

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.

#	Coordinate System	Juno Frame SPICE name	Origin	Notes
1	Jupiter System III	S3RH -> IAU_JUPITER S3LH -> <i>no SPICE frame</i>	Jupiter	In Jupiter's rotating frame.
2	Jupiter Magnetic	JUNO_JMAG_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 coordinate 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: `et21st 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 $R_J = 71,492 \pm 4$ km (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 1.76×10^{-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.

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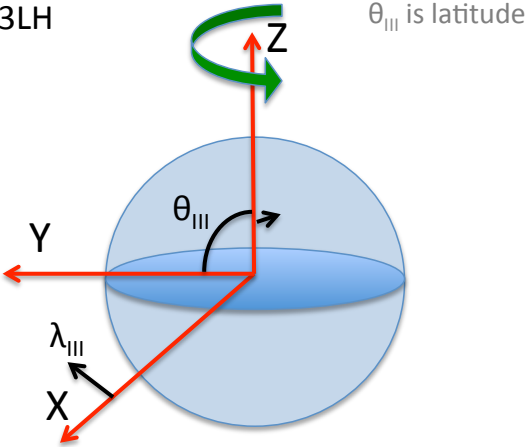
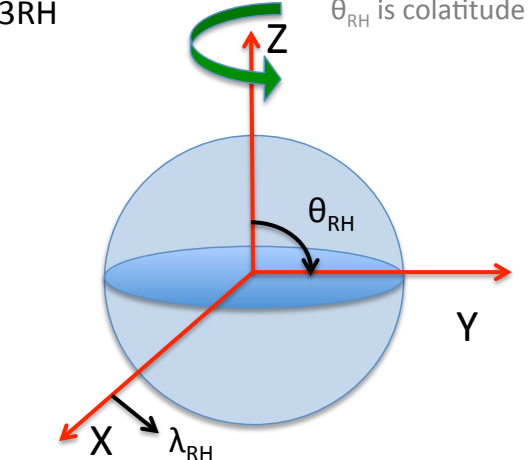
Jupiter Pole

The jovian pole is defined from the 2009 IAU report.

Key Jupiter parameters are in SPICE kernel "pck00010.tpc":

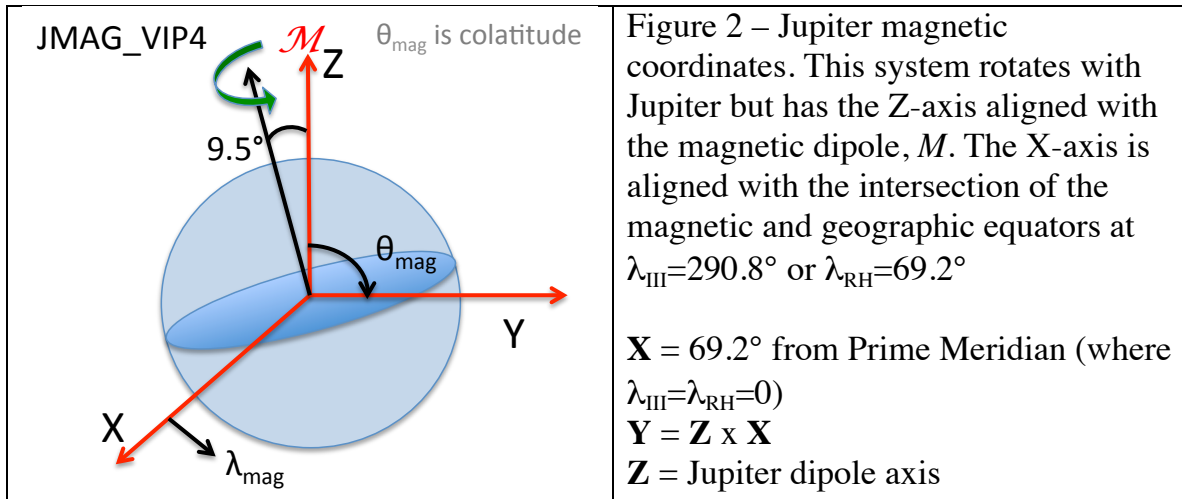
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BODY599_PM         = ( 284.95          870.5360000    0.)
