On-Board Data Products Inside 0.25 AU from the Low-Energy Telescopes (LETs) on Solar Probe Plus

R. A. Mewaldt
Caltech

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Abstract

This report documents a draft plan for the data products that get recorded onboard during the portions of the Solar Probe Plus (SPP) orbit inside 0.25 AU when the full EPI-HI bit rate is available. It tries to include all data products needed from LET to meet the science requirements for EPI-Hi. It also provides data for some additional measurement "Goals."

This update of earlier estimates that has several differences. In particular, it recognizes that the L1•L2 trigger mode is not an exact continuation of the L0•L1 mode and so these require separate matrices. Similarly, A-end particles that stop in L3B have a different geometry factor than that for the preceding ranges. These changes cost additional bit rate because some energy bins are now recorded in more than one separate matrix.

In addition, this summary provides additional rationale for data choices that have been made in an effort to invite feedback as well as encourage ideas for alternative approaches.

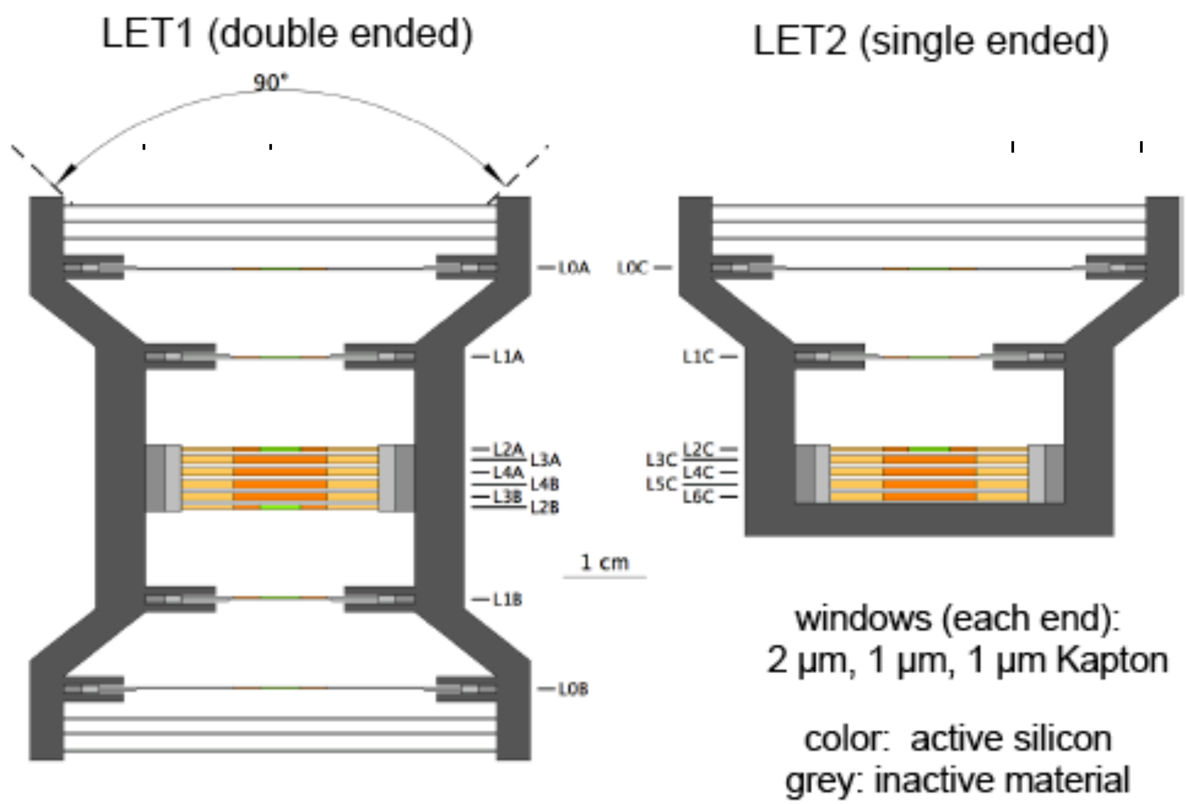
Contents

1. Introduction

In Figure 1 below diagrams of the LET1 and LET2 telescopes are shown. LET1 is doubled ended with several trigger modes, including (from the A end): (1) L0A•L1A triggers that do not trigger L2A or the L2A Guard., L1A•L2A events that stop in the detector stack without triggering any Guards or L3B, and a Penetrating mode

that includes particles that trigger L2A•L2B or L2A•L1B. In LET2 the Penetrating signature is L1C•L2C•L6C. The three windows have a net equivalent thickness of only 4 microns of Si.

Figure 1



LET Detector Data

Shown here are drawings of the LET and HET detectors, and a Table of their properties. Also shown is a prototype of a LET L1 detector.

Table 1

EPI-Hi Silicon Solid-State Detector Designs

Detector Telescope	Detector Designations	Thickness	Number of Central / Guard / Small Pixel Segments	Central Active Area	Guard Active Area	Notes
LET1	L0A, L0B	12 µm	5 / 0 /0	1.0 cm^2	N/A	[1]
	L1A, L1B	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2A, L2B	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3A, L3B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4A, L4B	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
LET2	L0C	12 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L1C	25 µm	5 / 0 / 0	1.0 cm^2	N/A	[1]
	L2C	500 µm	5 / 1 / 1	1.0 cm^2	3.0 cm^2	[2]
	L3C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L4C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L5C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
	L6C	1000 µm	2 / 0 / 1	4.0 cm^2	N/A	[2]
HET	H1A, H1B	500 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H2A, H2B	1000 µm	5 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H3A, H3B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H4A, H4B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]
	H5A, H5B	2 × 1000 µm	1 / 1 / 1	1.0 cm^2	1.73 cm^2	[2]

Notes:

[1] new technology development

[2] small pixel at edge for rate monitoring on some detectors; area: 1 mm^2

Figure 3

Segmentation of Active Areas:

