Jupiter Coordinate Systems

Introduction

Purpose: This document pulls together various coordinate systems that might be useful for the Juno team to use at Jupiter. Different teams have their own preferred systems to work with. The purpose here is not to suggest teams change anything. The goal is to help the larger Juno team become familiar with the full range of coordinate systems they may come across. Furthermore, the JPL NAIF team provide navigation tools – specifically SPICE – for the Juno project and we have tried to relate the names used by SPICE to these systems.

Six Juno Systems. We describe the six main coordinate systems of potential use by the *Juno* mission. These are all available in SPICE frame kernel **juno_v09.tf**.

#	Coordinate System	Juno Frame SPICE name	Origin	Notes
1	Jupiter System III	S3RH -> `IAU_JUPITER` S3LH -> *no SPICE frame*	Jupiter	In Jupiter's rotating frame.
2	Jupiter Magnetic	`JUNO_MAG_VIP4`	Jupiter	Based on the VIP4 magnetic field model.
3	Jupiter-De-Spun-Sun	`JUNO_JSS`	Jupiter	Similar to 1 except not rotating.
4	Jupiter-Sun-Orbit	`JUNO_JSO`	Jupiter	Based on direction to the Sun and Jupiter's orbital motion.
5	Jupiter Heliospheric	`JUNO_JH`	Jupiter	For solar wind intervals only. Based on the Sun's spin vector.
6	Juno Sun Equator Radial Tangential Normal	`JUNO_SUN_EQU_RTN`	Juno	For solar wind intervals only. Based on the Sun's spin vector.

Notes:

1. All these systems are Jupiter-centered except #6 JUNO_SUN_EQN_RTN that is centered on the spacecraft.

2. The #1 traditional System III Longitude that has the longitude of a semi-stationary observer (such as at Earth) increasing with time, is a left-handed system. The RH system has longitude decreasing with time.

3. SPICE only does right-handed coordinates; therefore coordinates used with SPICE should be right handed.

4. SPICE kernel **pck00010.tpc** *must* be used for all Juno SPICE work.
   This has Jovian radius as 71492 km, spin period at 9h55m29.711s and also defines the Jupiter pole (based on the IAU 2009 report). Use of this specific kernel is essential for Jupiter System III calculations.

5. For other, older systems, see the end of the document.

6. No apparent positions (aberration corrected) are used in any of these co-ordinate system definitions. This makes it easier to transform between systems.
   (The apparent position of the Sun and the geometric position differ by under 0.002° at Jupiter, or in local time is under 0.6 seconds; however the SPICE local solar time command rounds seconds, hence no practical effect to within uncertainty of the SPICE command: `et2lst` with `type = 'PLANETOCENTRIC'`.)

Jupiter Radius (R_J)

First we need to clarify the fiducial value of the radius of Jupiter. Dessler (1983) declared use of the value R_J = 71,400 km in the appendix of *Physics of the Jovian Magnetosphere*. A full description of the planetary parameters and coordinate systems is provided in Appendix 2 of *Jupiter: Planet, Satellites, Magnetosphere* (Bagenal, Dowling, McKinnon, (eds), 2004) where the equatorial radius at the 1-bar level is given as R_J = 71,492 ± 4km (Lindal et al. 1981). The JPL navigation team that provides *Juno* trajectory information uses ***R_J = 71492 km, the value we propose for all Juno activities throughout the mission***. Note that because of the rapid rotation of the planet, the polar radius of Jupiter is much less (66,854 km).

Spin Period

Jupiter has a spin period of 9h 55m 29.711s = 9.92492 hours (or angular velocity of 1.76 x 10^{-4} rad/s = 870.536°/day). This is the current IAU value.

Note that Higgins et al. (1996, 1997) proposed, based on 35 years of radio observations of Jupiter, that the rotation rate of the planet interior maybe ~25 ms shorter than the System III (1965) rotation rate (see also discussion in relation to magnetic field models by Russell et al. 2001; Yu & Russell, 2009; Hess et al. 2011). A 25 ms shorter spin period amounts to just 0.2°/yr which is negligible over the duration of the *Juno* mission but is significant for comparing *Voyager* and *Juno* epochs. Since this is a minimal change in the rotation rate the IAU and the *Juno* project have decided not to change the official System III rotation rate to limit confusion between systems and to allow easy comparison of data sets from different epochs.

Please note that the rotation rate (9.92425 hr) stated in appendix of the Bagenal et al. (2004) Jupiter book is incorrect.