BODY599_POLE_RA   = ( 268.056595      -0.006499      0.)
BODY599_POLE_DEC  = ( 64.495303       0.002413      0.)
```

(1) Jupiter System III (S3LH, S3RH)

<p>S3LH</p>  <p>θ_{III} is latitude</p>	<p>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 $\lambda_{III}=0^\circ$ (prime meridian). The Y-axis completes the orthogonal left-handed system. Latitude (θ_{III}) is defined from the equator.</p> <p>X = 0° latitude, Prime Meridian Y = $\mathbf{X} \times \mathbf{Z}$ Z = Jupiter spin axis</p>
<p>S3RH</p>  <p>θ_{RH} is colatitude</p>	<p>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.</p> <p>X = 90° colatitude, Prime Meridian Y = $\mathbf{Z} \times \mathbf{X}$ Z = Jupiter spin axis</p> <p>$\lambda_{RH}=360^\circ-\lambda_{III}$</p>

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 1.76×10^{-4} rad/s = $870.536^\circ/\text{day}$). 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 ($\lambda_{RH}=360^\circ-\lambda_{III}$) 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_JMAG_VIP4)



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 $\lambda_{\text{III}}=200.8^\circ$ or $\lambda_{\text{RH}}=159.2^\circ$.

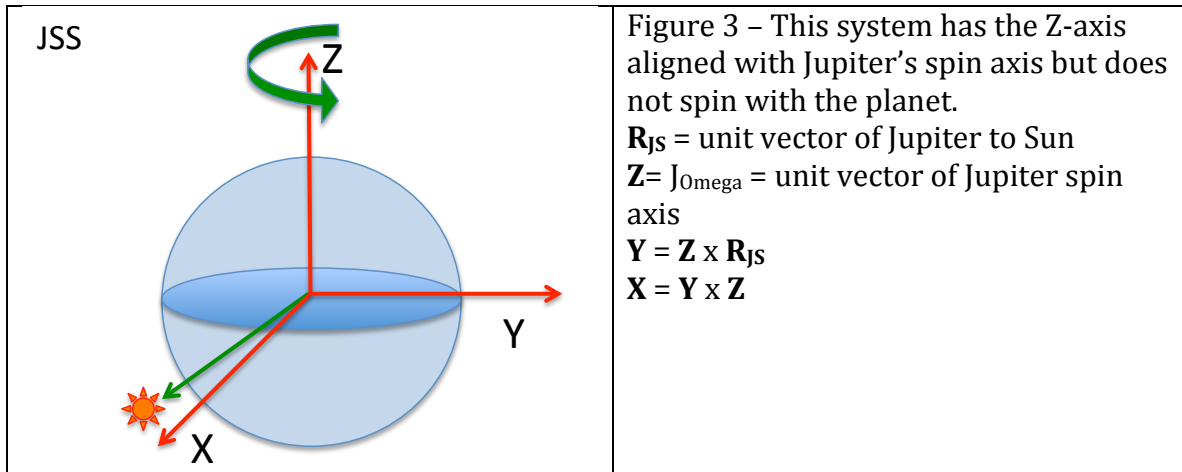
This tilt is based on the VIP4 model (Connerney et al. 1998). The magnetic longitude is defined with respect to the meridian where the magnetic and geographic equators cross (where $\theta_{\text{III}} = 0^\circ$ and $\theta_{\text{RH}} = \theta_{\text{MAG}} = 90^\circ$) at $\lambda_{\text{III}}=290.8^\circ$ or $\lambda_{\text{RH}}=69.2^\circ$. 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 $\lambda_{\text{III}}=202^\circ$ 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).

Note: All Earth dipole MAG SPICE frames have +Y in the direction where the magnetic and spin equators align. In the above system we have +X in this direction. 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.