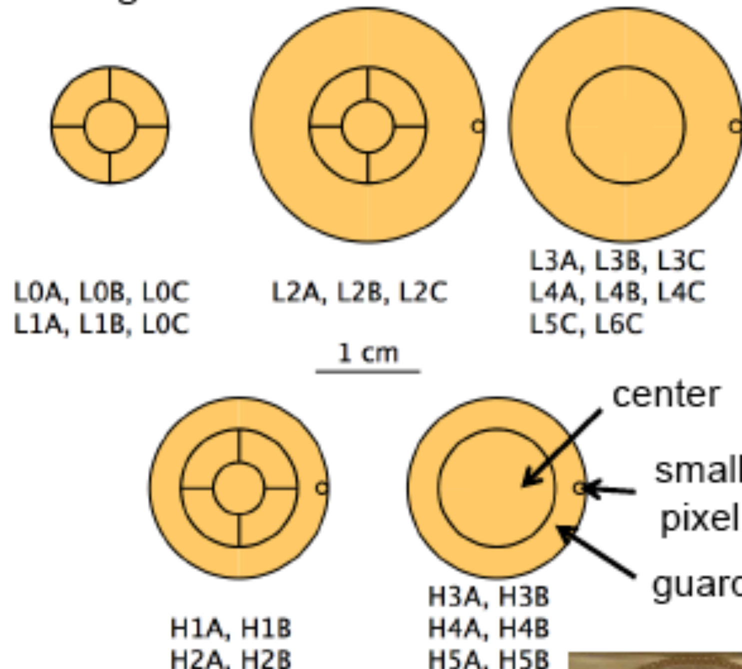
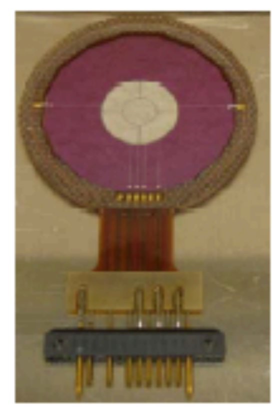


Figure 4

prototype L1 detector



Energy and Species Coverage

Figure 5

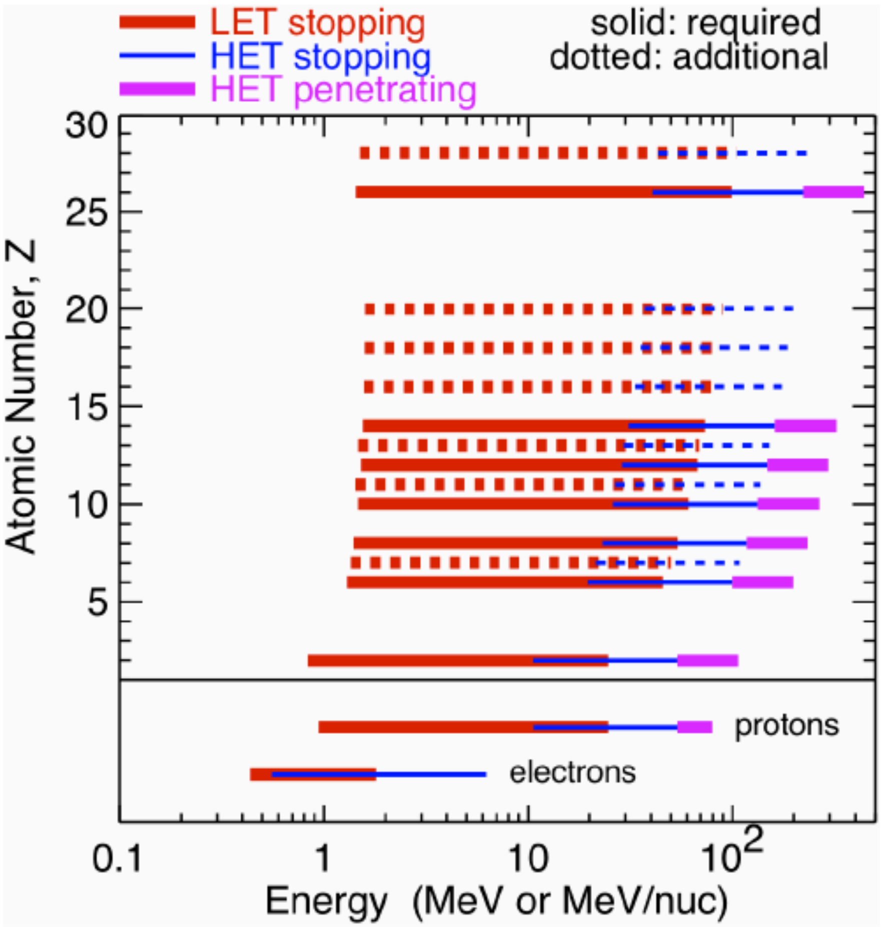


Figure 6

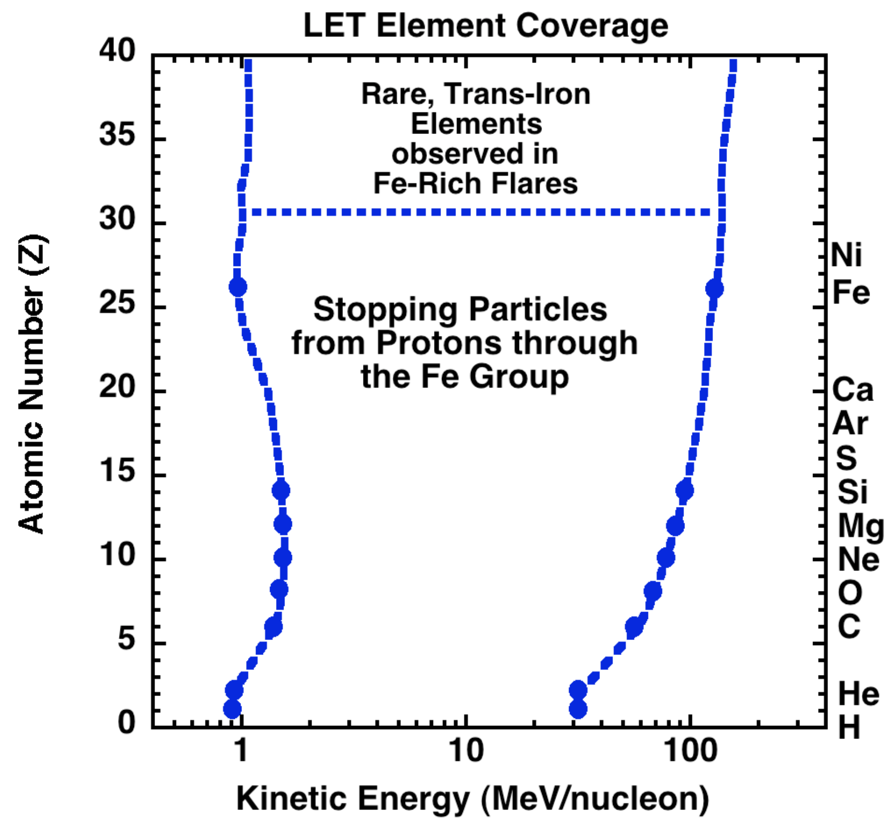


Figure 5 on the left provides a summary of the LET and HET species and energy coverage for particles stopping in LET1 and HET and for HET penetrating particles. The figure on the right shows energy coverage for ions stopping in the LET1 Telescope. The blue dots indicate elements that are required.