Jupiter Pole

The values are defined in the 2009 IAU report. Key Jupiter parameters are in the SPICE kernel "pck00010.tpc" and that file should be used as the primary reference, however key values are copied below. "599" is the NAIF code for Jupiter, hence names of values begin BODY599_*.

```
BODY599_RADII          = ( 71492        71492          66854  )

BODY599_POLE_RA        = (   268.056595     -0.006499       0. )
BODY599_POLE_DEC       = (    64.495303      0.002413       0. )
BODY599_PM             = (   284.95        870.5360000      0. )
BODY599_LONG_AXIS      = (     0.                              )

BODY599_NUT_PREC_RA  = ( 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.000117
                                                       0.000938
                                                       0.001432
                                                       0.000030
                                                       0.002150 )

BODY599_NUT_PREC_DEC = ( 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.000050
                                                       0.000404
                                                       0.000617
                                                      -0.000013
                                                       0.000926 )

BODY599_NUT_PREC_PM  = ( 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.0
                                                       0.0
                                                       0.0
                                                       0.0
                                                       0.0 )

BODY5_NUT_PREC_ANGLES  = (    73.32      91472.9
                              24.62      45137.2
                             283.90       4850.7
                             355.80       1191.3
                             119.90        262.1
                             229.80         64.3
                             352.25       2382.6
                             113.35       6070.0
                             146.64     182945.8
                              49.24      90274.4
                              99.360714   4850.4046
                             175.895369   1191.9605
                             300.323162    262.5475
                             114.012305   6070.2476
                              49.511251     64.3000 )
```

Note 1: BODY5_NUT_PREC_ANGLES is for the whole Jupiter system rather than just Jupiter, hence it does not have 599 in the name.

Note 2: Failure to include the nutation/precession terms in calculations can cause an offset of Jupiter's pole orientation of 10s of microradians during Juno's mission.

(1) Jupiter System III (S3LH, S3RH)

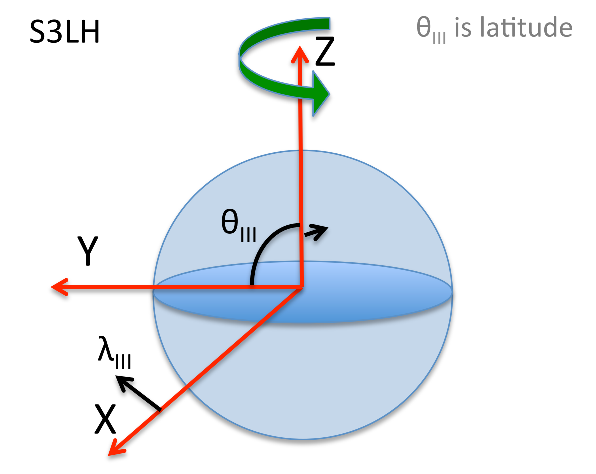

Figure 1a - Jupiter System III (1965) coordinates (S3LH). The Z-axis is defined by the spin axis of Jupiter. The X-axis is defined by 0° latitude on the System III longitude λ_{III}=0° (prime meridian). The Y-axis completes the orthogonal left-handed system. Latitude (θ_{III}) is defined from the equator.

X = 0° latitude, Prime Meridian
Y = **X** x **Z**
Z = Jupiter spin axis

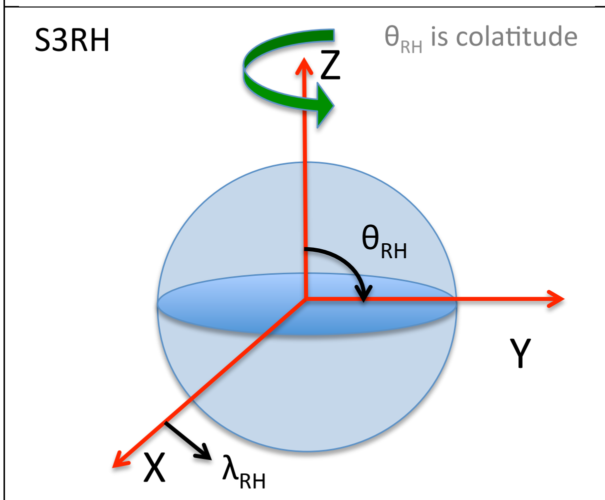

Figure 1b – Right-handed System III. This coordinate system has the same basis as the left-handed System III except that longitude is (λ_{RH}) decreases with time and co-latitude (θ_{RH}) is used.

X = 90° colatitude, Prime Meridian
Y = **Z** x **X**
Z = Jupiter spin axis

λ_{RH}=360°-λ_{III}

This system rotates with the planet at the sidereal System III (1965) spin period of 9h 55m 29.711s = 9.92492 hours (or angular velocity of 1.76 x 10^{-4} rad/s = 870.536°/day). This spin period was originally based on ground-based radio observations and the longitude (λ_{III}) was defined to increase with time, as observed from Earth. The problem with this system is that it is a left-handed coordinate system (which we label S3LH). Since many prefer right-hand coordinate systems, we also define a RH system (S3RH) where the longitude (λ_{RH}=360°-λ_{III}) decreases with time as viewed from Earth. These two variations on jovian System III are shown above. The location of the Prime Meridian (the meridian plane in both systems and where both longitudes are zero) is defined in terms of the Central Meridian Longitude (i.e. Earth-Jupiter vector) on a specific date in 1965. S3LH uses latitude (θ_{III}) while S3RH uses colatitude (θ_{RH}).

