

# RHESSI Aspect Solution Users Guide

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## Introduction

RHESSI has two subsystems (SAS and RAS) of sensors, which acquire data for off-line reconstruction of the aspect solution. The SAS (Solar Aspect System) consists of three lens/sensor pairs measuring the Solar limb at about 670 nm. The off-line data analysis reconstructs the Sun center with respect to the imaging axis (the reference telescope axis). The RAS (Roll Angle System) is a star tracker pointing radially outwards. With respect to the rotating spacecraft, the images of stars are traveling over a linear CCD and are triggering star events to be included in the telemetry data. By comparing with a star catalog, the off-line analysis software calculates the momentary roll angle. The integration of both information provides the aspect solution to be used for image reconstruction.

## 1 Software Flow Overview

The transmitted data consists of Solar limb data from the SAS, CCD pixels around the intersection of a Solar image with three linear CCDs, and Star event data from the RAS, CCD pixels induced by passages of Star images over a linear CCD. Fig. 2 shows the flow diagram of the aspect solution software. The Solar limbs and the Star events are fitted independently. Knowing the geometry of all features of the SAS, the position of the Sun center, with respect to a spacecraft fixed coordinate system, can be calculated, and a list of position angle marks can be generated by fitting of the Star events and subsequent comparison with a Star catalog. Integrating these information allows a correction and interpolation of the roll angles. Finally, the coordinates are converted into the needed pointing and roll angle format with respect to a Solar fixed coordinate system.

## 2 The Aspect Coordinate System

### Solar Aspect System SAS

The SAS features define the reference coordinate system to be used for the image reconstruction. This coordinate system is called the imaging coordinate system (or SAS coordinate system) and has been chosen in order to optimize the SAS field of view in a symmetrical way. The z-axis is parallel to the line from the center of gravity of the three CCD mid-points to the center of gravity of the lens centers and its pointing towards the Sun. The x- and y-axis are chosen to form a right-handed Cartesian coordinate system with the y-axis being parallel to the xy-plane of the rear tray coordinate system, which had been used as the reference for building the imager. The origin of the imaging coordinate system is the center of gravity of the CCD mid-points.

In Fig. 1  $\tilde{x}$  and  $\tilde{y}$  refers to the SAS coordinate system. In spacecraft fixed coordinates, the pointing is given by the vector from the origin of the SAS coordinate system to the momentary Sun center and is measured as an angle in arcsec. Therefore, the pointing is the  $\tilde{x}$ - and  $\tilde{y}$ -component of the angle between the  $\tilde{z}$ -axis and the direction towards the Sun center. Internally of the aspect

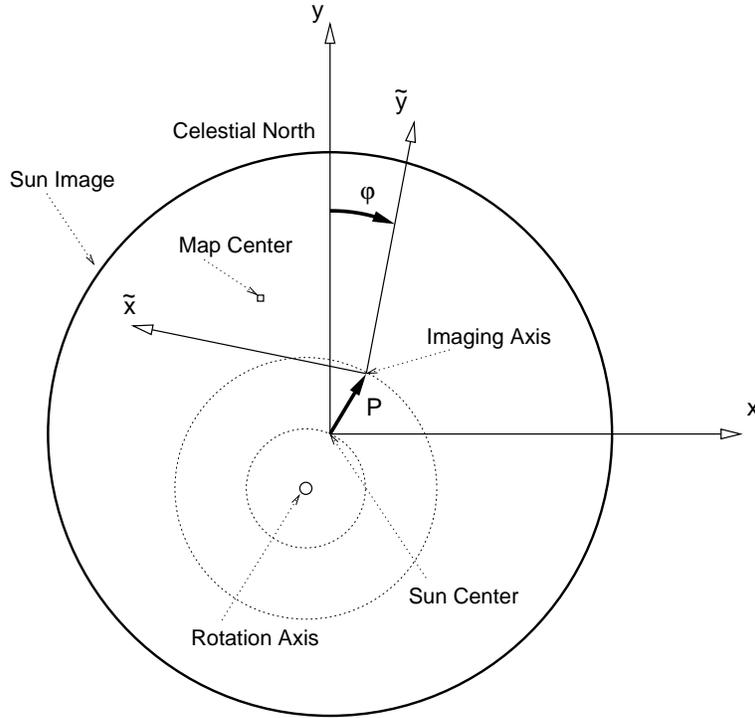


Figure 1: **The aspect coordinate system.** The circle drawn with a solid line represents the Solar limb.  $(x,y)$  refers to an inertial coordinate system with  $y$  pointing towards the north celestial pole.  $(\tilde{x},\tilde{y})$  refers to the imaging coordinate system, which is fixed to the S/C.  $P$  is the pointing vector in units of [arcsec] and  $\varphi$  is the rotation angle in [radian], which is increasing in time.

solution software, the limb positions are calculated in a pixel based coordinate system. Using the appropriate plate scale, the coordinates are converted to arcsec in order to provide a SAS solution.