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



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: $\text{Lat} = \arcsin(z / R) * 180/\pi$
(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

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

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

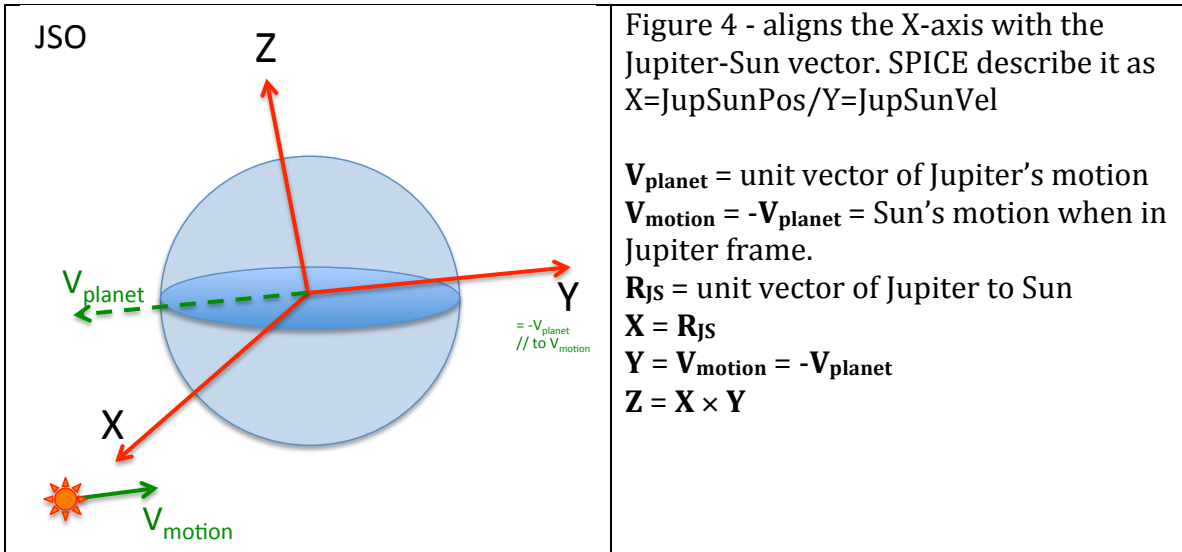
Local Time has units of hours (24 hours to 360 degrees) and translates longitude such that noon (12 hours) local time would be 0 degrees longitude, dusk (18 hours) local time would be 90 degrees longitude, midnight (00 hours) local time would be 180 degrees longitude, and dawn (06 hours) local time would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

Local Time = $\text{LT} = [(\text{Lon} + 180 \text{ degrees}) * 24/360] \text{ MOD } 24$

Local Time = $\text{LT} = [(\arctan(y,x) + \pi) * 12/\pi] \text{ MOD } 24$

The SPICE command `et21st` (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)



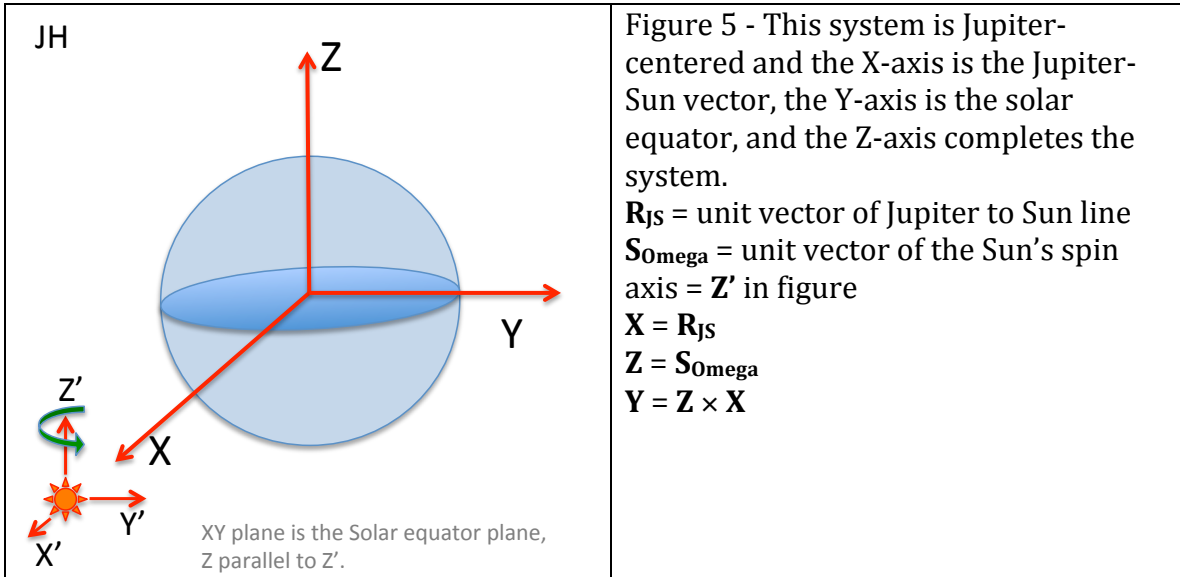
