THEMIS
Science Coordinate Systems Definition

THM-SOC-110

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3	2010-07-29	Added description of HDZ coordinates	David King

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1. Introduction

1.1 Purpose and Scope.

The THEMIS coordinate systems are used in the transformation of sensor raw data into geophysical coordinates. Such transformations rely on ground measurements of Sun Sensor location relative to the magnetometers and also on ground or in orbit measurements of the Spin axis relative to the probe Geometry axis.

1.2 Applicable Documents.

1.	THM_SYS_012_PDMP	THEMIS Project Data Management Plan
2.	THM_SOC_101_TIME	THEMIS TIME Definition
3.	THM_SOC_108_GMAG_L1_VARNAMES	THEMIS GMAG Variable Name Def's
4.	THM_SOC_111_SUNSENSPROC	THEMIS SUN SENSOR Science Processing
5.	THM_SOC_112_ATTPAIPROC	THEMIS Science ATT & Inertia Determ.
6.	THM_SOC_113_FGM_CALPROC	THEMIS FGM CAL File and Processing
7.	THM_SOC_114_SCM_CALPROC	THEMIS SCM CAL File and Processing
8.	THM_SOC_115_EFI_CALPROC	THEMIS EFI CAL File and Processing
9.	THM_SOC_116_ESA_CALPROC	THEMIS ESA CAL File and Processing
10.	THM_SOC_117_SST_CALPROC	THEMIS SST CAL File and Processing
11.	SAI-SPEC-1079A (Oct 26, 2005)	THEMIS Coordinate systems
12.	SAI-RPT-0722a (September, 2006)	Probe Alignment Report (MSSS data, p18)
13.	pturin e-mail on Faro alignment results (9/28/06)	FGM, SCM mag alignments
14.	THM-MB-MEC-005-Magnetometer clocking r7.pdf	MAG clocking angles

2. Probe-Centered Coordinate Systems

The probe-centered coordinate systems have their origin at the probe (rather than at Earth) and are named in accordance with the general rule ABC, where $A \in \{S, D\}$ denotes spinning or despun coordinates; $B \in \{P, S, S\}$ denotes the general direction of the X axis being along the ProbeX axis, the SunSensor X axis or the Sun, and finally $C \in \{G \text{ or } L\}$ denotes the Z axis direction being along the geometric Z axis or the probe L-vector.

2.1 SPG (Spinning Probe Geometric)

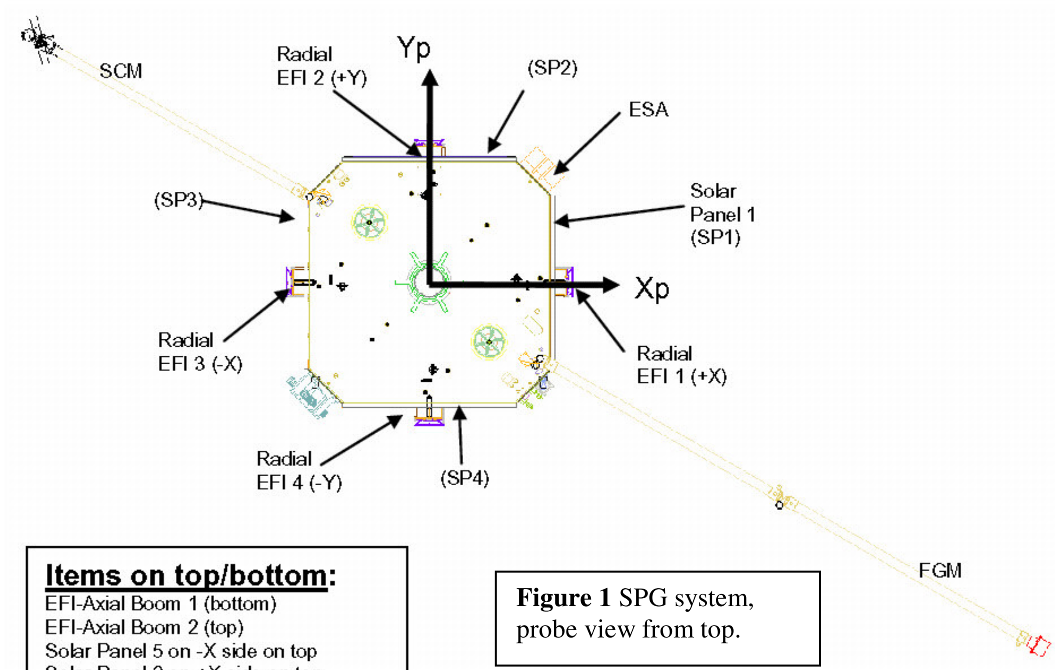
This system (Fig. 1) is defined by the mechanical designers of the probe in SAI-SPEC-1079A. Definition:

1) <u>Origin location</u>. The coordinate system is placed at the geometric center of the separation plane of the probe. The lowest reaching portion of the attachment ring, whose center is aligned with the Z-Axis, defines this plane.

