

Pointing and Orbit Data for the SEP Instruments on the STEREO Spacecraft

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This document provides information about orientation of the LET instrument on the STEREO Ahead and Behind spacecraft, and instructions for calculating pointing (attitude) and position vectors for any SEP instrument from the spacecraft ancillary data.

- Sections 1 and 2 deal with defining a LET coordinate system, and provide a recipe for converting vectors in the LET system to the spacecraft coordinate system. No recipe is provided for the other SEP instruments – this is left to the respective instrument teams.
- Section 3 describes a procedure for transforming pointing vectors in the spacecraft coordinate system to other useful coordinate systems, using transformation matrices provided by Caltech. These transformation matrices are provided in text data files, and the format of these files is described.
- Section 4 describes the format of the STEREO orbit data text files provided by Caltech.

1. LET Orientation with Respect to the Spacecraft Coordinate System

1.1. *Both Spacecraft*

For both spacecraft:

- LET is mounted on the S/C +Y panel.
- The S/C +X axis points sunward.
- During normal flight operations, the S/C X-Z plane and the ecliptic plane will generally be co-planar, approximately.

For both spacecraft, we define a LET coordinate system as follows:

- X: center of LET forward Field of View (FOV).
- Y: outward from spacecraft (same as S/C +Y axis).
- Z: completes the right-hand orthogonal set.

For the purposes of this discussion, we may ignore the fact that the origins of the LET and S/C origins are not co-located.

1.2. *Ahead Spacecraft*

The Ahead S/C Y-axis points towards the north ecliptic pole. The LET X-Z plane is rotated $\theta = +45^\circ$ about the S/C Y-axis (see Figure 1). To transform a vector \mathbf{v} in the LET_a system to a vector \mathbf{v}' in the S/C_a system,

