IVOA – SSIG
Solar System Reference Frames Update

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May 14, 2019

Issue

- Currently the IVOA data model only includes a small set of reference frames that are used in astronomy
- This list does not include the most commonly used planetary and heliophysics reference frames
- SSIG has recently taken on the task of trying to address this issue in order to facilitate access to solar system data sets using IVOA tools

Work Plan

- Our first step is to go through the literature and existing planetary/heliophysics data systems and collect a list of frames that are currently in use

- We will organize this list and make sure that each named system has a well-defined quantitative definition

- Many of the systems in use are identical (same exact mathematical description but different name) or nearly identical (different reference epoch, etc.)
  - We will use this list to define a frame alias list
  - We will try to define a convention for reference frame naming

List of Data Sources

- NAIF/SPICE Repository (check all kernels)
- Europlanet/VESPA Planetary Coord Systems
- IVOA Space Time Coordinate Mode: Standard Reference Frames List
- SPASE Data Model: CoordinateSystemName
- M.A.Hapgood, Space physics coordinate transformations: A user guide, PSS, 40-5, 1992, 711-717
- Fränz & Harper, Heliospheric Coordinate Systems
- CDPP/TREPS tool
- HELIO-FP7 Coordinate Systems
- Juno Coord System Document
- OMNIWeb Geomagnetic Frames
- Geophysical Coordinate Transformations, C. Russel, IGPP, UCLA
- MSSL UCL Ref list
- Coordinate systems for solar image data, W. T. Thompson, A&A 449, 791-803 (2006)
- Coordinate Systems for ACE
- SPENVIS Coordinate Systems
- STEREO Science Center Coordinate Systems
- IAU code - Data get from IAU report and source code to convert to WKT-crs

Team Working the Issue

- Steven Joy (UCLA/IGPP, PDS/PPI, IVOA/SSIG, IPDA)
- Baptiste Cecconi (Observatoire de Paris, EPN/VESPA, IVOA/SSIG, IPDA)
- Stéphane Erard (Observatoire de Paris, EPN/VESPA, IVOA/SSIG, IPDA)
- Marc Costa (ESA/ESAC, SPICE expert)
- Jean-Christophe Malapert (CNES, OGC Expert)

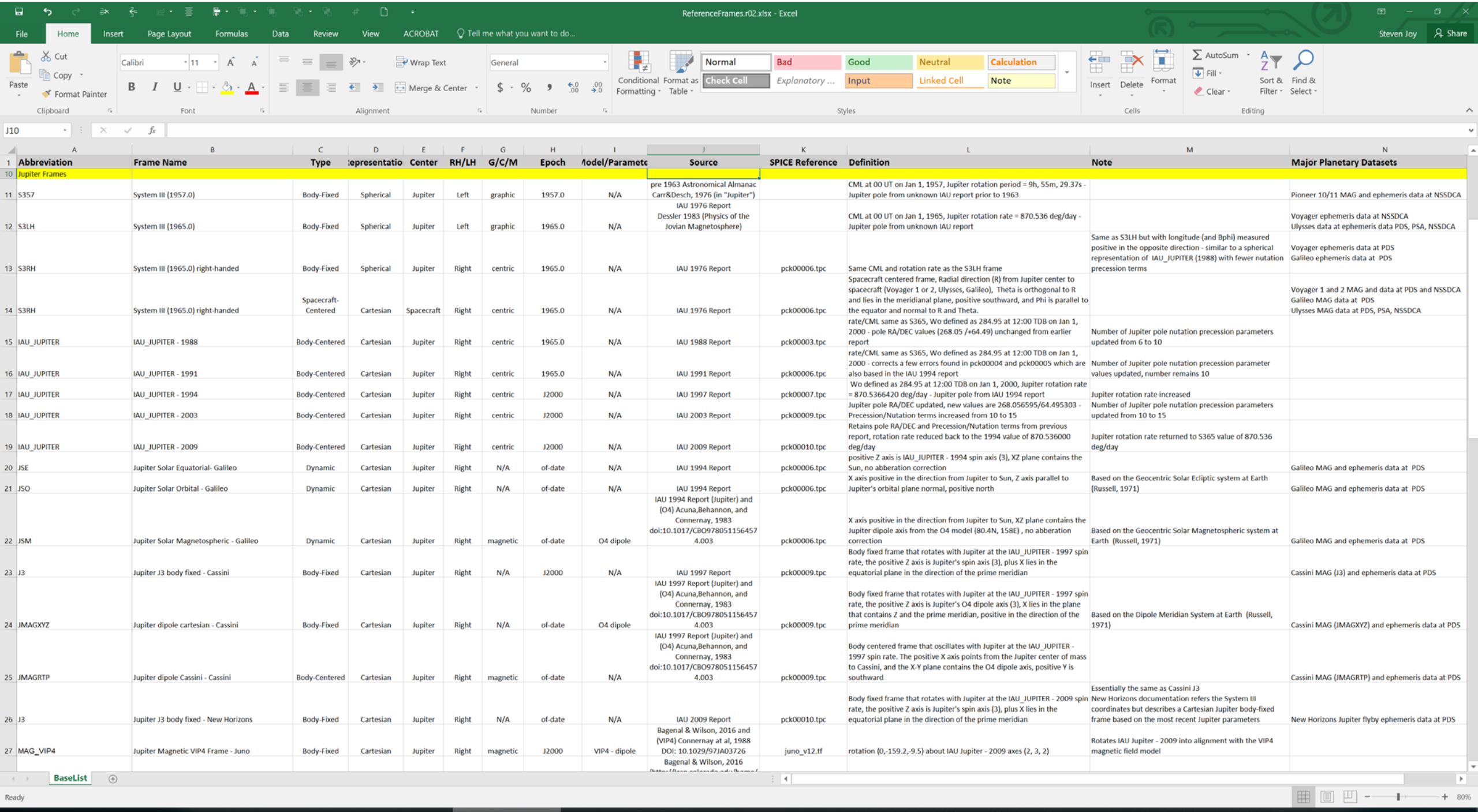
- Others are encouraged to join us in this effort

