot and visualise all the available EPI-Hi data from the database. Using the multipanel and the loop_plot functions we made two, five and seven day plots. An example of what the multipanel plot looks like is shown in Figure 4.

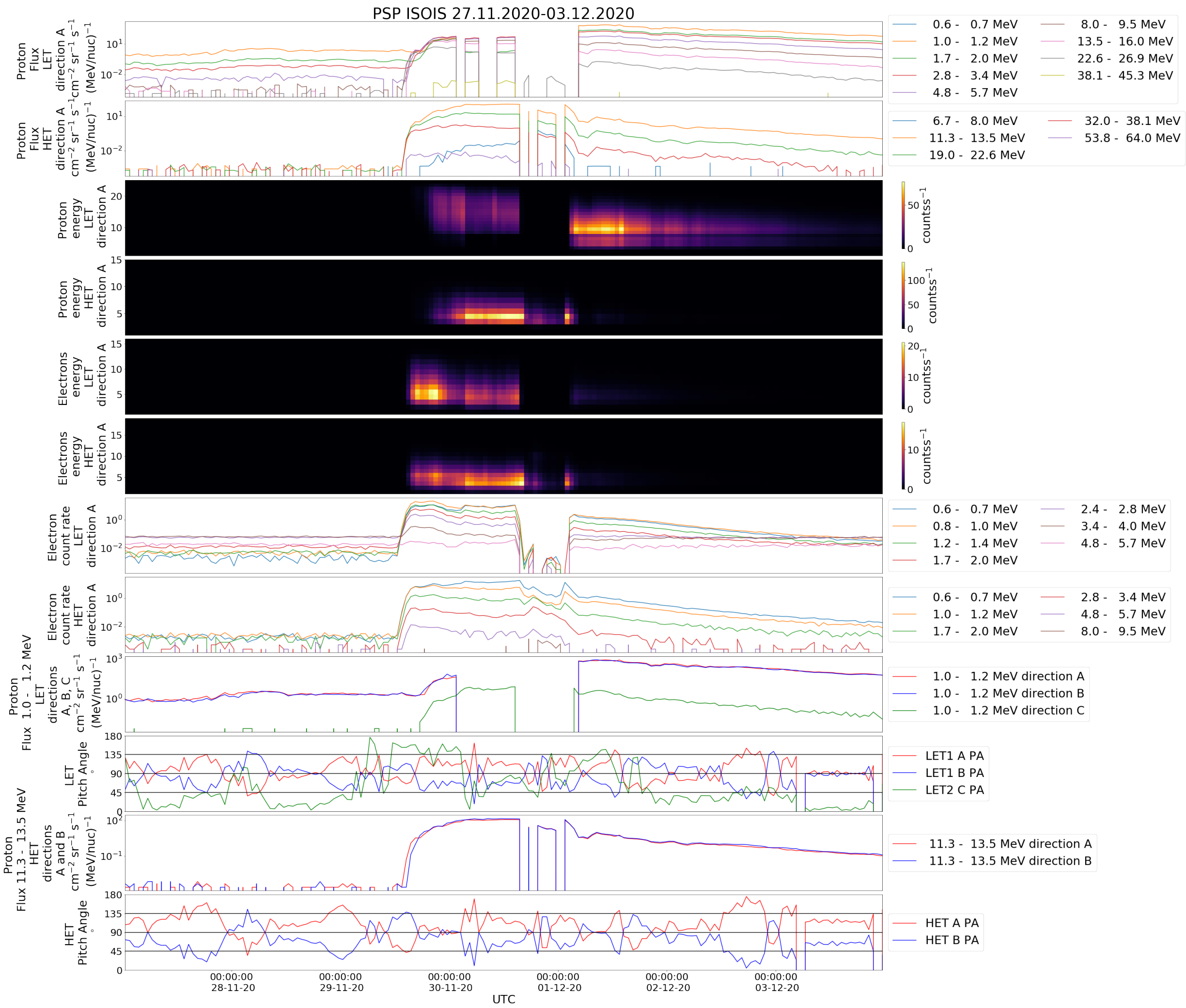

Figure 4: A seven day example of what the final plot product looks like. The panels in order: 1. Proton flux for direction A (LET), 2. Proton flux for direction A (HET), 3. Count rate of protons for LET as a spectrogram, 4. Count rate of protons for HET as a spectrogram, 5. Count rate of electrons for LET as a spectrogram, 6. Count rate of electrons for HET as a spectrogram, 7. Electron count rate direction A LET, 8. Electron count rate direction A HET, 9. Proton Flux 1.2-1.4 MeV directions A,B,C (LET), 10. Pitch Angle LET directions A,B,C, 11. Proton Flux 11.3-13.5 MeV directions A and B (HET), 12. Pitch Angle directions A and B (HET).

6 Discussion

Although the format of the data made creating tools for plotting and analysing the data challenging, focusing on EPI-Hi data made the challenge easier. Major changes in the data versions e.g. change in the variable names may lead to some complications. The tools that were created are able to recognise and adapt to new versions of the data when downloading it from the database. Possible data gaps are also handled by the functions.

As already mentioned, most of the functions of the software focus on EPI-Hi data. This does not exclude the possibility to make implementations or additions to the software to adapt it also to EPI-Lo data in the future. These implementations will not be easy to achieve given the even more complex format of EPI-Lo data.

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