2) <u>Z-Axis</u>. This axis is directed through the probe normal to the attachment plane.

3) <u>X-Axis</u>. This axis is aligned normal to the face sheet of Solar Panel 1. This face has an adjacent corner, moving counterclockwise, housing the ESA. In other words the ESA shall fall in the +X/+Y quadrant of the Probe coordinate system. ***Note: This was chosen to provide an obvious indicator of the X/Y orientation when the probe is viewed from the top during integration operations.***

4) <u>Y-Axis</u>. This axis completes a right-handed orthogonal triad.



Items on top/bottom:
EFI-Axial Boom 1 (bottom)
EFI-Axial Boom 2 (top)
Solar Panel 5 on -X side on top
Solar Panel 6 on +X side on top
Solar Panel 7 on -X side on bottom
Solar Panel 8 on +X side on bottom

Figure 1 SPG system, probe view from top.

2.2 SSL (Spinning SunSensor – L-vectorZ)

This system points with Z along the Spin axis of the probe (the momentum vector is along the principal axis of inertia). The Izz was measured during spin balance tests at JPL to be within 0.25deg of the geometric axis assuming (by modeling) magnetometer booms have been deployed but EFI booms are stowed. As fuel is consumed this angle is expected to change but not by much. Nevertheless we shall track it as function of time, after accurate determination (to within 0.1deg) by modeling magnetometer data through perigee. This angle is recorded in the daily STATE file.

The X axis of the system points towards the Sun Sensor (Miniature Spinning Sun Sensor) look direction. Theoretical angle between the Sun Sensor look direction and the probe X axis is 135 deg (must rotate Xgeometric about Zgeometric axis to obtain Xsunsensor). A detailed figure of the sun sensor it shown in Figure 2, excerpt from SAI-spec 1079a. The Zaxis of the sun sensor is aligned within <1deg to the Zgeometric axis of the probe, based on alignment measurements at JPL. The theoretical transformation matrix that takes a vector in the SPG system into one in the SSL system is thus given (based on ICDs) by:

MAG Booms Deployed			**G2S**	
ICDs		α	β	$\gamma=-\alpha+\phi$
8/26/2006	**Euler Angles (deg)=**	45.00	0.25	90.00
	Sin	0.71	0.00	1.00
Xgeom to X Sun Sensor ϕ= 135.00	**Cos**	0.71	1.00	0.00
			G2S	
		PROBE GEOMETRIC TO SPIN AXIS		
	Orthogonal Rotation Matrix	-0.71	0.71	0.00
	Columns **are Old Unit Vectors in New System**	-0.71	-0.71	0.00
	… Or Computed from Euler Angles	0.00	0.00	1.00

The actual rotation matrix based on measured alignments at JPL is given in the appendix.

