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# Converting from RAPID Coordinates to GSE


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**A note to clarify some misunderstandings**

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# 1 Introduction

The electron and ion data acquired by RAPID on Cluster are sorted by directions relative to a coordinate system fixed to the spacecraft. There are 16 spin sectors (Figure 1) numbered 0 through 15 and 9 (electrons) or 12 (ion) polar segments (Figure 2). However, for any data analysis, it is necessary to have these directions in Geocentric Solar Ecliptic (GSE) coordinates.

This note explains how the user can determine the precise GSE coordinates for any vector specified in RAPID sector and polar directions. The key to this is a rotation matrix derived from the attitude information provided by the ESOC on the CD-ROMs plus RAPID housekeeping data for the origin of the sector system relative to the sun pulse. This rotation matrix is written to all the science files (`*.SCI`) and offers the most accurate conversion to GSE.

# 2 The ideal geometry

Figures 2 and 1 have often been used by experimenters together with the statement that "the spin axis points along the southern GSE Z-axis" to obtain a rough translation from sector/polar to GSE. However, this procedure neglects two important factors:

- The spin axis is not exactly along the GSE $-$Z-axis, but can deviate by as much as $6^\circ$. The Experiment Interface Document (Part A) merely states that the solar aspect angle is to be between $92^\circ$ and $96^\circ$.
- The RAPID sector origin is a variable, whose default value does not coincide with Figure 1; it must be set by command to achieve this configuration, and these values are occasionally lost (via DPU reset, patch corruption). There was even a case where ESOC uploaded the wrong values!

It must be emphasized that Figure 1 is not hardwired into the RAPID instrument, but is a goal that we wish to maintain.

# 3 Specifications needed for conversion

The parameters required to convert from the RAPID-based system to GSE are:

- The location of RAPID on the spacecraft. This is fixed (I darn well hope so) at $60.0^\circ$ from the reference direction.
- The position of the solar sensor. This too is fixed at $26.2^\circ$, but that is not the deciding factor. The ESOC attitude files specify the spin phase of the reference direction at the time of the sun reference pulse, which can vary with solar aspect angle and sensor sensitivity. On August 22, 2001, this spin phase was $333.928^\circ$, corresponding an effective position of $26.072^\circ$ for the solar sensor. Figure 1 was drawn assuming $26.2^\circ$.

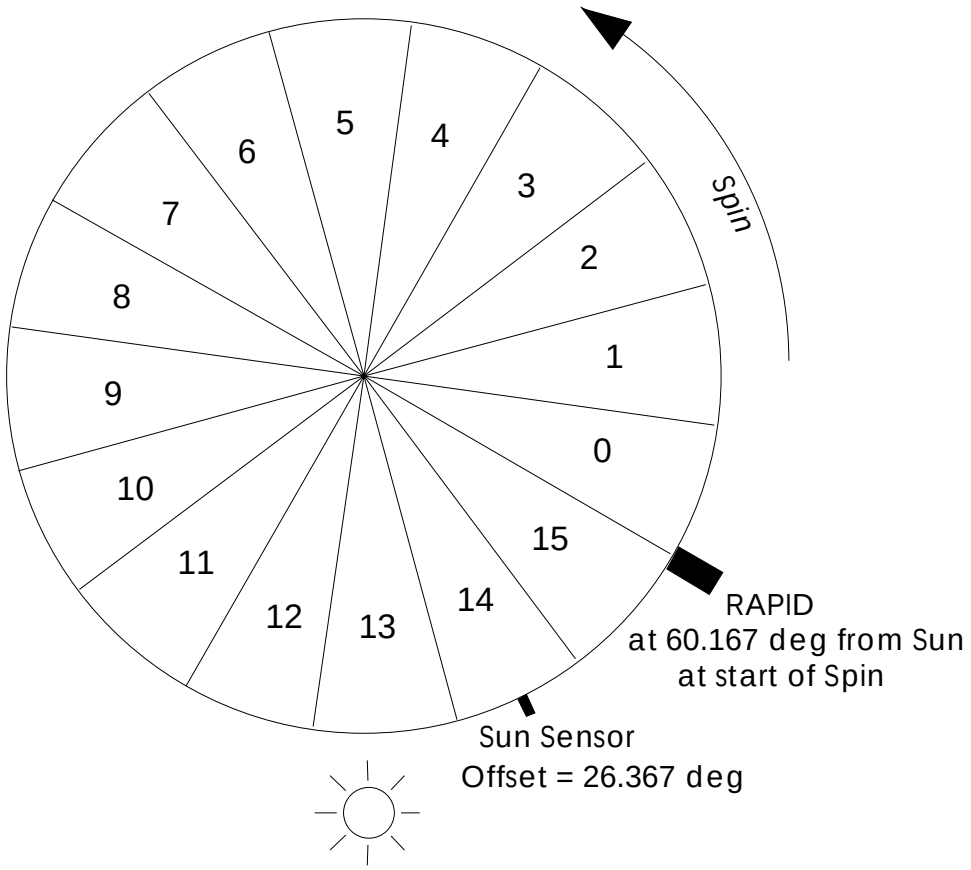


Figure 1: RAPID sectorization relative to the sun; the spin axis really points to the GSE south pole so this scheme is effectively as viewed from the south.