$$\mathbf{v}' = \mathbf{T}_a \mathbf{v}$$

where $T_a = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix}$

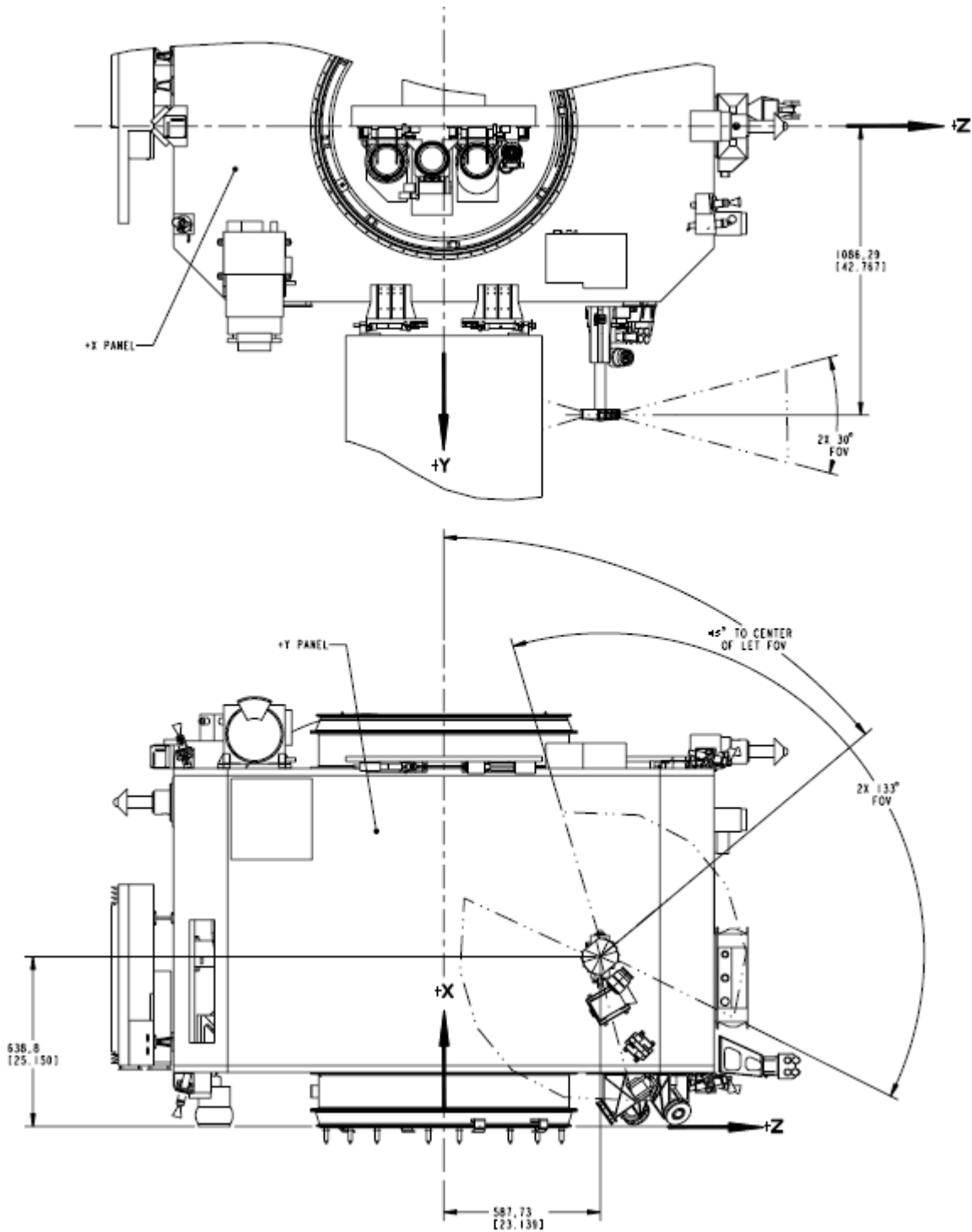


Figure 1: LET mounting and orientation on the Ahead Spacecraft, showing S/C X, Y, and Z axes. For illustration purposes only, positions and dimensions not exact.

1.3. Behind Spacecraft

The Behind S/C Y-axis points towards the south ecliptic pole. A diagram of the LET mounting on the Behind spacecraft is TBD. The LET is mounted in a different position on the S/C +Y panel, and The LET X-Z plane is rotated $\theta = -45^\circ$ about the S/C Y-axis (note the negative angle). The transformation matrix to transform a vector \mathbf{v} in the LET_b system to a vector \mathbf{v}' in the S/C_b system is the same as for the Ahead S/C: just be sure to use the correct sign for the angle θ .

2. LET Sectors (Look Directions)

The various combinations of L1 and L2 segments define a total of 300 different directions in the LET X-Z plane. These directions are sorted during onboard data processing into sixteen sectors, defined in Table 1.

Table 1: LET Detector Combinations Sorted into Sectors

	L1A0			L1A1			L1A2			L1A3			L1A4		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
L2A0	6	5	5	3	3	3	2	1	1	0	0	0	0	0	0
L2A1	6	6	6	4	4	3	2	2	2	0	0	0	0	0	0
L2A2	7	6	6	5	4	4	3	2	2	1	1	0	0	0	0
L2A3	7	7	6	5	5	4	3	3	2	1	1	1	0	0	0
L2A4	7	7	7	6	5	5	4	3	3	2	1	1	0	0	0
L2A5	7	7	7	6	6	5	4	4	3	2	2	1	0	0	0
L2A6	7	7	7	6	6	6	5	4	4	3	2	2	1	0	0
L2A7	7	7	7	7	6	6	5	5	4	3	3	2	1	1	0
L2A8	7	7	7	7	7	7	5	5	5	4	3	3	1	1	1
L2A9	7	7	7	7	7	7	6	6	5	4	4	4	2	2	1
	L1B0			L1B1			L1B2			L1B3			L1B4		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
L2B0	14	13	13	11	11	11	10	9	9	8	8	8	8	8	8
L2B1	14	14	14	12	12	11	10	10	10	8	8	8	8	8	8
L2B2	15	14	14	13	12	12	11	10	10	9	9	8	8	8	8
L2B3	15	15	14	13	13	12	11	11	10	9	9	9	8	8	8
L2B4	15	15	15	14	13	13	12	11	11	10	9	9	8	8	8
L2B5	15	15	15	14	14	13	12	12	11	10	10	9	8	8	8
L2B6	15	15	15	14	14	14	13	12	12	11	10	10	9	8	8
L2B7	15	15	15	15	14	14	13	13	12	11	11	10	9	9	8
L2B8	15	15	15	15	15	15	12	13	13	12	11	11	9	9	9
L2B9	15	15	15	15	15	15	14	14	13	12	12	12	10	10	9

Each sector points in a direction defined by an angle with the LET +X axis. From this angle, the pointing vector for each sector may be calculated. The angles and pointing vectors (in the LET and the S/C coordinate systems) are listed in Table 2. Angles and pointing vectors for each individual LET L1-L2 detector combination are given in an appendix (TBD).

Table 2: LET Sector Pointing Vectors, in the LET and S/C coordinate systems.