Status

- A spreadsheet has been developed and populated with information about the various reference frames that have been used for outer planets data
- This spreadsheet has been distributed to the team working the issue for comment and review
- Currently we have described:
  - Inertial Frames (6)
  - Jupiter Frames (27)
  - Saturn Frames (11)
  - Uranus Frames (5)
  - Neptune Frames (5)
  - Pluto Frames (5)
- We will continue to populate this spreadsheet adding non-inertial frames commonly used in heliophysics, as well as the inner planets.

Spreadsheet content (14 columns):

- Abbreviation & Name: Two columns that give the common frame name and abbreviation
- Type: Frame type (inertial, body-centered, body-fixed, dynamic, spacecraft-centered)
- Representation: (Cartesian, Spherical, etc.)
- Center: Frame center (Jupiter, Saturn, Cassini, etc.)
- RH/LH: right-handed or left-handed frame
- G/C/M: Planetographic, Planetocentric, or Magnetic
- Epoch: (J2000, B1950, of-date, etc.)
- Model/Parameter: Magnetic model or body shape model used in definition
- Source: Defining document(s)
- SPICE reference: SPICE PCK or FK that defines the frame
- Definition: Frame definition text
- Note: Any notes or comments about the frame definition
- Major Planetary Datasets: List of known datasets that use this frame for archive