## Roll Angle System RAS

The roll angle system measures the momentary roll angle of the rotation spacecraft. From the spacecraft looking towards the Sun, the spacecraft is rotating clockwise. Therefore, the momentary rotation vector is pointing more or less in the direction of the  $z$ -axis of the imaging coordinate system. After correcting for the off-pointing (i.e. align the  $z$ -axis to point towards the Sun center), the roll angle is defined to be the angle between the Solar fixed  $y$ -axis, which is pointing from the Sun center towards the north celestial pole (see Fig. 1), and the imaging  $\tilde{y}$ -axis. The angle is defined to be increasing in time and is measured in radians.

## The Aspect Solution

For the imaging reconstruction, the momentary grid phase and roll angle is relevant. Nevertheless, in order to have a clean and easy to understand interface, the aspect solution is defined to be a discrete list of sets of a pointing vector in Solar fixed coordinates, a roll angle and a time mark. The pointing vector contains the  $x$ - and  $y$ -component of the angle from the direction towards the Sun center and the imaging  $\tilde{z}$ -axis as shown in Fig. 1 and is measured in arcseconds. The roll angle is defined as described above.

### 3 The Aspect Reconstruction Software

For the most of the RHESSI data analysis, the aspect reconstruction suppose to be completely transparent. For documentation reason, especially for analysis software programmers, the command line interface is described here on the level of the aspect solution object.

#### Create an Object and Retrieve Data

The following commands show how to create an instance of the aspect solution object and how to retrieve data for a given time range. The definition of the 'aspect\_time\_range' is optional. If it's omitted, it's automatically set to 'obs\_time\_interval'. Setting the 'obs\_time\_interval' requires the RHESSI database files to be correctly installed and the RHESSI related environment variables to be set.

```
IDL> o=hsi_aspect_solution()
IDL> o->set, obs_time_interval='2002-03-13 '+'12:30','13:00']
IDL> o->set, aspect_time_range='2002-03-13 '+'12:40','12:45']
IDL> data=o->getdata()
```

Instead of defining an 'obs\_time\_interval', the 'filename' and 'file\_type' can be set directly. This is especially useful to analyze smex-files, which are not included in the RHESSI database, yet. The following example it's assumed, that the given file resides in the current directory. Otherwise, the current directory has to be changed or the filename has to be given including the relative or absolute path. Once again, the definition of the 'aspect\_time\_range' is optional. By default, it's set to 'file\_time\_range'.

```
IDL> o=hsi_aspect_solution()
IDL> o->set, filename='vc3_20020314065802.0',file_type='smex'
IDL> o->set, aspect_time_range='2002-03-13 '+'12:40','12:45']
IDL> data=o->getdata()
```

#### Aspect Data Format

Assuming the variable 'o' is an instance of an aspect solution object, which is defined as shown above. The returned aspect solution data is then structured as shown by the following commands.

```
IDL> data=o->getdata()
IDL> help, data, /struct
** Structure <85d36c4>, 4 tags, length=384788, data length=384788, refs=2:
  TIME          LONG          Array[19239]
  T0            STRUCT       -> HESSI_SCTIME_FULL Array[1]
  POINTING      FLOAT        Array[19239, 2]
  ROLL          DOUBLE       Array[19239]
```

The tag 'T0' of the variable 'data' holds the reference time in the sctime format. The tag 'time' is an array of relative times of the data points with respect to 'T0' and is given in units of  $2^{-7}$  seconds. The components [ $*$ ,0] of the tag 'pointing' are the x-components and the [ $*$ ,1] are the y-components of the pointing vector in units of arcseconds as described in section 2. Finally, the tag 'roll' holds the array of roll angles in radians as described in section 2.