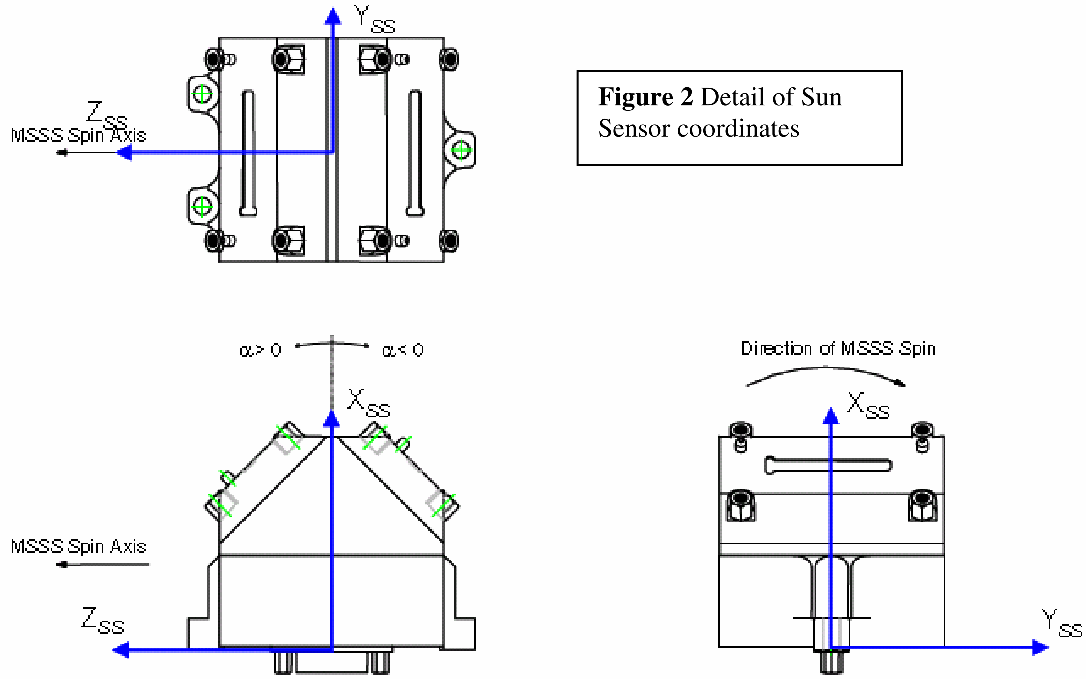


Figure 2 Detail of Sun Sensor coordinates

The orientation of the sun sensor relative to the magnetometers in seen in Figure 3 (THM-MB-MEC-005).