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Abbreviation	Frame Name	Type	epresentatio	Center	RH/LH	G/C/M	Epoch	Model/Paramete	Source	SPICE Reference	Definition	Note	Major Planetary Datasets
10	Jupiter Frames													
11	S357	System III (1957.0)	Body-Fixed	Spherical	Jupiter	Left	graphic	1957.0	N/A	pre 1963 Astronomical Almanac Carr&Desch, 1976 (in "Jupiter")		CML at 00 UT on Jan 1, 1957, Jupiter rotation period = 9h, 55m, 29.37s - Jupiter pole from unknown IAU report prior to 1963		Pioneer 10/11 MAG and ephemeris data at NSSDCA
12	S3LH	System III (1965.0)	Body-Fixed	Spherical	Jupiter	Left	graphic	1965.0	N/A	IAU 1976 Report Dessler 1983 (Physics of the Jovian Magnetosphere)		CML at 00 UT on Jan 1, 1965, Jupiter rotation rate = 870.536 deg/day - Jupiter pole from unknown IAU report		Voyager ephemeris data at NSSDCA Ulysses data at ephemeris data PDS, PSA, NSSDCA
13	S3RH	System III (1965.0) right-handed	Body-Fixed	Spherical	Jupiter	Right	centric	1965.0	N/A	IAU 1976 Report	pck00006.tpc	Same CML and rotation rate as the S3LH frame	Same as S3LH but with longitude (and Bphi) measured positive in the opposite direction - similar to a spherical representation of IAU_JUPITER (1988) with fewer nutation precession terms	Voyager ephemeris data at PDS Galileo ephemeris data at PDS
14	S3RH	System III (1965.0) right-handed	Spacecraft-Centered	Cartesian	Spacecraft	Right	centric	1965.0	N/A	IAU 1976 Report	pck00006.tpc	Spacecraft centered frame, Radial direction (R) from Jupiter center to spacecraft (Voyager 1 or 2, Ulysses, Galileo), Theta is orthogonal to R and lies in the meridianal plane, positive southward, and Phi is parallel to the equator and normal to R and Theta.		Voyager 1 and 2 MAG and data at PDS and NSSDCA Galileo MAG data at PDS Ulysses MAG data at PDS, PSA, NSSDCA
15	IAU_JUPITER	IAU_JUPITER - 1988	Body-Centered	Cartesian	Jupiter	Right	centric	1965.0	N/A	IAU 1988 Report	pck00003.tpc	rate/CML same as S365, Wo defined as 284.95 at 12:00 TDB on Jan 1, 2000 - pole RA/DEC values (268.05 /+64.49) unchanged from earlier report	Number of Jupiter pole nutation precession parameters updated from 6 to 10	
16	IAU_JUPITER	IAU_JUPITER - 1991	Body-Centered	Cartesian	Jupiter	Right	centric	1965.0	N/A	IAU 1991 Report	pck00006.tpc	rate/CML same as S365, Wo defined as 284.95 at 12:00 TDB on Jan 1, 2000 - corrects a few errors found in pck00004 and pck00005 which are also based in the IAU 1994 report	Number of Jupiter pole nutation precession parameter values updated, number remains 10	
17	IAU_JUPITER	IAU_JUPITER - 1994	Body-Centered	Cartesian	Jupiter	Right	centric	J2000	N/A	IAU 1997 Report	pck00007.tpc	Wo defined as 284.95 at 12:00 TDB on Jan 1, 2000, Jupiter rotation rate = 870.5366420 deg/day - Jupiter pole from IAU 1994 report	Jupiter rotation rate increased	
18	IAU_JUPITER	IAU_JUPITER - 2003	Body-Centered	Cartesian	Jupiter	Right	centric	J2000	N/A	IAU 2003 Report	pck00009.tpc	Jupiter pole RA/DEC updated, new values are 268.056595/64.495303 - Precession/Nutation terms increased from 10 to 15	Number of Jupiter pole nutation precession parameters updated from 10 to 15	
19	IAU_JUPITER	IAU_JUPITER - 2009	Body-Centered	Cartesian	Jupiter	Right	centric	J2000	N/A	IAU 2009 Report	pck00010.tpc	Retains pole RA/DEC and Precession/Nutation terms from previous report, rotation rate reduced back to the 1994 value of 870.536000 deg/day	Jupiter rotation rate returned to S365 value of 870.536 deg/day	
20	JSE	Jupiter Solar Equatorial- Galileo	Dynamic	Cartesian	Jupiter	Right	N/A	of-date	N/A	IAU 1994 Report	pck00006.tpc	positive Z axis is IAU_JUPITER - 1994 spin axis (3), XZ plane contains the Sun, no abberation correction		Galileo MAG and ephemeris data at PDS
21	JSO	Jupiter Solar Orbital - Galileo	Dynamic	Cartesian	Jupiter	Right	N/A	of-date	N/A	IAU 1994 Report	pck00006.tpc	X axis positive in the direction from Jupiter to Sun, Z axis parallel to Jupiter's orbital plane normal, positive north	Based on the Geocentric Solar Ecliptic system at Earth (Russell, 1971)	Galileo MAG and ephemeris data at PDS