(2) Jupiter Magnetic (JUNO_MAG_VIP4)

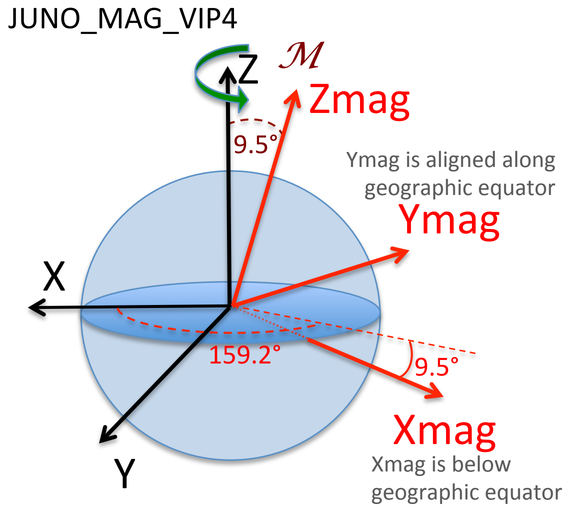

Figure 2 – Jupiter magnetic coordinates based on the VIP4 model (red axes). The black axes are for the S3RH system. The magnetic system rotates with Jupiter but has the Z-axis aligned with the magnetic dipole, *M*. The Y-axis is aligned with the intersection of the magnetic and geographic equators; in S3RH: [249.2° longitude, 0° latitude]
The +X-axis is south of the geographic equator, in S3RH:
[159.2° longitude, -9.5° latitude]

J_{Omega} = unit vector of Jupiter spin axis
$\mathbf{X} = \mathbf{Y} \times \mathbf{Z}$
$\mathbf{Y} = J_{Omega} \times M$
$\mathbf{Z} = M$ = Jupiter magnetic dipole axis

This system (above) is the System III (RH) but is tilted by the 9.5° of the dipole approximation to the magnetic field of Jupiter, tilted towards λ_{III}=200.8° or λ_{RH}=159.2°.

This tilt is based on the VIP4 model (Connerney et al. 1998). Since most models tend to work in right-handed coordinates, we propose a right-handed magnetic system for *Juno*.

Not to be confused with... Jupiter Solar Magnetospheric (JSM) coordinates used during the Galileo mission, which used a dipole a tilt of 9.6° and λ_{III}=202° based on the O4 model of Connerney (1981). For further info on JSM, see the DATA_SET_DESCRIPTION of PDS data set GO-J-POS-6-SC-TRAJ-JUP-COORDS-V1.0 : https://pds.nasa.gov/ds-view/pds/viewProfile.jsp?dsid=GO-J-POS-6-SC-TRAJ-JUP-COORDS-V1.0 In our new naming convention we would call this JMAG_O4.

Comparisons of dipole approximations for different magnetic models are shown in Appendix 2 of the Jupiter book (Bagenal et al. 2004) and in Connerney et al. (1998). The full range of internal magnetic field models is reviewed by Connerney (2007) as well as evaluated in the light of possible secular variation by Ridley & Horne (2016).

(3) Jupiter-De-Spun-Sun (JUNO_JSS)

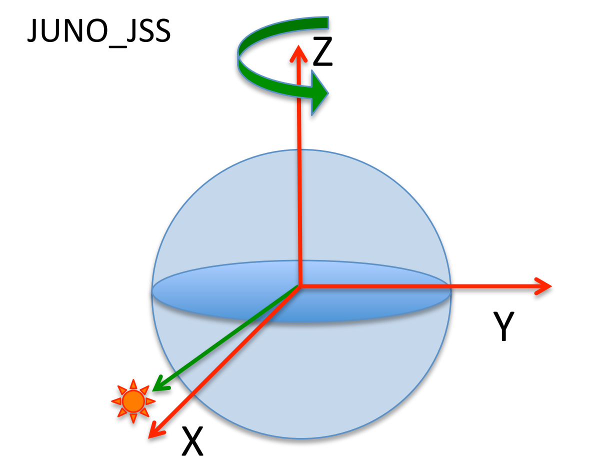

Figure 3 – This system has the Z-axis aligned with Jupiter's spin axis but does not spin with the planet.
$\mathbf{R}_{JS}$ = unit vector of Jupiter to Sun
$\mathbf{Z}$= J_{Omega} = unit vector of Jupiter spin axis
$\mathbf{Y} = \mathbf{Z} \times \mathbf{R}_{JS}$
$\mathbf{X} = \mathbf{Y} \times \mathbf{Z}$

JSS expressed in radial distance, latitude and local time

An alternative to Cartesian (x,y,z) coordinates, the JSS system can be expressed in spherical coordinates in radial distance, latitude and local time (R, Lat, Lon or LT)

Radial distance is the magnitude: $R = (x^2 + y^2 + z^2)^{1/2}$

Latitude is given by trigonometry: $Lat = \arcsin(z / R) * 180/\pi$
(with the $180/\pi$ factor to go from radians in to degrees.)