Fields of View

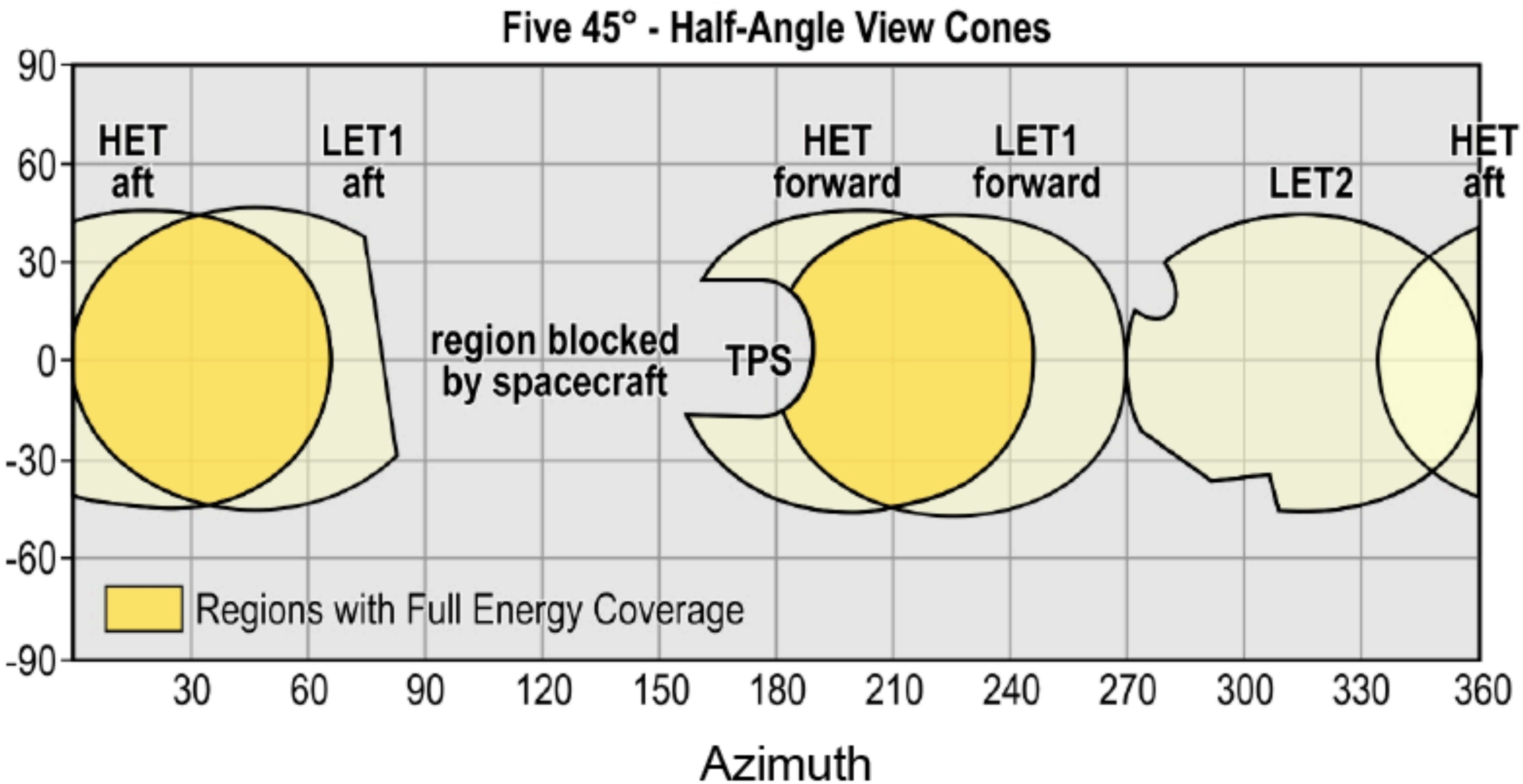


Figure 7: The field of view (FOV) of the LET and HET telescopes are shown above. Note that some directions are obstructed by the spacecraft, including the thermal protection system (TPS). Each of these fields of view is divided into 25 directions. Some H, He, electron, and Z ≥ 3 energy intervals can be viewed by all five view cones (LET sectored data are discussed on slide 19)

2. Approach and Assumptions

- The approach described below is based on that in STEREO LET (see Mewaldt et al. 2008), and on the in-flight experience with this approach.
- We adopt common energy intervals for all matrices that are spaced by $(2)^{1/4.}$ This gives ~14 energy bins/decade.
- This memo is for the LET trigger modes in the normal operation mode. It does not include new trigger modes to come up in some proposed "Dynamic Threshold" operational modes.
- Here we have used either 8-bit, 12-bit and 16-bit rates. This is meant to imply rates that have a pseudo-logarithmic base. In some cases fewer bits may be needed.
- It is expected that most of the positions in these matrices will have zero counts during quiet time periods. We should find a way to capture this information with as few bits as possible and devote the unused bits to other purposes such as storing additional PHA data for individual events.

3. LET 1-minute Ion Rates

As on STEREO, the LET and HET 1-minute rates are meant to be the basic time-intensity and composition data used for SEP studies inside 0.25 AU. From these one can build longer-term data products like 10-minute, 1-hour, and daily rates of all species that we measure. Although we will also measure certain abundant species (e.g., H, He, and electrons) on 1 and 10 second time scales when the energetic particle intensities are sufficiently high, 1-minute is the highest time base for which we plan to assemble a near-complete record of all species at all energies (during intense SEP events we will raise trigger thresholds such that the lowest energy particles are no longer measured).

L0•L1 Events: As can be seen on Slide 3 the L0•L1 trigger mode in the LETs has a separate view cone from that of L1•L2, although there is overlap. Therefore, events triggering L0 and L1, but not L2 (signified L0•L1~L2), will be counted separately from events triggering L0•L1•L2 and beyond, or L1 and L2 without L0 (signified ~L0•L1•L2…). The matrix below shows the species and energy intervals to be measured with L1•L2 events. The energy intervals include stopping events at all angles, with at least 1 nominally empty interval above and below the nominal response (TBR once we have actual detector thicknesses and optimized range-energy relations). It is assumed that energy loss in L0 and a 4 micron-thick window are added in. The "3's" indicate the three LET apertures are tabulated separately.