22	JSM	Jupiter Solar Magnetospheric - Galileo	Dynamic	Cartesian	Jupiter	Right	magnetic	of-date	O4 dipole	IAU 1994 Report (Jupiter) and (O4) Acuna,Behannon, and Connernay, 1983 doi:10.1017/CBO9780511564574.003	pck00006.tpc	X axis positive in the direction from Jupiter to Sun, XZ plane contains the Jupiter dipole axis from the O4 model (80.4N, 158E) , no abberation correction	Based on the Geocentric Solar Magnetospheric system at Earth (Russell, 1971)	Galileo MAG and ephemeris data at PDS
23	J3	Jupiter J3 body fixed - Cassini	Body-Fixed	Cartesian	Jupiter	Right	N/A	J2000	N/A	IAU 1997 Report	pck00009.tpc	Body fixed frame that rotates with Jupiter at the IAU_JUPITER - 1997 spin rate, the positive Z axis is Jupiter's spin axis (3), plus X lies in the equatorial plane in the direction of the prime meridian		Cassini MAG (J3) and ephemeris data at PDS
24	JMAGXYZ	Jupiter dipole cartesian - Cassini	Body-Fixed	Cartesian	Jupiter	Right	N/A	of-date	O4 dipole	IAU 1997 Report (Jupiter) and (O4) Acuna,Behannon, and Connernay, 1983 doi:10.1017/CBO9780511564574.003	pck00009.tpc	Body fixed frame that rotates with Jupiter at the IAU_JUPITER - 1997 spin rate, the positive Z axis is Jupiter's O4 dipole axis (3), X lies in the plane that contains Z and the prime meridian, positive in the direction of the prime meridian	Based on the Dipole Meridian System at Earth (Russell, 1971)	Cassini MAG (JMAGXYZ) and ephemeris data at PDS
25	JMAGRTP	Jupiter dipole Cassini - Cassini	Body-Centered	Cartesian	Jupiter	Right	magnetic	of-date	N/A	IAU 1997 Report (Jupiter) and (O4) Acuna,Behannon, and Connernay, 1983 doi:10.1017/CBO9780511564574.003	pck00009.tpc	Body centered frame that oscillates with Jupiter at the IAU_JUPITER - 1997 spin rate. The positive X axis points from the Jupiter center of mass to Cassini, and the X-Y plane contains the O4 dipole axis, positive Y is southward		Cassini MAG (JMAGRTP) and ephemeris data at PDS
26	J3	Jupiter J3 body fixed - New Horizons	Body-Fixed	Cartesian	Jupiter	Right	N/A	of-date	N/A	IAU 2009 Report	pck00010.tpc	Body fixed frame that rotates with Jupiter at the IAU_JUPITER - 2009 spin rate, the positive Z axis is Jupiter's spin axis (3), plus X lies in the equatorial plane in the direction of the prime meridian	Essentially the same as Cassini J3 New Horizons documentation refers the System III coordinates but describes a Cartesian Jupiter body-fixed frame based on the most recent Jupiter parameters	New Horizons Jupiter flyby ephemeris data at PDS
27	MAG_VIP4	Jupiter Magnetic VIP4 Frame - Juno	Body-Fixed	Cartesian	Jupiter	Right	magnetic	J2000	VIP4 - dipole	Bagenal & Wilson, 2016 and (VIP4) Connernay at al, 1988 DOI: 10.1029/97JA03726 Bagenal & Wilson, 2016	juno_v12.tf	rotation (0,-159.2,-9.5) about IAU Jupiter - 2009 axes (2, 3, 2)	Rotates IAU Jupiter - 2009 into alignment with the VIP4 magnetic field model	

Some obvious issues…

1. It’s very clear that frame definitions must include a date. The IAU issues new reports every few years and some key parameters (pole RA/DEC, rotation rate, precession/nutation terms, etc.) are updated
   - Many of the frame definitions are nothing more than updates related to new IAU parameters
2. IAU convention for the definition of “north pole” differs for planets and small bodies – Pluto pole reversed after reclassification from planet to minor planet.
3. The same name is used for different frames and identical frames are given different names by different teams/datasets

Where we're going

- Current the IVOA data model has a hard-coded list of reference frame names that can be used to search the data
- Eventually, we would like to propose a reference frame naming convention to the Semantics WG for consideration.
  - The purpose of the spreadsheet of frame definitions is to identify the commonly recurring elements that will need to be incorporated into a naming convention.
- When and if the SWG agrees to adopt some version of our proposed naming system, then we would go the Data Modeling WG