Local time as an angle with respect to the Sun (or solar longitude, Lon) would be the four quadrant inverse tangent of y and x (i.e., arctan(y,x) in code), which can be expressed in degrees

$Lon= \arctan(y,x) * 180/\pi$).

If the angle is negative then 360° is added so that $0 \leq$ longitude < 360 degrees.

Local Time has units of hours (24 hours to 360 degrees) and translates longitude such that noon (12 hours) local time would be 0 degrees longitude, dusk (18 hours) local time would be 90 degrees longitude, midnight (00 hours) local time would be 180 degrees longitude, and dawn (06 hours) local time would be 270 degrees longitude.

Local Time = LT = [(Lon + 180 degrees) * 24/360] MOD 24
Local Time = LT = [(arctan(y,x) + π) * 12/π] MOD 24

The SPICE command `et2lst` (with `type = 'PLANETOCENTRIC'`) can also be used to calculate local time, however it does include an aberration correction on the Sun position (`abcorr = 'LT+S'`). However the difference is < 0.6s LT at Jupiter and the code returns whole seconds only, so practically is equivalent to using no correction.

(4) Jupiter-Sun-Orbit (JUNO_JSO)

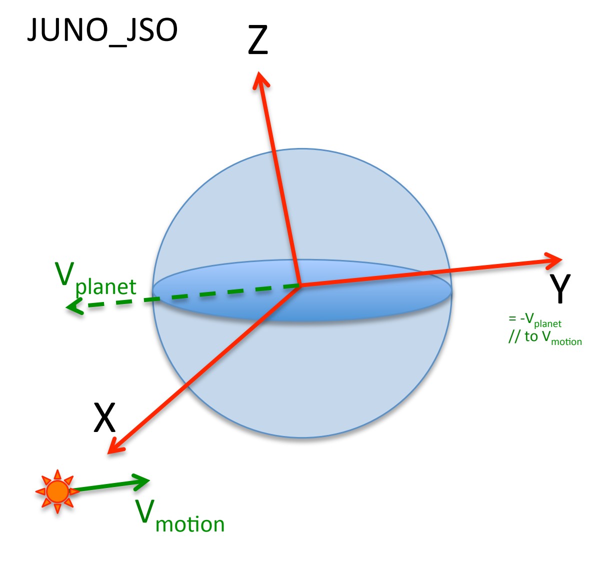

Figure 4 - aligns the X-axis with the Jupiter-Sun vector. SPICE describe it as X=JupSunPos/Y=JupSunVel

$\mathbf{V_{planet}}$ = unit vector of Jupiter's motion
$\mathbf{V_{motion}}$ = -$\mathbf{V_{planet}}$ = Sun's motion when in Jupiter frame.
$\mathbf{R_{JS}}$ = unit vector of Jupiter to Sun
$\mathbf{X} = \mathbf{R_{JS}}$
$\mathbf{Y} = \mathbf{V_{motion}} = -\mathbf{V_{planet}}$
$\mathbf{Z} = \mathbf{X} \times \mathbf{Y}$

This is similar to Earth's Geocentric Solar Ecliptic (GSE) system, and that since V_{planet} is no longer in the XY plane then +Z is not ecliptic north.

Note:

1) Jupiter's orbit is tilted by 1.303° to the ecliptic plane and by 6.09° to the Sun's equator.
2) Jupiter's spin axis is tilted by 3.13° with respect to its orbital plane.

(5) Jupiter Heliospheric (JUNO_JH)

Since *Juno* measures solar wind conditions surrounding Jupiter's magnetosphere we need a coordinate system that is based on heliospheric properties. This is the heliocentric system centered on Jupiter. For other heliospheric coordinate systems see Hapgood (1992) and Franz and Harper (2002).

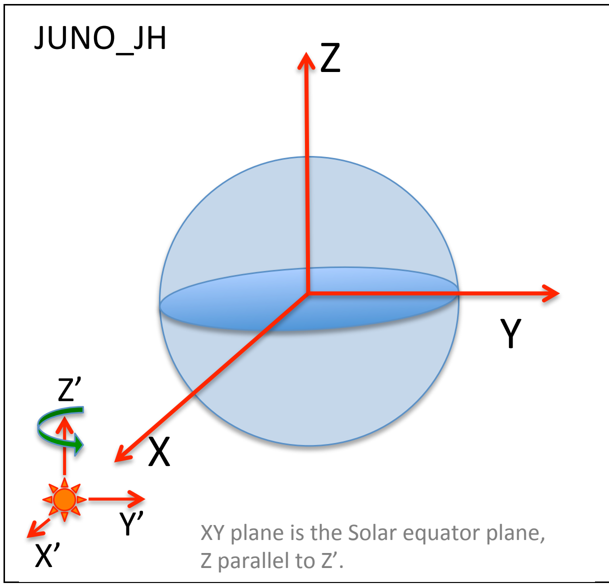

Figure 5 - This system is Jupiter-centered and the X-axis is the Jupiter-Sun vector, the Y-axis is the solar equator, and the Z-axis completes the system.