This is similar to Earth's Geocentric Solar Ecliptic (GSE) system, and that since V_{planet} is no longer in the XY plane then +Z is not ecliptic north.

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).

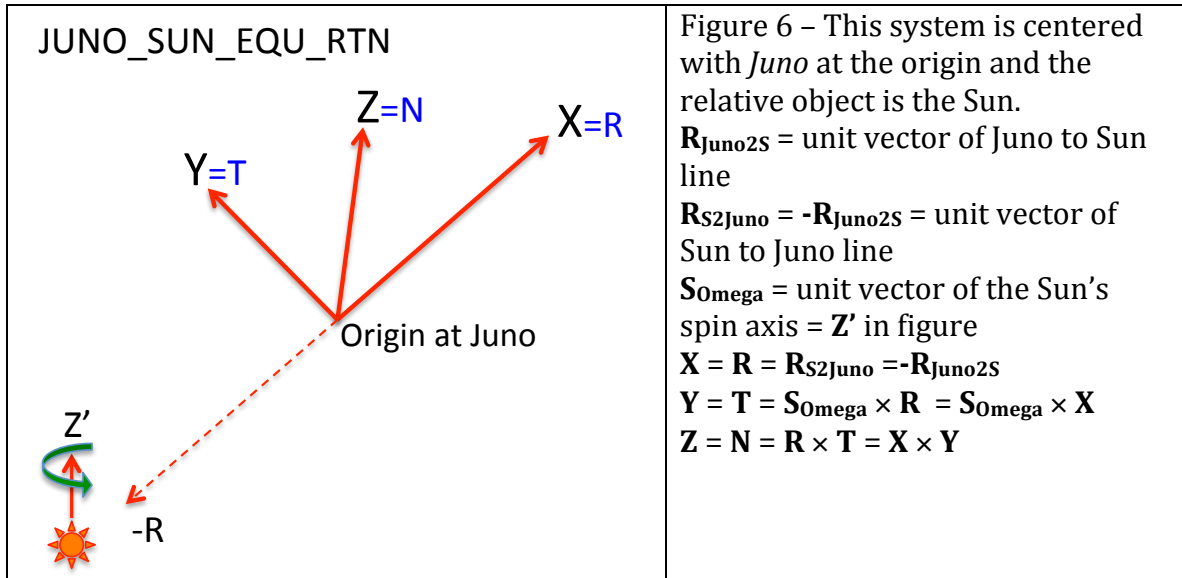


Note:

- 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.)



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 COHWeb website: http://omniweb.gsfc.nasa.gov/coho/html/cw_data.html

“COHWeb 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

	Local Time		Mission used by	Subset of JSS.
	Jupiter Solar Magnetospheric	JSM	Galileo	Similar to JUNO_JMAG_VIP4 but tilt and l_{III} angles are slightly different (tilt of 9.6° and $\lambda_{III}=202^\circ$, 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 ([Ω]). 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.

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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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