#### Aspect Data at Given Times

To calculate an aspect solution for an array of given times the three input parameter THIS\_UT\_REF, THIS.TIME and THIS.UNIT.TIME can be specified to the getdata() methode of the aspect solution object as shown below.

```

IDL> data=o->getdata(this_ut_ref='2002-03-13 12:41', $
                    this_time=findgen(40), this_unit=2L^18)
IDL> help,data
DATA          STRUCT    = -> HSI_ASPECT Array[40]
IDL> help,data,/str
** Structure HSI_ASPECT, 5 tags, length=20, data length=20:
   DX          FLOAT      579.793
   DY          FLOAT     -69.4515
   PHI         FLOAT      345.195
   P_ERROR     FLOAT      0.0905938
   R_ERROR     FLOAT      0.000290888

```

The return value is an array of structures {hsi\_aspect}. 'DX' and 'DY' are the two components of the pointing vector and 'PHI' is the roll angle, both as described above. 'P\_ERROR' is the estimated error of the measured pointing and is returned in arc seconds. It includes an estimated error of the discrete pointing measurements and the induced error from the interpolation between the measured data points. The error of the roll angle is given by 'R\_ERROR' and is returned in radians. Currently, it's fixed set to 1 arc minute.

## Retrieve Aspect Information from Existing Imaging Object

Let's assume the variable 'o' refers to an instance of an object class, which inherits an aspect solution object. For instance, let's assume 'o' refers to an instance of the 'hsi\_image' object class. Using the following command line, the corresponding aspect solution data can be retrieved. The variable 'data' has the same format as described above.

```
IDL> data=o->getdata(class='hsi_aspect_solution',/this_class)
```

## Control Parameters

In Table 1 an overview of the control parameters of the aspect solution object is given. Reconstructing an image, the aspect solution control parameters suppose to have reasonable default value. Nevertheless, there are various circumstances where the aspect solution has to be controlled in more detail.

Parameter Name	Short Description	Default Value	Units
ASPECT_CNTLLEVEL	control levels between -2 and 10	0	-
ASPECT_TIMERANGE	optional time range	obs_time_int	anytim
RAS_TIME_EXTENSION	extension of time range for RAS	[-1400,+1400]	second
ASPECT_SIM	use simulated pointing	0	-
SASZERO	use pointing (0,0)	0	-
AS_SPIN_PERIOD	S/C spin period	4.0	second
AS_ROLL_OFFSET	roll angle at beginning of file	0.0	radian
AS_ROLL_SOLUTION	select mode of roll solution	'DBASE'	-
AS_NO_EXTRAPOL	allow/deny extrapolation of data	1	-
PMTRAS_DIAGNOSTIC	levels of diagnostics for PMTRAS	0u	-

Table 1: The control parameters of the aspect solution object.

1. ASPECT\_CNTLLEVEL. At various places of the aspect solution software error messages or warnings are produced, quality control values are calculated and plots are generated.

With the control parameter 'aspectctl\_level' level of controlling outputs can be selected. By default, aspect\_cntl\_level is set to zero, which print errors and some warnings to the IDL log window. The Table 2 shows the valid settings and their results. In general, the higher the parameter is set, the more controlling messages, values and plots are generated.

-2	no Errors and no Warnings
-1	no Warnings
0	write Errors and Warnings
1	write some info to log window
2	write more info to log window
3	plot aspect solution
4	calculate quality (radii, triangle ...)
5	calculate quality, but no aspect plots
6	plot quality, but no aspect plots
7	aspect and quality plots
8	aspect and more quality plots

Table 2: The valid values of the control parameter ASPECT\_CNTL\_LEVEL.

2. ASPECT\_TIME\_RANGE. With this control parameter, the time range can be specified, for which an aspect solution has to be calculated. In general, it's set automatically to a reasonable value. In particular, it can be useful to specify an aspect time range if an aspect solution object is defined by giving a filename. The 'aspect\_time\_range' has to be set to a valid 'anytim' format.
3. RAS\_TIME\_EXTENSION. A two element vector of delta times in seconds that specify the extension of the aspect time range to be used to calculate the roll solution. The first value is added to the beginning and the second is added the end to the time range. Therefore, the first value suppose to be a negative and the second a positive number. Currently, the aspect time range with the ras time extension can not exceed the observation time interval by more the 1400 seconds. The default value is [-1400,1400].
4. ASPECT\_SIM. This control parameter is a flag, which is used to switch between the reconstructed aspect solution from the aspect packets and a simulated aspect behavior. The default value is zero, which means that the software reconstructs the aspect solution from the packets. Setting the value to 1 produces a simulated aspect behavior.
5. SASZERO. Setting the control parameter saszero to 1, forces the pointing vector to be constant at [0,0]. This does not affect the roll solution.
6. AS\_SPIN\_PERIOD. With this control parameter, spin period of the aspect solution can be controlled. It has to be given in seconds per revolution. This spin period is used for the simulated aspect behavior and for the case where as\_roll\_solution is set to 'FIX' (see below).
7. AS\_ROLL\_OFFSET. In the case where as\_roll\_solution is set to 'FIX', the roll angle is set to as\_roll\_offset at the beginning of the accessed file.
8. AS\_ROLL\_SOLUTION. By this parameter, the method of the roll angle solution can be chosen. Currently, the values given in Table 3 are valid.
9. AS\_NO\_EXTRAPOL. By default, the user is prevented from using aspect data point, which had to be extrapolated from measured data points. By setting this control parameter to 0 (zero), the software returns all measured data points within the aspect time range. If the