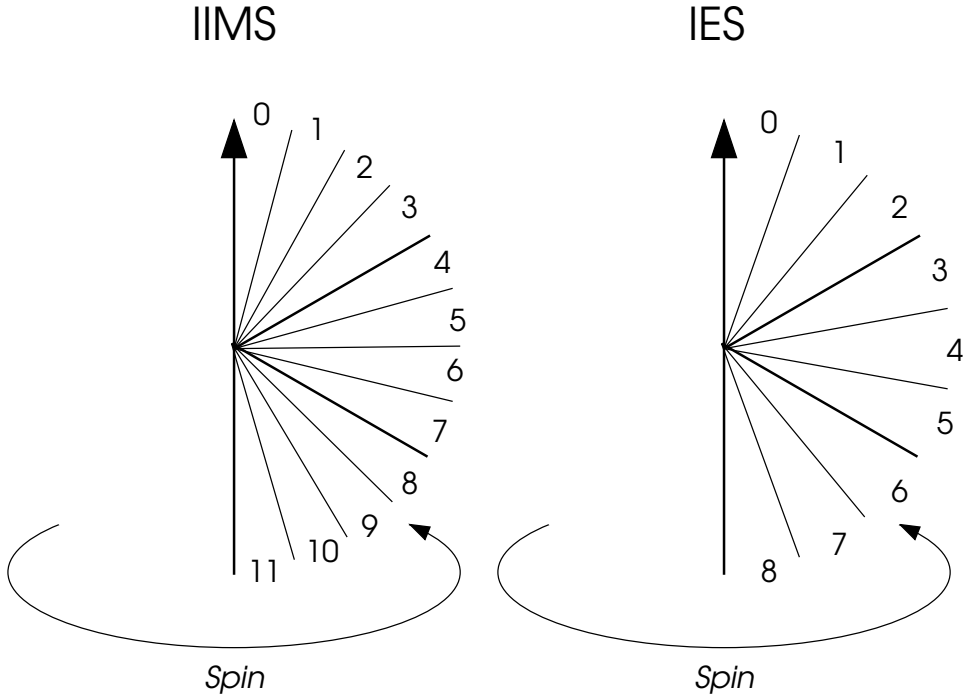


Figure 2: IIMS and IES polar segments, relative to the SC spin axis, which actually points to the GSE south pole.

- The orientation of the spin axis. This is given in the ESOC attitude files in declination and right ascension, the coordinates of the astronomers' Geocentric Equatorial Inertial (GEI) system. This is converted to GSE using the standard algorithms.
- The location of the sun pulse in the RAPID sector scheme. There is an agreement among the Cluster experimenters to define the start of a spin simultaneously, so that spin averaged data all cover exactly the same time interval. Each experiment has its restrictions on defining the spin start, and the common solution was found to be that the spin start (sector 0.0 for RAPID) should $\frac{75}{1024}$ of a rotation after the sun pulse, or an offset of $\approx$26.367°.

  The parameters that are uploaded to RAPID, and which are found in the housekeeping words `ERDSPSEC` and `ERDSSPOS` specify the sector and fraction of sector where RAPID is pointing when the sun pulse comes. This is essentially the negative of the offset. The parameters needed to achieve this are `ERDSPEC=14` and `ERDSSPOS=212` (meaning sector 14 plus $\frac{212}{256}$ of a sector. The default values are 0 and 127, corresponding to a difference in the offset of 37.6° or 1.6 sectors.

The conventional offset of 26.367° with the sun sensor at 26.2° results in the sun being located at sector 13.32 (viewing sector number as a continuous value from 0.0 to 15.999). For the default offset, the sun would be at sector 14.99.

# 4 The RAPID to GSE rotation matrix

Let us define the RAPID coordinate system to be relative to unit vectors $\hat{u}$ along sector 0.0, $\hat{v}$ along sector 4.0, and $\hat{w}$ along the spin axis. The look direction for sector $s$ and (ion) polar direction $d$ (both viewed as continuous numbers from 0.0) is a vector

$$\mathbf{V} = a\hat{u} + b\hat{v} + c\hat{w} \tag{1}$$

and

$$\begin{aligned} a &= \sin\left(\frac{\pi \cdot d}{12}\right)\cos\left(\frac{2\pi \cdot s}{16}\right) \\ b &= \sin\left(\frac{\pi \cdot d}{12}\right)\sin\left(\frac{2\pi \cdot s}{16}\right) \\ c &= \cos\left(\frac{\pi \cdot d}{12}\right) \end{aligned} \tag{2}$$

(For electrons, $d$ goes from 0.0 to 8.999, so must be divided by 9, not 12.)