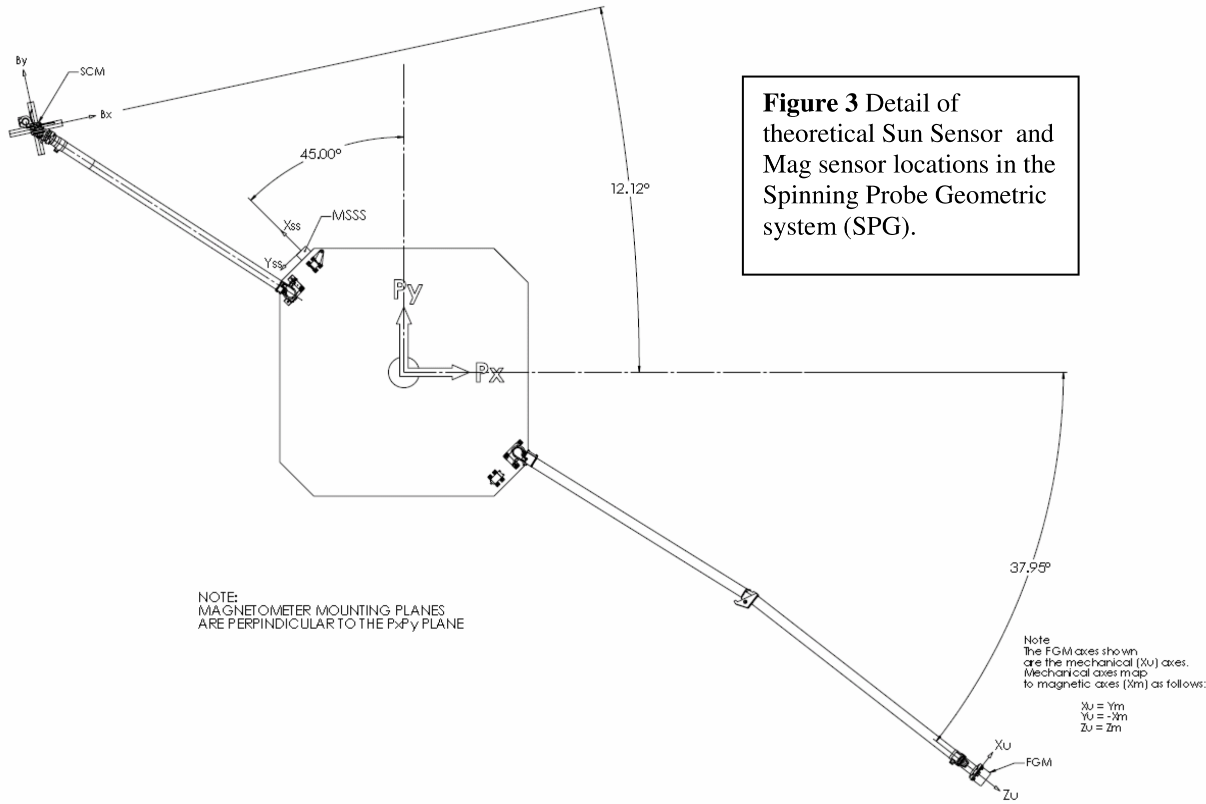


Figure 3 Detail of theoretical Sun Sensor and Mag sensor locations in the Spinning Probe Geometric system (SPG).

2.3 DSL (Despun Sun – L-vectorZ)

This is the system whose Z axis points towards the spin axis, the Y axis is normal to Z and the Spacecraft Sun direction viewed from the probe, and X completes the triad.

Operationally the despun system is obtainable by a rotation about the spin axis by an angle equal to Spin Phase in the direction *opposite* the spin direction. This rotation provides the DSL system at the time of the Spin Phase. This information is determined using the sun pulse signal by science operations, and written into the STATE file at 1min resolution for future use for coordinate transformation. Box car averaging is applied such that the noise level of the sun pulse is reduced, and the spin phase moves gradually from one point to the next, and interpolation between successive points to determine the spin phase is possible.

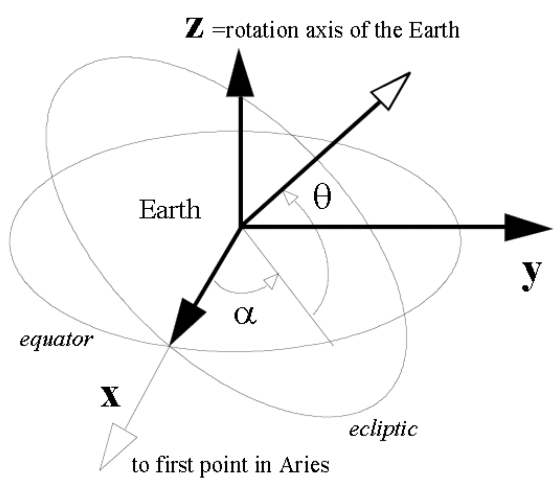
Since the plane defined by the Spin axis and the Spacecraft Sun direction ought to contain the intersection line of the nominal sun sensor field of view and the spin axis, the X-axis can be operationally defined as the intersection of the nominal sun sensor field of view at the time of the sun pulse, and the actual spin plane.

The theoretical and practical (measured) spin axis will be within <0.25deg of each other. The measured sun sensor view plane is within <1deg of the geometric axis. For spin axes near the ecliptic normal (as expected during the science operations phase) the sun pulse will occur when the sun sensor view direction is within a negligible angle (<0.1deg) from the DSL X axis.

In the arbitrary (or unfortunate) case when the spin axis ends up at a large angle to the geometric axis, the Sun Sensor plane at the time of the sun pulse may be a large angle to the theoretical DSL axis. In that case, there needs to be either an elevation-dependent correction to the sun pulse time or an elevation-dependent Spin Phase rotation.

3. Earth-Centered Coordinate Systems

3.1 GEI (Geocentric Equatorial Inertial)



The Z-axis is parallel to the rotation axis of the Earth.
The X-axis is defined by the intersection of the equator plane and the ecliptic plane, and is pointing towards the first point of Aries (Sun position at the vernal equinox).

one can define the *right ascension* α and the *declination* θ as:

right ascension $\alpha = \tan^{-1}(V_y/V_x)$

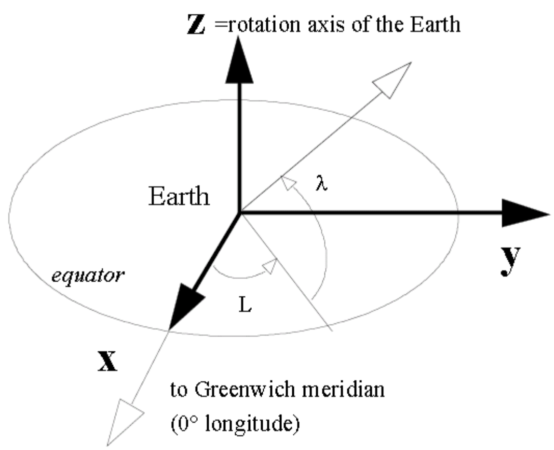
with α in [0°,180°] for $V_y>0$

α in [180°,360°] for $V_y<0$

declination $\theta = \sin^{-1}(V_z/V)$

with θ in [-90°,90°]