$\mathbf{R}_{JS}$ = unit vector of Jupiter to Sun line

$\mathbf{S}_{Omega}$ = unit vector of the Sun's spin axis = **Z'** in figure

$\mathbf{X} = \mathbf{R}_{JS}$

$\mathbf{Z} = \mathbf{S}_{Omega}$

$\mathbf{Y} = \mathbf{Z} \times \mathbf{X}$

Note:

1) Jupiter's orbit is tilted by 6.09° to the Sun's equator (which is perpendicular to the Sun's spin axis, obviously). The Sun's equatorial spin period is 25 days).
2) With Jupiter's spin axis being tilted by 3.13° with respect to its orbital plane, then the spin axes of Jupiter and the Sun can be separated by up to 9.22°.

(6) Juno Sun Equator RTN (JUNO_SUN_EQU_RTN)

(Not JRTN which could be confused with Jupiter_RTN, that would have Jupiter at the origin and the R vectors would be the along the Jupiter-Sun line.)

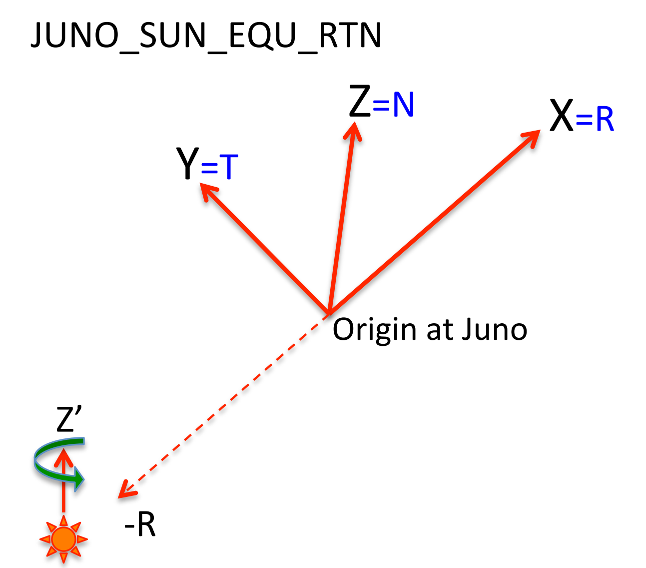

Figure 6 – This system is centered with *Juno* at the origin and the relative object is the Sun.
$\mathbf{R}_{\mathbf{Juno2S}}$ = unit vector of Juno to Sun line
$\mathbf{R}_{\mathbf{S2Juno}}$ = $-\mathbf{R}_{\mathbf{Juno2S}}$ = unit vector of Sun to Juno line
$\mathbf{S}_{\mathbf{Omega}}$ = unit vector of the Sun's spin axis = **Z'** in figure
$\mathbf{X} = \mathbf{R} = \mathbf{R}_{\mathbf{S2Juno}} = -\mathbf{R}_{\mathbf{Juno2S}}$
$\mathbf{Y} = \mathbf{T} = \mathbf{S}_{\mathbf{Omega}} \times \mathbf{R} = \mathbf{S}_{\mathbf{Omega}} \times \mathbf{X}$
$\mathbf{Z} = \mathbf{N} = \mathbf{R} \times \mathbf{T} = \mathbf{X} \times \mathbf{Y}$

Calling a co-ordinate system RTN is not sufficient - more information is required to define it, predominantly where the origin is and what object your RTN system is related to. For the Juno mission, JUNO_RTN is centered with Juno at the origin and the relative object is the Sun – also known as JUNO_SUN_EQU.

The following description of RTN for solar wind missions is quoted from the COHOWeb website: http://omniweb.gsfc.nasa.gov/coho/html/cw_data.html

> "COHOWeb provides access to heliospheric magnetic field, plasma and spacecraft position data for each of many spacecraft identified."

"The RTN system is centered at a spacecraft or planet and oriented with respect to the line connecting the Sun and spacecraft or planet. The R (radial) axis is directed radially away from the Sun through the spacecraft or planet. The T (tangential) axis is the cross product of the Sun's spin vector (North directed) and the R axis, i.e. the T axis is parallel to the solar equatorial plane and is positive in the direction of planetary rotation around the Sun. The N (normal) axis completes the right handed set. The RTN system is preferable for analyzing solar wind and energetic particle data."