L0•L1 Events Time Res (s)					60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60			
E1	E2	Elec	H	He	He3	He3.5	He4	C	N	O	Ne	Ne20	Ne21	Ne22	Na	Mg	Al	Si	S	Ar	Ca	Cr	Fe	Ni	30-40	40-50	50-60	>60	He Sum	Z≥6 Sum	Z≥30 SUM
0.354	0.420																												0	0	0
0.420	0.500																												0	0	0
0.500	0.595																												0	0	0
0.595	0.707		3	3		3	3																3	3	3	3	3	3	30	6	12
0.707	0.841		3	3	3	3	3															3	3	3					24	9	0
0.841	1.00				3	3	3														3	3	3	3					21	12	0
1.00	1.19		Available		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					60	51	0
1.19	1.41		as 10-s		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	72	51	12
1.41	1.68		Rates		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					60	51	0
1.68	2.00				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					60	51	0
2.00	2.38				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					60	51	0
2.38	2.83		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	78	51	12
2.83	3.36		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					66	51	0
3.36	4.00				3	3		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					57	51	0
4.00	4.76							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					51	51	0
4.76	5.66							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	63	51	12
5.66	6.73										3	3	3	3	3	3	3	3	3	3	3	3	3	3					42	42	0
6.73	8.00															3	3	3	3	3	3	3	3	3					27	27	0
8.00	9.51																		3	3	3	3	3	3					18	18	0
9.51	11.3																								3	3	3	3	12	0	12
11.3	13.5																												0	0	0
13.5	16.0																												0	0	0
																												rates	771	606	48
																												bits	16	12	8
																												bps	205.6	121.2	6.4
																												Sum	333.2		

Heavy lines outline expected response

LET 1-minute Rates -(continued)

L2A thru L4B: Since particles incident on the A-end of LET that trigger L1A and L2A and then stop in detectors down to L2B, L3B, and L5C all have the same geometry factor (~0.53 cm^{2}sr) we can combine them on the same matrix, as seen below. In order to estimate the required bit rate we have identified all intervals that would be triggered taking into account opening angle, nominal isotopic composition, and nominal detector thicknesses, and also included a higher and lower energy bin that is not expected to be triggered. A Monte Carlo calculation should be used to check these estimates. The "3's" signify that there should be a separate matrix for each of the three telescopes.

If the LETs should go into one of the "Dynamic Threshold" modes the same matrix can be used but the geometry factor used to normalize the intensities may be different for H, He, and electrons than for Z≥6 ions. Such changes need to take place on 1-minute boundaries.

LET 1-Min Ions
Stop in L2A thru L4B (L2B - L4A; L2C-L4C)

Time Res (s)		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60					H+He	6≤Z≤28	
E1	E2	Elec	H	He	He3	3.5He	4He	C	N	O	Ne	Ne20	Ne21	Ne22	Na	Mg	Al	Si	S	Ar	Ca	Cr	Fe	Ni	30-40	40-50	50-60	>60	Sum	Sum	
1.00	1.19		3	3	3	3	3																						15	0	0
1.41	1.68				3	3	3																						9	0	0
1.68	2.00				3	3	3																						9	0	0
2.00	2.38				3	3	3	3	3																3	3	3	3	9	6	12
2.38	2.83		Available		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
2.83	3.36		as 10-s		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
3.36	4.00		rates		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
4.00	4.76				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	9	51	12
4.76	5.66				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
5.66	6.73				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
6.73	8.00				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
8.00	9.51				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	9	51	12
9.51	11.3				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
11.3	13.5				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
13.5	16.0				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
16.0	19.0		3		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	12	51	12
19.0	22.6		3		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					12	51	0
22.6	26.9				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					9	51	0
26.9	32.0			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					12	51	0
32.0	38.1			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	12	51	12
38.1	45.3				3	3		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					6	51	0
45.3	53.8							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					0	51	0
53.8	64.0							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					0	51	0
64.0	76.1							3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0	51	12
76.1	90.5									3	3	3	3	3	3	3	3	3	3	3	3	3	3	3					0	45	0
90.5	108															3	3	3	3	3	3	3	3	3					0	27	0
108	128																		3	3	3	3	3	3					0	18	0
128	152																				3	3	3	3	3	3	3	3	0	12	12
152	181																							3					0	3	0
181	215																											rates	171	1131	84
215	256																											bits	16	12	8
																												bps	45.6	226.2	11.2
																												Sum	283.0		

LET 1-minute Rates – Continued
Particles Stopping in the Last of the Four 1-mm Thick Detectors

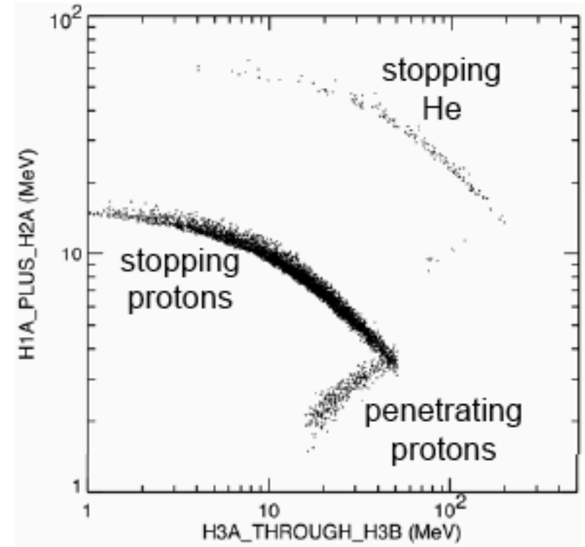
The geometry factor for A-end particles in Range L3B is smaller than that for earlier ranges. This occurs in all three LET telescopes. As a result, we tabulate A-end L3B events in a separate matrix. They can be added into those from earlier ranges by weighting them appropriately. In addition, this range is not available in LET2.

LET 1-Minute Ions
Stop in L3B, L3A, L4C

Time Res (s)		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60					Sum		
E1	E2	Elec	H	He4	He3.5	3He	C	N	O	Ne	Ne20	Ne21	Ne22	Na	Mg	Al	Si	S	Ar	Ca	Cr	Fe	Ni	30-40	40-50	50-60	>60	H,He	6≤Z≤28	Z≥30
16.0	19.0			2																								2	0	
19.0	22.6			2	2	2																						6	0	
22.6	26.9		2	2	2	2																						8	0	
26.9	32.0		2	2	2	2	2																					8	2	
32.0	38.1			2	2	2	2	2	2																			6	6	
38.1	45.3			2	2	2	2	2	2	2	2	2	2	2														6	16	
45.3	53.8			2	2	2	2	2	2	2	2	2	2	2														6	16	
53.8	64.0						2	2	2	2	2	2	2	2	2	2	2											0	22	
64.0	76.1						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2							0	30	0
76.1	90.5						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	34	8
90.5	107.6								2	2	2	2	2	2	2	2	2	2	2	2	2	2	2					0	30	0
108	128.0									2	2	2	2	2	2	2	2	2	2	2	2	2	2					0	28	0
128	152.2																	2	2	2	2	2	2					0	12	0
152	181.0																					2	2	2	2	2	2	0	4	8
181	215.3																											0	0	0
215	256.0																											0	0	0
256	304.4																											0	0	0
																									2	2	2	0	0	6
																														0
																														0
																														0
																											Rates	42	200	16
																											bits	16	12	8
																											bps	11.2	40.0	2.1
																											Sum	53.3		

4. Energy Spectra of Penetrating Particles

"Penetrating" particles as those that enter one end of the telescope and pass out the other end. A workable signature in LET-1 is L2A•L2B. The Figure at right (for HET) demonstrates that the energy spectrum of penetrating H and He in LET can be determined over a limited energy range by plotting the energy-loss spectrum in the center of the stack (e.g., L3A+L4A+L4B+L3B) vs. L2. In HET measurements of penetrating ions will extend H and He spectra to the goal of 100 MeV/nuc (stopping H&He end at ~55 MeV/nuc). The spectra of abundant Z ≥ 6 ions can also be extended in energy.