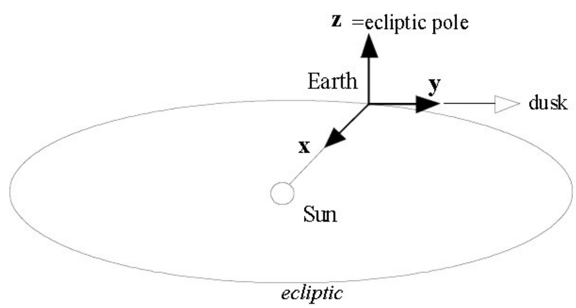
3.2 GEO (Geographic)



The Z-axis is parallel to the rotation axis of the Earth.
The X and Y axis are included in the equator plane.
The X axis is pointing from the centre of the Earth to the Greenwich meridian (0° longitude).

The GEO system is fixed with the rotating Earth. Longitude L and latitude λ are defined in this system in the same way as right ascension and declination in GEI system.

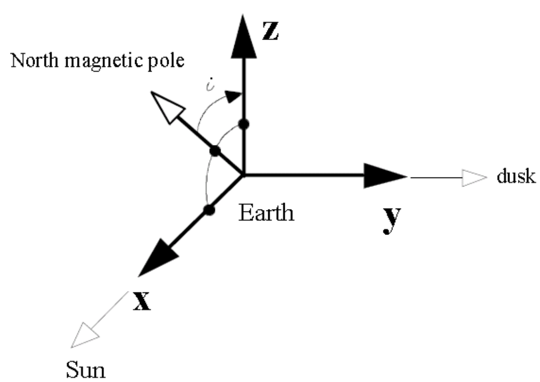
3.3 GSE (Geocentric Solar Ecliptic)



The X-axis is pointing from the Earth towards the Sun.
The X-axis and the Y-axis are include in the ecliptic plane.
The Y-axis is pointing toward the dusk, opposing to the planetary motion.

The Z-axis is parallel to the ecliptic pole. The GSE system has a yearly rotation with respect to the inertial system.

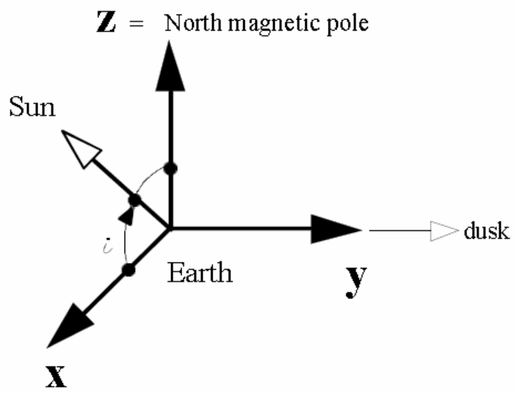
3.4 GSM (Geocentric Solar Magnetospheric).



The X-axis is pointing from the Earth towards the Sun.
The X-Z plane contains the dipole axis.
The Y-axis is perpendicular to the Earth's magnetic dipole, towards the dusk and include in the magnetic equator plane.

The positive Z-axis is chosen to be in the same sense as the northern magnetic pole; the dipole tilt angle i is positive when the north magnetic pole is tilted towards the Sun. In addition to a yearly period due to the motion of the Earth about the Sun, the GSM system rocks about the Solar direction with a 24 h period.

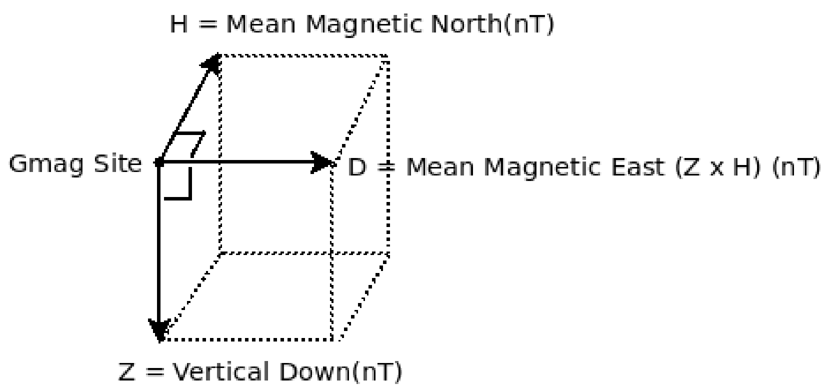
3.5 Solar Magnetic (SM)



The Z-axis is parallel to the North magnetic dipole.
The X-Z plane contains the direction of the Sun.
The Y-axis is perpendicular to the Earth-Sun line toward dusk.