Side	Sector	Angle with LET +X-axis (nominal)	Pointing Vector in LET coord.sys		Pointing Vector in Ahead S/C coord.sys		Pointing Vector in Behind S/C coord.sys	
			x	z	x'	z'	x'	z'
A	0	50	0.6428	0.7660	-0.0872	0.9962	0.9962	0.0872
A	1	31.25	0.8549	0.5188	0.2377	0.9713	0.9713	-0.2377
A	2	18.75	0.9469	0.3214	0.4423	0.8969	0.8969	-0.4423
A	3	6.25	0.9941	0.1089	0.6259	0.7799	0.7799	-0.6259
A	4	-6.25	0.9941	-0.1089	0.7799	0.6259	0.6259	-0.7799
A	5	-18.75	0.9469	-0.3214	0.8969	0.4423	0.4423	-0.8969
A	6	-31.25	0.8549	-0.5188	0.9713	0.2377	0.2377	-0.9713
A	7	-50	0.6428	-0.7660	0.9962	-0.0872	-0.0872	-0.9962
B	8	-130	-0.6428	-0.7660	0.0872	-0.9962	-0.9962	-0.0872
B	9	-148.75	-0.8549	-0.5188	-0.2377	-0.9713	-0.9713	0.2377
B	10	-161.25	-0.9469	-0.3214	-0.4423	-0.8969	-0.8969	0.4423
B	11	-173.75	-0.9941	-0.1089	-0.6259	-0.7799	-0.7799	0.6259
B	12	173.75	-0.9941	0.1089	-0.7799	-0.6259	-0.6259	0.7799
B	13	161.25	-0.9469	0.3214	-0.8969	-0.4423	-0.4423	0.8969
B	14	148.75	-0.8549	0.5188	-0.9713	-0.2377	-0.2377	0.9713
B	15	130	-0.6428	0.7660	-0.9962	0.0872	0.0872	0.9962

Note: The **y** component of all LET pointing vectors is zero, in both the LET and S/C coordinate systems.

Figure 2 below shows the coverage in longitudinal angle for each of the LET sectors. The "Longitude from LET Axis" is the same angular measure as in column 3 of Table 2 above. Basically, the view cones are $\sim \pm 8$ deg in the ecliptic and $\sim \pm 14^\circ$ out of the ecliptic, except for the outside segments which are twice as wide. There are some variations from center to edge.

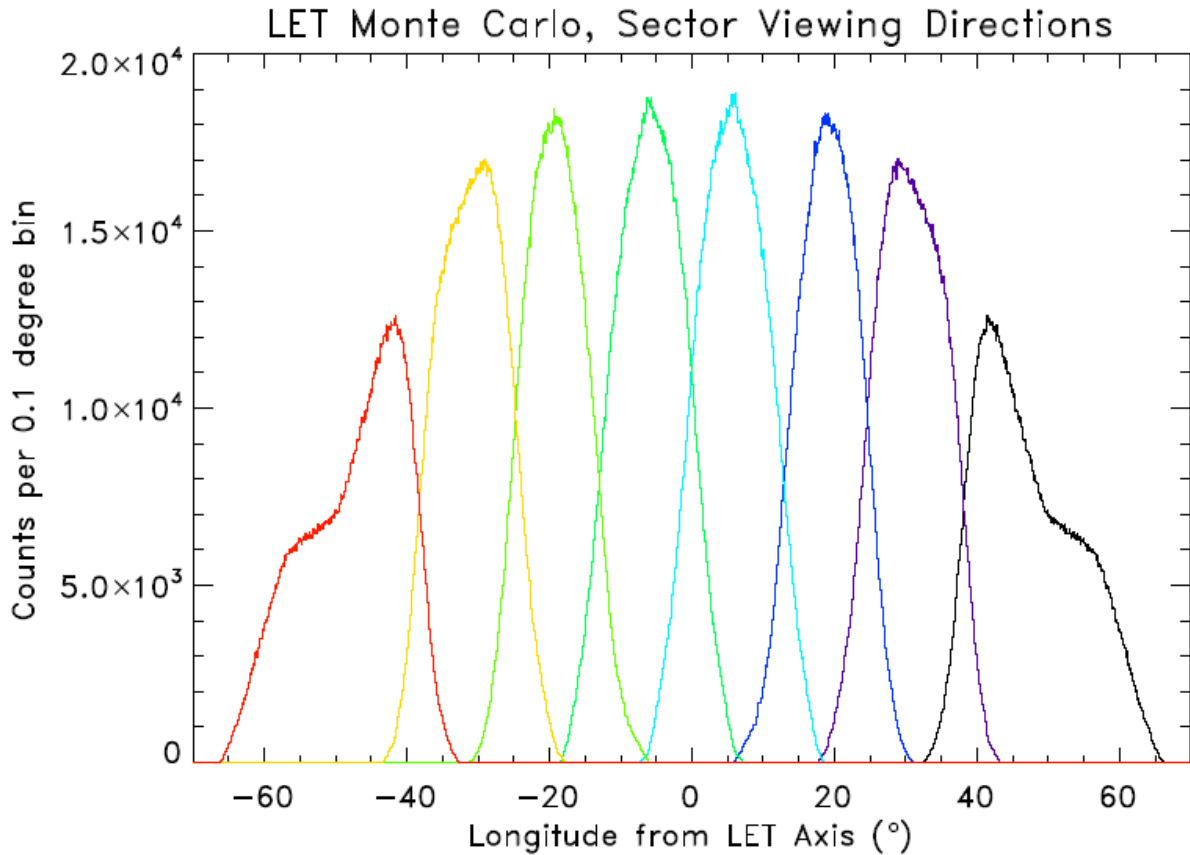


Figure 2: Coverage in longitudinal angle for each of the LET sectors.