'DBASE'	read roll solution from the provided database
'FIX'	fixed spin period, use AS_SPIN_PERIOD and AS_ROLL_OFFSET
'PMT'	use the PMTRAS to generate the roll solution
'RAS'	use the CCD-RAS to generate the roll solution

Table 3: The valid values of the control parameter AS\_ROLL\_SOLUTION.

keywords THIS\_UT\_REF, THIS\_TIME and THIS\_UNIT\_TIME are used, the requested data points outside the aspect time range are extrapolated. In general, extrapolated data points can't be used for any data analysis.

10. PMTRAS\_DIAGNOSTIC. By setting this parameter to a nonzero value, the PMTRAS software will print various information on the log window and produce various plot windows for diagnostic purposes. See the PMTRAS documentation for further information.

## The Quality of the Aspect Solution

The aspect data are redundant in many ways. Therefore, the quality of the reconstructed aspect solution can be measured. However, at the current stage, many of the quality measurements are not in place yet. Describing only the quality measures which are calculated by the present software release, this section will evolve over time. Setting the control level to 4 or higher, the quality measures are calculated and stored in the info structure of the aspect solution object. The following command lines show how to access this information.

```
IDL> o->set,aspect_cntl_level=4
IDL> data=o->getdata()
IDL> info=o->get(/info)
IDL> help,info.as_quality,/struct
** Structure <40697188>, 3 tags, length=752476, refs=2:
  RADII          FLOAT      Array[26874, 6]
  TRIANGLE       FLOAT      Array[26874]
  RAS_RESIDUALS  POINTER     <NullPointer>
```

**Reduced Triangle.** For each SAS integration time, three pairs of Solar limbs are measured. Reconstructing the Sun center in the SAS coordinate system, the three mid-perpendiculars of the three pairs of limbs do not intersect in one point but form a triangle. The size of this reduced triangle is a measure for the quality of the SAS solution. Setting the control level to 6, the size is calculated, the moments of the size are displayed on the log window and the data versus time is plotted. Currently, a mean value  $< 0.5$  arcsecond and a variance of  $\approx 0.5$  arcsecond<sup>2</sup> are reasonable values.

## 4 Simulated Aspect Data

There are two different ways to simulate an aspect solution instead of reconstructing it from the measured data. The simulation software is incorporated in the aspect solution object and can be controlled by the control parameters ASPECT\_SIM and SASZERO. Setting ASPECT\_SIM=1 produces an aspect solution with a simulated pointing behavior which is qualitatively similar to reality. The roll angle is calculated according to the control parameter AS\_SPIN\_PERIOD. Setting SASZERO=1 (preceding over ASPECT\_SIM=1) produces an aspect solution assuming a perfect pointing to Sun center and calculating the roll angle according the control parameters AS\_ROLL\_SOLUTION and AS\_SPIN\_PERIOD.

## 5 Current Status and Restrictions

1. Although, the limbs are fitted to provide the pointing on a sub- arcsecond level, it's not checked whether the pointing accuracy complies with the 0.4 arcsecond requirements. Nevertheless, the estimated error is returned in the tag 'P\_ERROR' if the aspect data is retrieved for given times.
2. Only SAS cycles with at least 2 limbs on two subsystems are taken as valid cycles. All other SAS cycles are currently ignored.
3. For the X-class flare on October 28, 2003, a customized pointing solution is read from the aspect database on SSW.
4. For the quality, only the triangle size and the solar radii from the SAS are calculated.
5. By default, the roll solution is read from the roll angle database on SSW. If no solution is available the software tries to reconstruct a PMTRAS solution. The control parameter AS\_ROLL\_SOLUTION can also be set to 'RAS' in order to reconstruct the roll angle from the CCD-RAS data. Although the latter isn't a robust software yet and the correct solution can depend critically from input parameters. Critical datagaps in the roll database will be filled with customized RAS solutions.
6. As default, the aspect time range has to be within the daytime portion of the orbit and the beginning and end must not fall within a big data gap of pointing measurements. By using the control parameter AS\_NO\_EXTRAPOL, the available data can be retrieved.