Using the factors listed in section 3 (ESOC attitude files, RAPID housekeeping parameters) it is possible to generate for any time the rotation matrix to convert between RAPID coordinates and GSE. This matrix is written at least once into the `*.SCI` files, with the prefix `A`, as for example:

```
A  9  2001-08-22T03:31:01.089Z C1  GSE X,Y,Z in SC coords (relative to sector 0.0)
0.4930 -0.8643 -0.0993 -0.8697 -0.4923 -0.0337 -0.0197  0.1030 -0.9944
```

It can be written more often if the offset angle should change.

The 9 values can be considered to be the components of the GSE unit vectors $\hat{x}$, $\hat{y}$, $\hat{z}$ expressed in RAPID coordinates. They are also the components $M_{11}$, $M_{12}$, $M_{13}$, $M_{21}$, ... of the matrix $\mathsf{M}$, that is, they are inserted into the matrix *by row*.

The GSE X-component of $\mathbf{V}$ is given as:

$$\begin{aligned} \mathbf{V} \cdot \hat{x}_{gse} &= a\,\hat{u} \cdot \hat{x}_{gse} + b\,\hat{v} \cdot \hat{x}_{gse} + c\,\hat{w} \cdot \hat{x}_{gse} \\ &= a\,M_{11} + b\,M_{12} + c\,M_{13} \end{aligned} \tag{3}$$

and so on for the other components. This is summarized as

$$\mathbf{V}_{gse} = \begin{pmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \tag{4}$$

or generally,

$$\mathbf{V}_{gse} = \mathsf{M} \cdot \mathbf{V}_{rap}$$

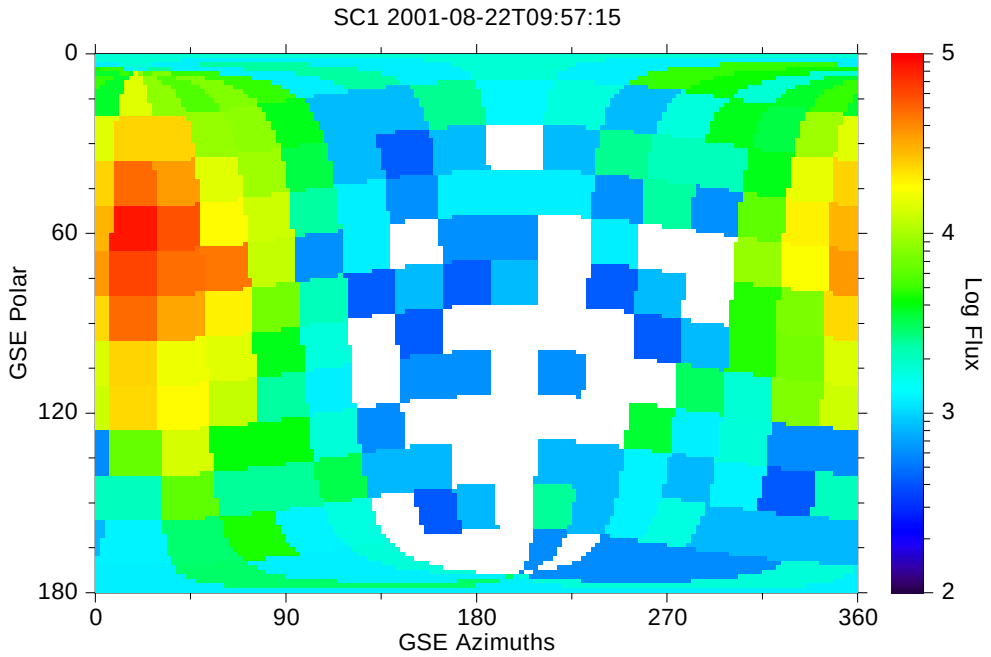


Figure 3: Sample of RAPID I3DD data with 16 sectors × 12 polar directions mapped into GSE, with tilted spin axis.

The rows of $\mathsf{M}$ are the GSE unit vectors in RAPID coordinates, while the columns are the RAPID unit vectors $\hat{u}$, $\hat{v}$, $\hat{w}$ in GSE. In particular, the 3rd column (the 3rd, 6th, 9th values) is the spin axis in GSE. Ideally this should be $(0., 0., -1.)$ if the axis were exactly along the southern GSE pole.

As a consequence of the tilt between spin axis and GSE south pole is that the RAPID sector/polar areas do not map into squares in GSE polar and azimuth, as shown in an example of a GSE representation of the I3DD flux for protons in Figure 3.

# 5 Summary

The precise determination of the GSE coordinates of any direction in the RAPID sector/polar system can only be made by considering several different parameters in the ESOC attitude files and in the RAPID housekeeping data, as well as with some knowledge of the geometry of the instrument's location. All these factors have been taken into account to produce a general rotation matrix $\mathsf{M}$ that is given in every `*.SCI` file. This matrix is applied as shown in equations 1 and 4.

This is the definitive conversion from sector and polar numbers to GSE coordinates. In contrast, Figure 1 can only be considered an ideal goal, not the absolute truth.