It is also useful to measure penetrating ions in LET (even though HET covers this energy range) to improve angular coverage and statistical accuracy. In addition, if HET failed, extending LET H and He spectra by ~X2 would ensure meeting the requirement of measuring H and He from 1 to 50 MeV/nuc.

Allan Labrador [ ] and Mark Wiedenbeck [ ] have developed approaches to measure the spectra of penetrating particles in ACE/SIS & ACE/CRIS. We assume these can be adapted to LET & HET. Here we estimate the bit rate necessary to extend LET penetrating spectra of abundant species a factor of ≥2 beyond that of stopping particles for LET1 (both ends) and LET2 (1 end).

For LET1 we assume the following signatures:

1) L2A•L2B (maximum angle ~32°). We need to keep the two directions separate.
2) L2A•L1B (maximum angle ~26°) moving away from the Sun
3) L2B•L1A (maximum angle ~26°) moving towards the Sun

This adds up to 4 separate penetrating spectra that must be tabulated for LET1.

For LET2 we assume the following signature: L1C•L2C•L6C (only for particles entering through the front). This latter signature will not work for protons because they will not trigger L1 at energies greater than ~16 MeV. Assuming an L1C threshold of 0.15 MeV penetrating He ions can in principle be measured to ~88 MeV/nuc.

The directions of travel of penetrating particles can be determined by comparing their energy losses in the 1-mm thick detectors.

4. Energy Spectra of Penetrating Particles - Continued

The matrix below summarizes the energy intervals for measuring the energy spectra of ions that penetrate through

LET. It is assumed that this may be possible up to ~3 times the energy of stopping ions. Since the LET2 stack is thinner than LET1, the LET2 intervals are all ~1 bin lower. In addition, in LET2 we only analyze Ions that enter through the front of the telescope. In LET1 we are accumulating ions in with two difference coincidence patterns, as discussed on the previous slide. separate matrices. We also analyze ions from both the A and B ends in LET1. As a result, there are 5 separate tabulations of LET penetrating ions.

LET Penetrating Ion Spectra

Time Res (s)		60	60	60			60	60	60	60	60	60	60	60	60	60	60	60	60	60	60		H,He	Z≥6
E1	E2	Elec	H	He	He3.5	3He	C	N	O	Ne	Ne22	Na	Mg	Al	Si	S	Ar	Ca	Cr	Fe	Ni		Sum	Sum
16.0	19.0																						0	0
19.0	22.6			1																			1	0
22.6	26.9		4	5																			9	0
26.9	32.0		4	5																			9	0
32.0	38.1		4	5																			9	0
38.1	45.3		4	5			1	1															9	2
45.3	53.8		4	5			5	5	1	1													9	12
53.8	64.0		4	5			5	5	5	5			1		1								9	22
64.0	76.1		4	5			5	5	5	5			5		5								9	30
76.1	90.5		4	5			3	5	5	5			5		5					1			9	29
90.5	108		4	4			5	5	3	5			5		5					5			8	33
108	128		4	4			5	5	5	5			5		5					5			8	35
128	152						5	5	5	5			5		5					5			0	35
152	181						4	5	5	5			5		5					5			0	34
181	215						4	4	4	5			5		5					5			0	32
215	256						4	4	4	4			5		5					5			0	31
256	304								4	4			4		4					5			0	21
304	362												4		4					5			0	13
362	431																			4			0	4
431	512																			4			0	4
																						rate	89	329
																						bits	12	8
																						bps	17.8	43.9
																						Sum	61.7	

5. LET 10-Second Rates

LET 10-second Rates provide opportunities for timing studies with solar events and studies of interplanetary structures for a wider spectrum of species than is possible with 1-second data. Shown below are the H and He rates. Note that protons will not trigger L1 at energies >~15 MeV (TBR)

In the LETs particles stopping in ranges L2A to L4B all have the same geometry factor and can be combined to produce common spectra. Similarly for B-end events. L0•L1 and long-range events that stop in L3B and L3A must be treated separately. The three H and HE matrices are shown below. Note that some energy bins must be accumulated in two matrices. The boxed bin represent the nominal response; the unboxed bins are "background" bins, which are transmitted only once per minute.

LET 10-Second H and He Rates

Last Detectors		L0A-L1A L0B-L1B L0C-L1C		L2A-L4B L2B-L4A L5C		L3B L3A		60 Transmit Each	10 Transmit Each
Cadence (sec)		10	10	10	10	10	10		
E1	E2	H	He	H	He	H	He	Minute	10 sec
0.595	0.707	3	3					6	0
0.707	0.841	3	3					6	0
0.841	1.000	3	3					6	6
1.00	1.189	3	3					0	6
1.19	1.414	3	3	3	3			6	6
1.41	1.682	3	3	3	3			6	6
1.68	2.000	3	3	3	3			0	12
2.00	2.378	3	3	3	3			6	6
2.38	2.828	3	3	3	3			6	6
2.83	3.364			3	3			0	6
3.36	4.000			3	3			0	6
4.00	4.757			3	3			0	6
4.76	5.657			3	3			0	6
5.66	6.727			3	3			0	6
6.73	8.000			3	3			0	6
8.00	9.514			3	3			0	6
9.51	11.314			3	3			0	6
11.31	13.454			3	3			0	6
13.45	16.000			3	3			0	6
16.00	19.027			3	3		2	4	3
19.03	22.627			3	3		2	4	3
22.63	26.909				3		2	0	5
26.91	32.000						2	0	2
32.00	38.055						2	2	0
38.05	45.255						2	2	0
							Rates	36	121
							Bits	12	12
							bps	7.2	145.2
							Total	152.4	

Boxed: Expect to be populated
Unboxed: Background bins

LET 10-Second Heavy-Ion Rates

The Matrix below includes six abundant heavy ions that could be used for timing or composition studies. Included (for A-end data) are events stopping in L2A through L4B. For these high-time-resolution rates we will ignore A-end (B-end) events that stop in L3B (L3A) because this is a limited energy range that also has a different geometry factor from the previous range.