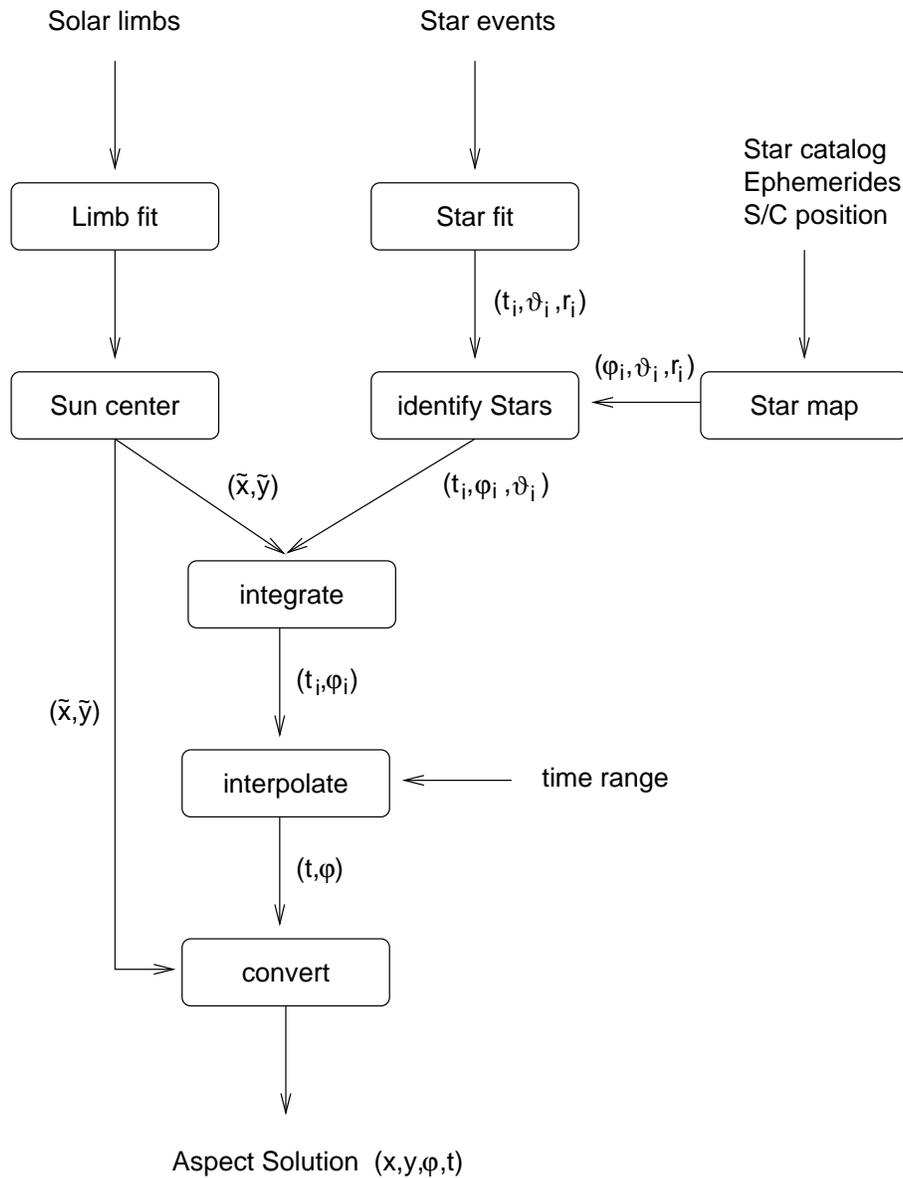


Figure 2: **Flow chart of the aspect solution software.** The Solar limbs and the Star events are fitted independently. Using a Star catalog and the known geometry, the position of the Sun center in a spacecraft fixed coordinate system and a list of position angle marks can be calculated. Integration of these information, interpolation and coordinate transformation provides the needed pointing and roll angle information with respect to a inertial coordinate system.