3. Transformations from Spacecraft to Other Coordinate Systems

We have described the transformation of vectors from the LET to the S/C coordinate system. This section summarizes the procedures for transforming vectors in the S/C coordinate system to other useful coordinate systems.

The STEREO Science Center provides IDL SPICE software via the Solarsoft library that facilitates the transformation of vectors in the S/C coordinate system to other useful coordinate systems. The full list of supported coordinate systems and their descriptions may be found in the STEREO Solarsoft documentation. The subset currently assumed to be useful for LET data analysis is listed and described in Appendix B (more can be added as needed). The descriptions are copied from the STEREO Solarsoft documentation. Included are GEI, GSE, GSM, RTN, and several heliocentric coordinate systems.

Since a number of SEP team investigators either do not use IDL, or do not wish to install Solarsoft, Caltech provides text files containing transformation matrices for converting vectors from the S/C coordinate system to the coordinate systems listed in Appendix B. The format of each record in these files is as follows:

YYYY DoY Second Flag M_00 M_01 M_02 M_10 M_11 M_12 M_20 M_21 M_22

Where YYYY is the 4-digit year

DoY is the day-of-year (counting from 1)

Second is the second-of-day

Flag is 0 if the data are predictive

1 if the data are definitive

M_{ij} are the transformation matrix elements from the S/C coordinate system to the new coordinate system, where i is the row index, j is the column index.

The time cadence of records within these files is variable. A new record is appended only

- at the beginning of each day, **or**
- if the direction of the S/C X-axis changes by more than TOL degrees, **or**
- if the direction of the S/C Y-axis changes by more than TOL degrees

TOL is currently set to 0.25 degrees.

4. STEREO Orbit Data

The STEREO Science Center provides IDL SPICE software via the Solarsoft library that returns the coordinates of either of the two STEREO spacecraft in any of the supported coordinate systems. **Again, since a number of SEP team investigators either do not use IDL, or do not wish to install Solarsoft, Caltech provides text files containing position coordinates for the ahead and behind spacecraft in the coordinate systems listed in Appendix B (except for HGRTN/RTN) . The format of each record in these files is:**

YYYY DoY Second Flag P_0 P_1 P_2

Where YYYY is the 4-digit year

DoY is the day-of-year (counting from 1)

Second is the second-of-day

Flag is 0 if the data are predictive

1 if the data are definitive

P_i are the components of the spacecraft position vector in the given coordinate system.

The time cadence of records within these files is variable. A new record is appended only

- at the beginning of each day, **or**
- if the position of the S/C changes by more than TOL kilometers from the previous position.

TOL is currently set to 1000 km.

Appendix A: Coordinate Systems useful for LET Data Analysis

Transformation matrices for converting vectors from the S/C coordinate system to these coordinate systems are provided by Caltech as text files to the SEP instrument teams.

GCI: Geocentric Equatorial Inertial. The X axis points toward the first point of Aries (i.e. the vernal equinox), and the Z axis is aligned with the geographic north pole. When expressed in terms of longitude and latitude, this is the well known celestial coordinate system of right ascension and declination. This is realized with the J2000 ecliptic.

GSE: Geocentric Solar Ecliptic. X is the Earth-Sun line, and Z is aligned with the north pole for the ecliptic of date.

GSM: Geocentric Solar Magnetospheric. X is the Earth-Sun line, and Z is the projection of the north dipole axis.

HCI: Heliocentric Inertial. Z is the solar north rotational axis, and X is the solar ascending node on the J2000 ecliptic.

HEE: Heliocentric Earth Ecliptic. X is the Sun-Earth line, and Z is the north pole for the ecliptic of date.

HEEQ: Heliocentric Earth Equatorial. Z is the solar rotation axis, and X is in the plane containing the Z axis and Earth, at the intersection of the solar central meridian, and the heliographic equator. When converted to longitude and latitude, this is known as Stonyhurst heliographic coordinates. In FITS files, this coordinate system is abbreviated as “HEQ”, so that variation is also recognized by the software.

HGRTN/RTN: Radial-Tangential-Normal. X axis points from Sun center to the spacecraft, and the Y axis is the cross product of the solar rotational axis and X , and lies in the solar equatorial plane (towards the West limb). For the STEREO Ahead spacecraft, this is realized through the dynamic coordinate frame STAHGRTN, while for STEREO Behind it is realized through STBHGRTN. When the Sun is used as the origin, the designation is HGRTN—with the spacecraft as origin, it’s simply RTN.