LET 10-Second Heavy Ion Rates

Time Resolution (sec)		10	10	10	10	10	10		10 sec
E1	E2	C	O	Ne	Mg	Si	Fe		
0.841	1.00								
1.00	1.19						3		3
1.19	1.41								0
1.41	1.68	3	3	3	3	3	3		18
1.68	2.00								0
2.00	2.38	3	3	3	3	3	3		18
2.38	2.83								0
2.83	3.36	3	3	3	3	3	3		18
3.36	4.00								0
4.00	4.76	3	3	3	3	3	3		18
4.76	5.66								0
5.66	6.73	3	3	3	3	3	3		18
6.73	8.00								0
8.00	9.51	3	3	3	3	3	3		18
9.51	11.3								0
11.3	13.5	3	3	3	3	3	3		18
13.5	16.0								0
16.0	19.0	3	3	3	3	3	3		18
19.0	22.6								0
22.6	26.9	3	3	3	3	3	3		18
26.9	32.0								0
32.0	38.1	3	3	3	3	3	3		18
38.1	45.3								0
45.3	53.8					3	3		6
53.8	64.0								0
64.0	76.1						3		3
76.1	90.5								
								Rates	192
								Bits	8
								bps	153.6

LET 10-Second Electron Rates

Matrices for the LET 10-sec electron rates are shown below. Those entries that are boxed represent the bins that are expected to be triggered, based on Beta-spectrometer calibrations of similar telescopes for IMP-7 & 8 (Mewaldt et al. 1974). Unboxed bins are "background bins". Simulations with GEANT-4 may improve our understanding of the LET electron response.

LET 10-sec Electron Rates

Time Res. (sec)		10	10	10	10		60	10
	LET1	L2A-L3A	L2A-L4A	L2A-L4B	L2A-L3B			
	LET1	L2B-L3B	L2B-L4B	L2B-L4A	L2B-L3A		Transmit	Transmit
	LET2	L2C-L3C	L2C-L4C	L2C-L5C	-		Each	Each
E1	E2						Minute	10 sec
0.354	0.42	3					3	
0.420	0.50	3					3	
0.500	0.59	3	3				3	3
0.595	0.71	3	3				3	3
0.707	0.84	3	3	3			3	6
0.841	1.00	3	3	3			3	6
1.000	1.19	3	3	3	2		2	9
1.189	1.41	3	3	3	2		2	9
1.414	1.68	3	3	3	2		0	11
1.682	2.00	3	3	3	2		0	11
2.000	2.38	3	3	3	2		0	11
2.378	2.83	3	3	3	2		0	11
2.828	3.36	3	3	3	2		3	8
3.364	4.00	3	3	3	2		3	8
4.000	4.76		3	3	2		3	5
4.757	5.66		3	3	2		6	2
5.657	6.73			3	2		5	0
6.727	8.00				2		2	
						Rates	44	103
						Bits	12	12
						bps	8.8	123.6
						Total	132.4	

Boxed: Expect to be populated
Unboxed: Background bins

6. LET 1-second Electron and Proton Rates

The SPP Report of the Science and Technology Definition Team has a requirement to measure electron and proton intensities with 1-second resolution to study objectives like acceleration at interplanetary shocks and the energetic particle behavior at other interplanetary structures. LET will provide both proton and electron 1-s rates from three separate directions that will complement data from HET and from EPI-Lo.

The matrix below shows a possible choice for 1-sec proton and electron rates, using all three telescopes. We do not need to transmit rates with no counts - we should just send a single 0 indicating no triggers. We should probably require a programmable minimum number of counts (e.g., 10?) to make these data worthwhile. We can estimate what fraction of the time these rates will be triggered using STEREO & ACE data. Here I make the (conservative) assumption that they are triggered 30% of the time for LET. The savings should allow more PHA data.

1-Sec Electron Rates

		Electron Intensity per (cm2-sr-s-MeV)	
E1	E2	LET	HET
0.354	0.42		
0.420	0.50		
0.500	0.59		
0.595	0.71		
0.707	0.84	3	2
0.841	1.00		
1.000	1.19		
1.189	1.41	3	2
1.414	1.68		
1.682	2.00		
2.000	2.38		
2.378	2.83		2
2.828	3.36		
3.364	4.00		
4.000	4.76		
4.757	5.66		
5.657	6.73		
6.727	8.00		

	LET	HET
Number	6	6
Bits	8	8
bps	48	48

1-Sec Proton Rates

		Proton Intensity per (cm2sr-s-MeV)	
E1	E2	LET	HET
1.000	1.19		
1.189	1.41	3	
1.414	1.68		
1.682	2.00		
2.000	2.38		
2.378	2.83		
2.828	3.36	3	
3.364	4.00		
4.000	4.76		
4.757	5.66		
5.657	6.73		
6.727	8.00		
8.000	9.51	3	
9.514	11.31		
11.314	13.45		2
13.454	16.00		
16.000	19.03		
19.027	22.63		
22.627	26.91		2
26.909	32.00		

	LET	HET
Number	9	4
Bits	8	8
bps	72	32

7. LET Pixel Rates

Both LET and HET have small (~1 mm^2) pixels (see Figure 3) located in the Guard regions of the detectors. If count rates get too high (e.g., trigger rates >10^5/sec) during a large SEP event, it should still be possible to measure heavy ions (Z ≥ 6) by raising thresholds, but it may not be possible to continue measuring H, He and electrons. The purpose of the "pixel" rates is to provide a means of monitoring the count rate of H+He at various depths in the stack under extreme conditions. Note that the pixel count rates can be calibrated against the standard H and He rates and energy spectra during smaller events and as the intensities build up to >10^5/s and then later as they retreat again.

The minimum threshold for reaching pixels located in L2A and L4A are ~2 and ~16 MeV/nuc for H and ^{4}He. The thresholds will be set sufficiently high to prevent triggering by electrons.

The pixel count rates will be counted by scalers that are not affected by deadtime in the coincidence logic. There are a maximum of eight pixels that can be implemented, requiring a maximum of eight 16-bit rates.