The SM system rotates with both a yearly and a daily period with respect to the inertial system.

3.6 HDZ (GMAG)



H-Axis points towards the approximate mean magnetic north as measured from installation site during quiet time.
D-Axis completes the right handed system. Note that D is NOT measured as an angle.
Z-Axis points downward from installation site.

Some gmags have installation errors and gmag orientation can drift over time. It is important to verify true coordinate system by comparing mean measured field to expected field.

4. Appendix: Ground measured rotation from SPG to SSL (G2S)

Probe A.

MAG Booms Deployed
Post I&T Spin-Balance and Alignment Measurement
9/16/2006

		G2S		
		α	β	γ=−α+ϕ
	Euler Angles (deg)=	45.00	0.25	90.17
	Sin	0.71	0.00	1.00
Xgeom to X Sun Sensor ϕ= 135.17	Cos	0.71	1.00	0.00

G2S
PROBE GEOMETRIC TO SPIN AXIS

Orthogonal Rotation Matrix	-0.709	0.705	0.000
Columns are Old Unit Vectors in New System	-0.705	-0.709	0.004
... Or Computed from Euler Angles	0.003	0.003	1.000

Probe B

MAG Booms Deployed
Post I&T Spin-Balance and Alignment Mea
9/16/2006

		G2S		
		α	β	γ=−α+ϕ
	Euler Angles (deg)=	45.00	0.25	89.88
	Sin	0.71	0.00	1.00
Xgeom to X Sun Sensor ϕ= 134.88	Cos	0.71	1.00	0.00

G2S
PROBE GEOMETRIC TO SPIN AXIS

Orthogonal Rotation Matrix	-0.706	0.709	0.000
Columns are Old Unit Vectors in New System	-0.709	-0.706	0.004
... Or Computed from Euler Angles	0.003	0.003	1.000

Probe C

MAG Booms Deployed
Post I&T Spin-Balance and Alignment Mea
9/16/2006

		G2S		
		α	β	γ=−α+ϕ
	Euler Angles (deg)=	45.00	0.25	89.98
	Sin	0.71	0.00	1.00
Xgeom to X Sun Sensor ϕ= 134.98	Cos	0.71	1.00	0.00

G2S
PROBE GEOMETRIC TO SPIN AXIS

Orthogonal Rotation Matrix	-0.707	0.707	0.000
Columns are Old Unit Vectors in New System	-0.707	-0.707	0.004
... Or Computed from Euler Angles	0.003	0.003	1.000

Probe D

MAG Booms Deployed
Post I&T Spin-Balance and Alignment Mea
9/16/2006

		G2S		
		α	β	γ=−α+ϕ
	Euler Angles (deg)=	45.00	0.25	-45.00
	Sin	0.71	0.00	-0.71
Xgeom to X Sun Sensor ϕ= 135.07	Cos	0.71	1.00	0.71

G2S
PROBE GEOMETRIC TO SPIN AXIS

Orthogonal Rotation Matrix	1.000	0.000	-0.003
Columns are Old Unit Vectors in New System	0.000	1.000	-0.003
... Or Computed from Euler Angles	0.003	0.003	1.000

Probe E.

MAG Booms Deployed			**G2S**	
Post I&T Spin-Balance and Alignment Mea		α	β	$\gamma=-\alpha+\phi$
9/16/2006	**Euler Angles (deg)=**	45.00	0.25	89.92
	Sin	0.71	0.00	1.00
Xgeom to X Sun Sensor ϕ= 134.92	**Cos**	0.71	1.00	0.00

G2S

PROBE GEOMETRIC TO SPIN AXIS

Orthogonal Rotation Matrix	-0.706	0.708	0.000
Columns **are Old Unit Vectors in New System**	-0.708	-0.706	0.004
… Or Computed from Euler Angles	0.003	0.003	1.000