Others and older systems

On June 30th 2016 a group of Juno MWG members met with JPL NAIF team and agreed that to be consistent with other planets (particularly Earth) the system. All Earth dipole MAG SPICE frames have +Y in the direction where the magnetic and spin equators align. In the system below we had +X in this direction. Since dipole MAG frames for other (but not all) planets also tend to use Earth dipole definitions with +Y in the direction of the intersection of magnetic and spin equators – we changed the JMAG_VIP4 system accordingly from this below to the one shown as (2) above. The two systems only differ by a 90° rotation around the dipole axis.

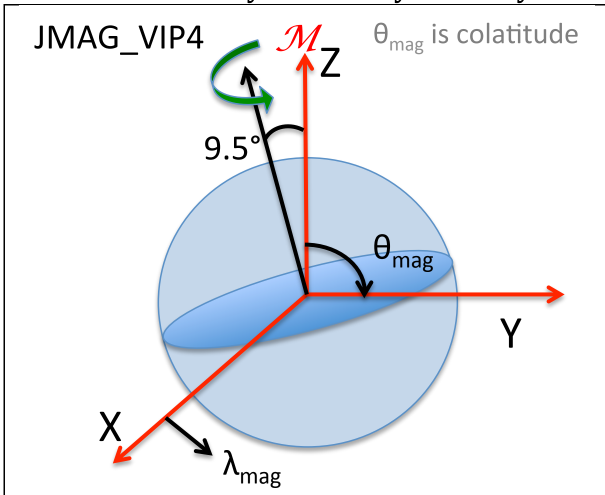

Figure 7 – OLD Jupiter magnetic coordinates. This system rotates with Jupiter but has the Z-axis aligned with the magnetic dipole, *M*. The X-axis is aligned with the intersection of the magnetic and geographic equators at λ_{III}=290.8° or λ_{RH}=69.2°

X = 69.2° from Prime Meridian (where $\lambda_{III}=\lambda_{RH}=0$)
Y = **Z** x **X**
Z = Jupiter dipole axis

Local Time		**Mission used by**	**Subset of JSS.**
Jupiter Solar Magnetospheric	JSM	Galileo	Similar to JUNO_MAG_VIP4 but tilt and l_{III} angles are slightly different (tilt of 9.6° and λ_{III}=202°, the O4 model parameters). Equivalent to JUNO_JMAG_O4.
JMAG_O4	JMAG_O4	Proposed name	Proposed name for a dipole MAG frame based on the O4 model. Frame equivalent to Jupiter Solar Magnetospheric.
Jupiter Solar Equatorial	JSE	Galileo	Equivalent to JUNO_JSS. Different to other JSE (Jovicentric Solar Ecliptic).
Jovicentric Solar Ecliptic	JSE	Galileo EPD team members	Similar to JUNO_JSO, but uses aberration corrected positions. Different to other JSE (Jupiter Solar Equatorial).

Jupiter Solar Equatorial (JSE) – Used by *Galileo* Mission

This JSS co-ordinate system is the same as Jupiter Solar Equatorial (JSE) that was used for Galileo instruments (see the DATA_SET_DESCRIPTION from PDS data set GO-J-POS-6-SC-TRAJ-JUP-COORDS-V1.0): https://pds.nasa.gov/ds-view/pds/viewProfile.jsp?dsid=GO-J-POS-6-SC-TRAJ-JUP-COORDS-V1.0

The description used for the Jupiter Solar Equatorial (JSE) system in the above PDS link for *Galileo* (edits encased in square brackets):

> "Local Time angle is the angle (HA) between the observer's ([spacecraft]) sub-Jupiter meridian and the anti-sunward meridian, measured in the [*Planetocentric*] jovian equatorial plane in the direction of planetary rotation. Local time is the conversion of the local hour angle into units of time by using the conversion factor that equates one hour to fifteen degrees of longitude. Magnetic local time follows the same convention with the difference being that the reference pole is the dipole moment vector (M) rather than the jovian spin axis ([J_{Omega}]). Local time values are provided here in units of decimal hours."

Note: planetocentric equatorial plane is expressed in the figure on the same page, so added to this text to avoid ambiguity.

Do not confuse this 'Jupiter Solar Equatorial' (JSE) with 'Jovicentric Solar Ecliptic' coordinates (JSE) that was used by some for *Galileo* EPD data. The Jovicentric Solar Ecliptic coordinates are equivalent to Jupiter-Sun-Orbit (JSO) below. If you see JSE it could be JSS or JSO – be careful!

The JSO co-ordinate system has previously been referred to Jovicentric Solar Ecliptic coordinates (JSE) for Galileo EPD (see http://galileo.ftecs.com/handbook/LGA-software/coord-systems.html , while the term JSE is used in PDS EPD browse plots, we have not located a description of this within PDS as yet). Note that the above Galileo EPD webpage confirms use of `abcorr = 'LT+S'` in their SPICE transformation to Jovicentric Solar Ecliptic. Do not confuse the 'Jovicentric Solar Ecliptic' (JSE) with 'Jupiter Solar Equatorial' coordinates (JSE) that was used for other Galileo work. If you see JSE it could be JSS or JSO – be careful!