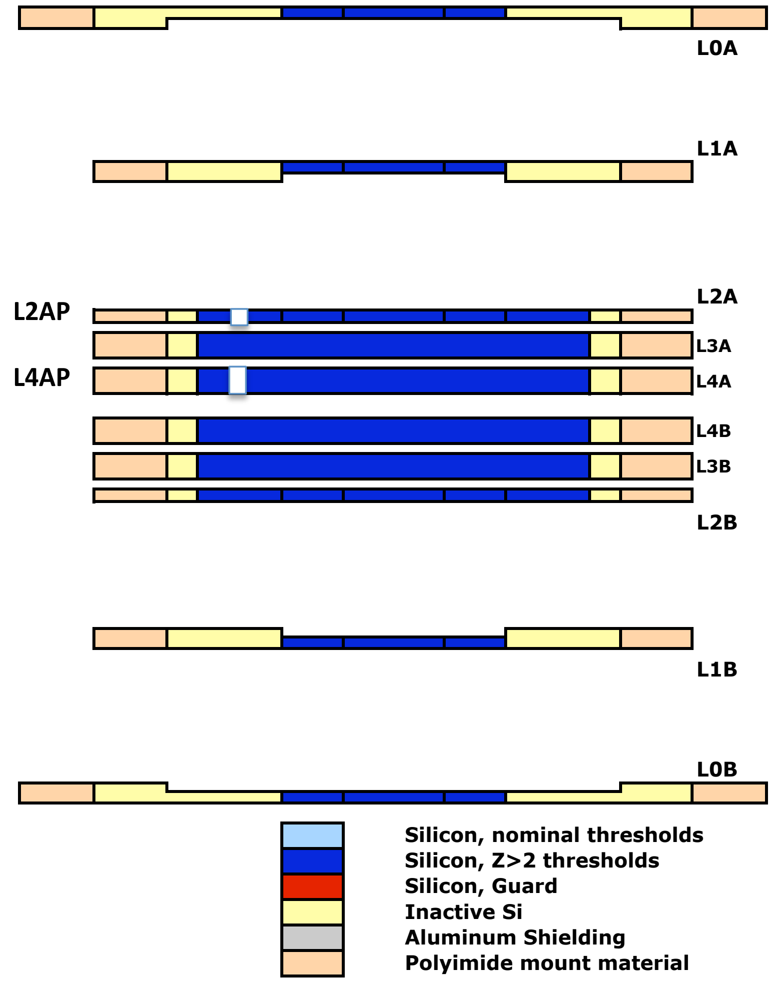
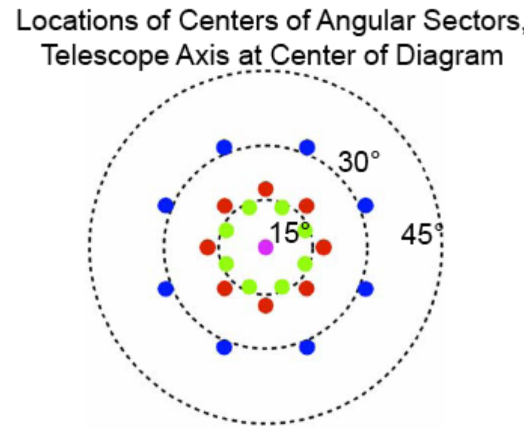


Figure 9: Drawing of the LET stack showing placement of pixel detectors in L2Aand L4A. The approximate proton energy thresholds are ~2 and ~16 MeV. The readout rate is TBD – here we assume every 10 seconds.

8. LET Sectored Data

The orientation of 5-segment L0, L1, and L2 detectors provides 5 L0•L1 sectors and 25 L1•L2 sectors. The centers of these overlapping sectors are shown at the right. In normal operation all LET events are assigned to a sector. The combination of the 3 LET apertures provide information on particle intensities from 75 overlapping directions, some of which will include obstructions (see slide 5). This strawman plan for tabulating Sectored data would collect 5-minute data from all 25 "sectors" of each aperture. Intervals labeled L0L1 are centered in the response of that detector combination (with L2 in anticoincidence), and similarly for those labeled L1L2. I used element groups to maximize statistical precision, but could use individual species (e.g., C, Mg, Fe) instead. I also included Cr and Ni with Fe in order to not miss any Fe.

During quiet times we expect many 5-minute periods with no counts in a given telescope. We need to find a compact way to store this information and apply the unused bits to uses like down-loading more PHA event data.

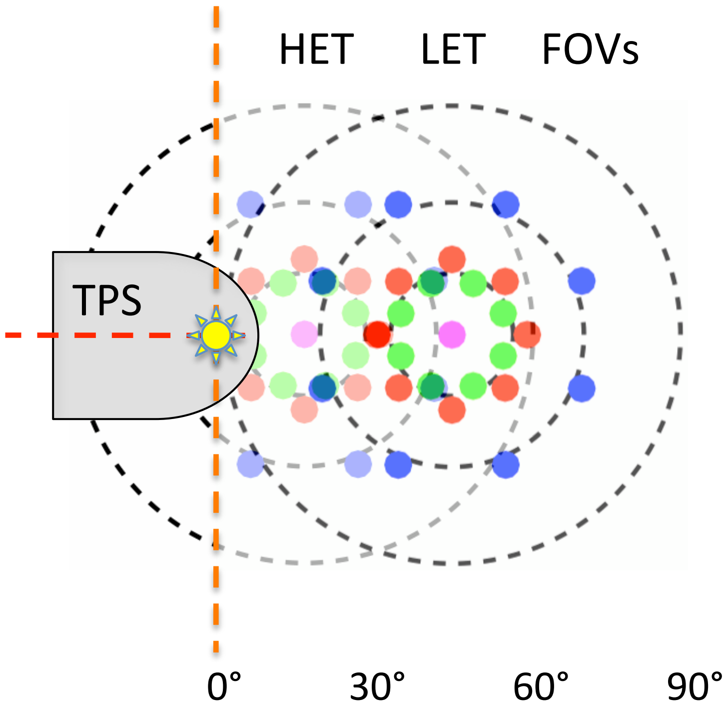


LET Sectored Data

There are 25 L1•L2 and 5 L0•L1 combinations - include all of them to help with intercalibration and obstructions

		L3A-L4B																					
L0•L1 Sectors			5	5		5		5					5								5			
L1•L2 Sectors		25	25	25		25		25				25								25			
Time Res		300	300	300		300		300				300								300			
		Elec	H	He		3He	C	N	O	Ne	Ne22	Na	Mg	Al	Si	S	Ar	Ca	Cr	Fe	Ni	L0L1	L1L2
0.354	0.50	3																					75
0.500	0.71																						0
0.707	1.00	3																					75
1	1.41		3	3	L0L1	3																45	
1.41	2.00	3																					75
2.00	2.83		3	3	L1L2	3		3				3			L0L1					3	L0L1	45	225
2.83	4.00				+																		0
4.00	5.66		3	3		3		3				3			L1L2					3	L1L2		450
5.66	8.00														+						+		0
8.00	11.3		3	3		3		3				3								3			450
11.3	16.0																						0
16.0	22.6					3		3				3								3			300
22.6	32.0																						0
32.0	45.3																						
45.3	64.0																				L0L1	12 bit	90
																					L1L2	12 bit	1650
																						bps	70

9. ENAs from the Charge-Exchange of CME-Shock Accelerated Particles



With the combination of LET & HET it may be possible to observe Energetic Neutral Atoms (ENAs) from the charge-exchange of CME shock-accelerated particles (Mewaldt et al. ApJ Letters 693, L11, 2009).