References

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Appendix: SPICE Frame description of these Jupiter Coordinate Systems

The following 4 pages are a copy of the description of the Jupiter frames of this document taken from SPICE kernel **`juno_v09.tf`**, lines 516-735.

```
Frames for Magnetospheric Studies at Jupiter
-------------------------------------------------------------------------------

   This section defines a few frames for magnetospheric studies at
   Jupiter described in [9].


Jupiter Magnetic VIP4 Frame

   The JUNO_MAG_VIP4 frame implements the JUNO mission Jupiter
   Magnetic VIP4 (MAG_VIP4) reference frame described in [9].

   It is defined as a fixed offset frame with respect to the
   IAU_JUPITER frame (which is equivalent to the System III right
   handed frame when used with pck00010.tpc) as follows:

      -  +Z axis is along planetocentric LON=159.2 deg/LAT=80.5 deg in
         in the IAU_JUPITER frame

      -  +Y axis is along planetocentric LON=249.2 deg/LAT=0 deg in
         the IAU_JUPITER frame

      -  +X completes the right handed frame

      -  the center is at the center of Jupiter.

   Two rotations are needed to align the IAU_JUPITER frame with the
   JUNO_MAG_VIP4 frame: first by +159.2 degrees about Z, second by +9.5
   degrees about Y.

   The keywords below implement the JUNO_MAG_VIP4 frame. Since the
   frame definition below contains the reverse transformation -- from
   the JUNO_MAG_VIP4 frame to the IAU_JUPITER frame -- the order of
   rotations is reversed and the signs of rotation angles are changed
   to the opposite ones compared to the description above.

   \begindata

      FRAME_JUNO_MAG_VIP4           = -61952
      FRAME_-61952_NAME             = 'JUNO_MAG_VIP4'
      FRAME_-61952_CLASS            = 4
      FRAME_-61952_CLASS_ID         = -61952
      FRAME_-61952_CENTER           = 599
      TKFRAME_-61952_SPEC           = 'ANGLES'
      TKFRAME_-61952_RELATIVE       = 'IAU_JUPITER'
      TKFRAME_-61952_ANGLES         = ( 0, -159.2, -9.5 )
      TKFRAME_-61952_AXES           = ( 2,     3,    2   )
      TKFRAME_-61952_UNITS          = 'DEGREES'
```

Continues on next page...

```
   \begintext


Jupiter-De-Spun-Sun Frame

   The JUNO_JSS frame implements the JUNO mission Jupiter-De-Spun-Sun
   (JSS) reference frame described in [9].

   It is defined as a dynamic frame as follows:

      -  +Z axis is along the Jupiter north pole (+Z of the IAU_JUPITER
         frame)

      -  +X axis is in the direction of the geometric position of the
         Sun as seen from Jupiter

      -  +Y completes the right handed frame

      -  the center is at the center of Jupiter.

   The keywords below implement the JUNO_JSS frame as a dynamic frame.

   \begindata

      FRAME_JUNO_JSS                = -61953
      FRAME_-61953_NAME             = 'JUNO_JSS'
      FRAME_-61953_CLASS            = 5
      FRAME_-61953_CLASS_ID         = -61953
      FRAME_-61953_CENTER           = 599
      FRAME_-61953_RELATIVE         = 'J2000'
      FRAME_-61953_DEF_STYLE        = 'PARAMETERIZED'
      FRAME_-61953_FAMILY           = 'TWO-VECTOR'
      FRAME_-61953_PRI_AXIS         = 'Z'
      FRAME_-61953_PRI_VECTOR_DEF   = 'CONSTANT'
      FRAME_-61953_PRI_FRAME        = 'IAU_JUPITER'
      FRAME_-61953_PRI_SPEC         = 'RECTANGULAR'
      FRAME_-61953_PRI_VECTOR       =  ( 0, 0, 1 )
      FRAME_-61953_SEC_AXIS         = 'X'
      FRAME_-61953_SEC_VECTOR_DEF   = 'OBSERVER_TARGET_POSITION'
      FRAME_-61953_SEC_OBSERVER     = 'JUPITER'
      FRAME_-61953_SEC_TARGET       = 'SUN'
      FRAME_-61953_SEC_ABCORR       = 'NONE'

   \begintext


Jupiter-Sun-Orbit Frame

   The JUNO_JSO frame implements the JUNO mission Jupiter-Sun-Orbit
   (JSO) reference frame described in [9].

   It is defined as a dynamic frame as follows:

      -  +X axis is along the geometric position of the Sun as seen
         from Jupiter

      -  +Y axis is in the direction of the inertial geometric velocity
         of the Sun as seen from Jupiter

      -  +Z completes the right handed frame

      -  the center is at the center of Jupiter.

   The keywords below implement the JUNO_JSO frame as a dynamic frame.
```