The 5x5 arrays of the L0, L1, L2 and the H1, H2 detectors each provide 25 different viewing directions extending to 45° from their pointing direction. At 0.25 AU they can view to ~9 Rs above of the solar surface – at 0.1 AU LET & HET can view down to within ~1 Rs. The thermal protection System (TPS) obscures the Sun.

ENAs can be identified by their timing and by their direction with respect to the Sun and IMF if the background count rates are sufficiently low.

Using LET & HET data during sufficiently quiet periods we will use the measured particle energy to compute minute-by-minute histograms of when protons in 50 overlapping sectors left the Sun (see slide 17) if we make use of the SPP distance from the Sun which is available each second.

Minute by Minute Catalog of ENA Candidates

ENA Protons

- **Can only detect ENAs when background proton count rates are low enough (< TBD cts/s) so that the Corona/CME stands out in direction & emission-time profile**
- **At 0.25 AU LET/HET view down to ~9 solar radii (Rs) above the surface**
  At 0.05 AU LET/HET can see the corona ~1 Rs above the surce
- **Record 1-minute files of protons in 5 forward L0•L1 sectors and 25 L1•L2 sectors**
- **Use measured kinetic energy to compute particle velocity**
  v = SQRT(2*Mp/E)
- **Using 1-sec S/C position information make histogram of when protons left the Sun**
  Tsun = Tobs - D/v
- **Arrival uncertainty dT = 1/SQRT(12) = 0.289 min**
- **There are also contributions to energy resolution due to noise and channel width, but overall we can get ~1 minute uncertainty in ENA release times**
- **During Quiet periods (e.g., 2007-2009) most 10-min periods will have 0 events. These need not be sent.**
- **During active periods (e.g., 2012-2013) most 10-min periods will have too many events (e.g., >100/s). These need not be sent.**
  Thus, the actual ENA bit rate will likely be <50% of the allocation.
  STEREO/LET data can be used to estimate what fraction of 10-minute periods meet the criteria.

Timing uncertainty for worst case of 0.25 AU

	Energy (MeV) E1	E2	Min Beta	Max Beta	Max T (min)	MinT (min)	sigT fromE (min)	Add in Time dT (min)	Sect
	0.59	0.84	0.036	0.042	58.5	49.2	2.69	2.71	5
L0L1	0.84	1.00	0.042	0.046	49.2	45.2	1.18	1.22	5
	1.00	1.19	0.046	0.050	45.2	41.4	1.08	1.12	5
	1.19	1.41	0.050	0.055	41.4	38.0	0.99	1.03	5
	1.41	1.68	0.055	0.060	38.0	34.8	0.91	0.95	5
	1.68	2.00	0.060	0.065	34.8	32.0	0.83	0.88	5
	2.00	2.38	0.065	0.071	32.0	29.3	0.76	0.82	5
L1L2	1.41	1.68	0.055	0.060	38.0	34.8	0.91	0.95	25
	1.68	2.00	0.060	0.065	34.8	32.0	0.83	0.88	25
	2.00	2.38	0.065	0.071	32.0	29.3	0.76	0.82	25
	2.38	2.83	0.071	0.077	29.3	26.9	0.70	0.76	25
	2.83	3.36	0.077	0.084	26.9	24.7	0.64	0.7	25
	3.36	4.00	0.084	0.092	24.7	22.6	0.59	0.66	25
	4.00	4.75	0.092	0.100	22.6	20.8	0.54	0.61	25
	4.75	5.65	0.100	0.109	20.8	19.1	0.50	0.57	25
	5.65	6.72	0.109	0.119	19.1	17.5	0.45	0.54	25
	6.72	7.99	0.119	0.130	17.5	16.1	0.42	0.51	25
L1L2L3	7.99	9.50	0.130	0.141	16.1	14.7	0.38	0.48	25
	9.50	11.3	0.141	0.154	14.8	13.5	0.35	0.45	25
	11.3	13.4	0.154	0.167	13.5	12.4	0.32	0.43	25
	13.4	16.0	0.167	0.182	12.4	11.4	0.29	0.41	25

Rates	**360**
bits	**12**
bps	**72**
Effective bps	**24**

10. Rate Data and Bit Rates for ≥0.25 AU:

These files are not yet defined, but the main philosophy will be to produce the same data products but with less time resolution (e.g., mostly 1-hr rates) with limited 1-minute data for SEP timing. We will also include key housekeeping data.

11. Quick-Look Data:

Ideally, these data would be the same content as as the ≥0.25 AU files. Then we would have a complete summary of the entire orbit available with uniform time bases that could be telemetered first and provide a summary of any SEP, CIR, or shock events, and temperature, noise, or background count-rate changes.

12. Summary of LET Bit Rate Estimates

The Table below summarizes the bit rates estimated in Sections 2 through 9. It also includes some quiet time count rates based on IMP-7&8 and it includes some description of what fraction of the rates will be non-zero.

Because the SPP/LET geometry factors are similar to those in STEREO/LET (and ~30 times lower than in ACE/SIS), we know that count rates due to galactic cosmic rays will be low (~1 per minute). Therefore, we should gain a lot from data compression during solar quiet times. Even during large SEP events, only a small fraction of the LET 1-minute composition bins will be triggered in a given minute.

Summary of LET Bit Rates

Data Product	Cadence (sec)	Category	Rates	bps	Typical Fraction of zero rates
LET 1-Minute Ions	60	L0•L1	1425	333	>90%
	60	L2A-L3B	1386	283	>90%
	60	L4B	258	53	>90%
LET Penetrating	60	Ions	418	62	>90%
LET 10-second	10	Electrons	147	132	~10%
	10	H&He	157	152	>90%
	10	Z≥6 Ions	192	154	99%
LET 1-second	1	Electrons	6	48	~20%
	1	Ions	9	72	~99%
LET Pixel Rates	600	Ions	2	3	99%
LET Sectored (5-min)	300	Ion/Electrons	1740	70	>90%
ENAs	60	ENAs	360	72	90%
Events	5/sec?	PHA Data		300	20%
Housekeeping	?	HK Data		80	0%
Total			6100	1814	

13. References

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