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```
   \begindata

      FRAME_JUNO_JSO                = -61954
      FRAME_-61954_NAME             = 'JUNO_JSO'
      FRAME_-61954_CLASS            = 5
      FRAME_-61954_CLASS_ID         = -61954
      FRAME_-61954_CENTER           = 599
      FRAME_-61954_RELATIVE         = 'J2000'
      FRAME_-61954_DEF_STYLE        = 'PARAMETERIZED'
      FRAME_-61954_FAMILY           = 'TWO-VECTOR'
      FRAME_-61954_PRI_AXIS         = 'X'
      FRAME_-61954_PRI_VECTOR_DEF   = 'OBSERVER_TARGET_POSITION'
      FRAME_-61954_PRI_OBSERVER     = 'JUPITER'
      FRAME_-61954_PRI_TARGET       = 'SUN'
      FRAME_-61954_PRI_ABCORR       = 'NONE'
      FRAME_-61954_SEC_AXIS         = 'Y'
      FRAME_-61954_SEC_VECTOR_DEF   = 'OBSERVER_TARGET_VELOCITY'
      FRAME_-61954_SEC_OBSERVER     = 'JUPITER'
      FRAME_-61954_SEC_TARGET       = 'SUN'
      FRAME_-61954_SEC_ABCORR       = 'NONE'
      FRAME_-61954_SEC_FRAME        = 'J2000'

   \begintext


Jupiter Heliospheric Frame

   The JUNO_JH frame implements the JUNO mission Jupiter Heliospheric
   (JH) reference frame described in [9].

   It is defined as a dynamic frame as follows:

      -  +X axis is along the geometric position of the Sun as seen
         from Jupiter

      -  +Z axis is in the direction of the Sun north pole.

      -  +Y completes the right handed frame

      -  the center is at the center of Jupiter.

   The keywords below implement the JUNO_JH frame as a dynamic frame.

   \begindata

      FRAME_JUNO_JH                = -61955
      FRAME_-61955_NAME             = 'JUNO_JH'
      FRAME_-61955_CLASS            = 5
      FRAME_-61955_CLASS_ID         = -61955
      FRAME_-61955_CENTER           = 599
      FRAME_-61955_RELATIVE         = 'J2000'
      FRAME_-61955_DEF_STYLE        = 'PARAMETERIZED'
      FRAME_-61955_FAMILY           = 'TWO-VECTOR'
      FRAME_-61955_PRI_AXIS         = 'X'
      FRAME_-61955_PRI_VECTOR_DEF   = 'OBSERVER_TARGET_POSITION'
      FRAME_-61955_PRI_OBSERVER     = 'JUPITER'
      FRAME_-61955_PRI_TARGET       = 'SUN'
      FRAME_-61955_PRI_ABCORR       = 'NONE'
      FRAME_-61955_SEC_AXIS         = 'Z'
      FRAME_-61955_SEC_VECTOR_DEF   = 'CONSTANT'
      FRAME_-61955_SEC_FRAME        = 'IAU_SUN'
      FRAME_-61955_SEC_SPEC         = 'RECTANGULAR'
      FRAME_-61955_SEC_VECTOR       =  ( 0, 0, 1 )
```

Continues on next page...

```
   \begintext


Juno Solar Equatorial RTN Frame

   The JUNO_SUN_EQU_RTN frame implements the JUNO mission JUNO RTN
   reference frame described in [9].

   It is defined as a dynamic frame as follows:

      -  +X axis is along the geometric position of Juno as seen
         from the Sun

      -  +Z axis is in the direction of the Sun north pole.

      -  +Y completes the right handed frame

      -  the center is at the JUNO spacecraft.

   The keywords below implement the JUNO_SUN_EQU_RTN frame as a dynamic
   frame.

   \begindata

      FRAME_JUNO_SUN_EQU_RTN        = -61956
      FRAME_-61956_NAME             = 'JUNO_SUN_EQU_RTN'
      FRAME_-61956_CLASS            = 5
      FRAME_-61956_CLASS_ID         = -61956
      FRAME_-61956_CENTER           = -61
      FRAME_-61956_RELATIVE         = 'J2000'
      FRAME_-61956_DEF_STYLE        = 'PARAMETERIZED'
      FRAME_-61956_FAMILY           = 'TWO-VECTOR'
      FRAME_-61956_PRI_AXIS         = 'X'
      FRAME_-61956_PRI_VECTOR_DEF   = 'OBSERVER_TARGET_POSITION'
      FRAME_-61956_PRI_OBSERVER     = 'SUN'
      FRAME_-61956_PRI_TARGET       = 'JUNO'
      FRAME_-61956_PRI_ABCORR       = 'NONE'
      FRAME_-61956_SEC_AXIS         = 'Z'
      FRAME_-61956_SEC_VECTOR_DEF   = 'CONSTANT'
      FRAME_-61956_SEC_FRAME        = 'IAU_SUN'
      FRAME_-61956_SEC_SPEC         = 'RECTANGULAR'
      FRAME_-61956_SEC_VECTOR       =  ( 0, 0, 1 )
```