An Overview of JPL DSMS Metric Predictions Services

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Predictions…..Do I Need Those?

- Imagine you have a bunch of antennas, and the requisite capability to send and receive signals, and
- You have a bunch of spacecraft all over the solar system that you want to communicate with,

What Do You Need To Know?…

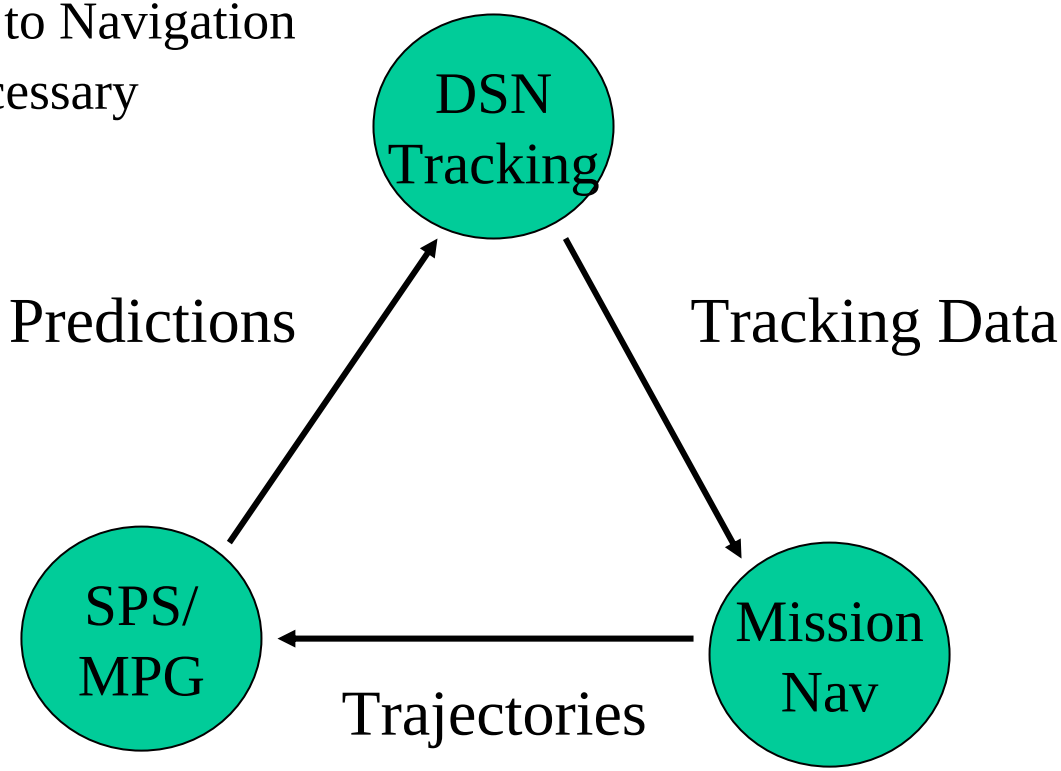
Questions, Questions, Questions

MPG answers all these questions…

- When does the spacecraft come up? Go down? When can I start transmitting? What about with the 400kW transmitter?
- Is the spacecraft moving too fast for the antenna to track? Is it too high? Too low? Does it dip behind the mountains?
- Would the antenna move farther than the cables attached to it?
- Is the spacecraft behind Mars? In the shadow? Umbra or Penumbra?
- When does the spacecraft reach and orbit's Apoapsis? Periapsis?
- If the signal goes up from one antenna, when will it come back? Which stations will be there to receive it?
- Which direction is the spacecraft, exactly? Where does it appear to be?
- What frequency do I need to transmit so the spacecraft will immediately lock?
- What frequency do I need to listen to?
- Say a signal leaves the spacecraft and is received by two antennas on Earth. What is the difference in arrival times?

MPG and the Tracking/Navigation Loop

- Mission Navigation team uses tracking data to correct and extend trajectories, which are sent to the MPG, via the SPS portal
- MPG uses the trajectories to create predicts, which are sent to the DSCC
- DSCC uses the predicts to track spacecraft and collects tracking data, which is sent to Navigation
- Repeat as necessary



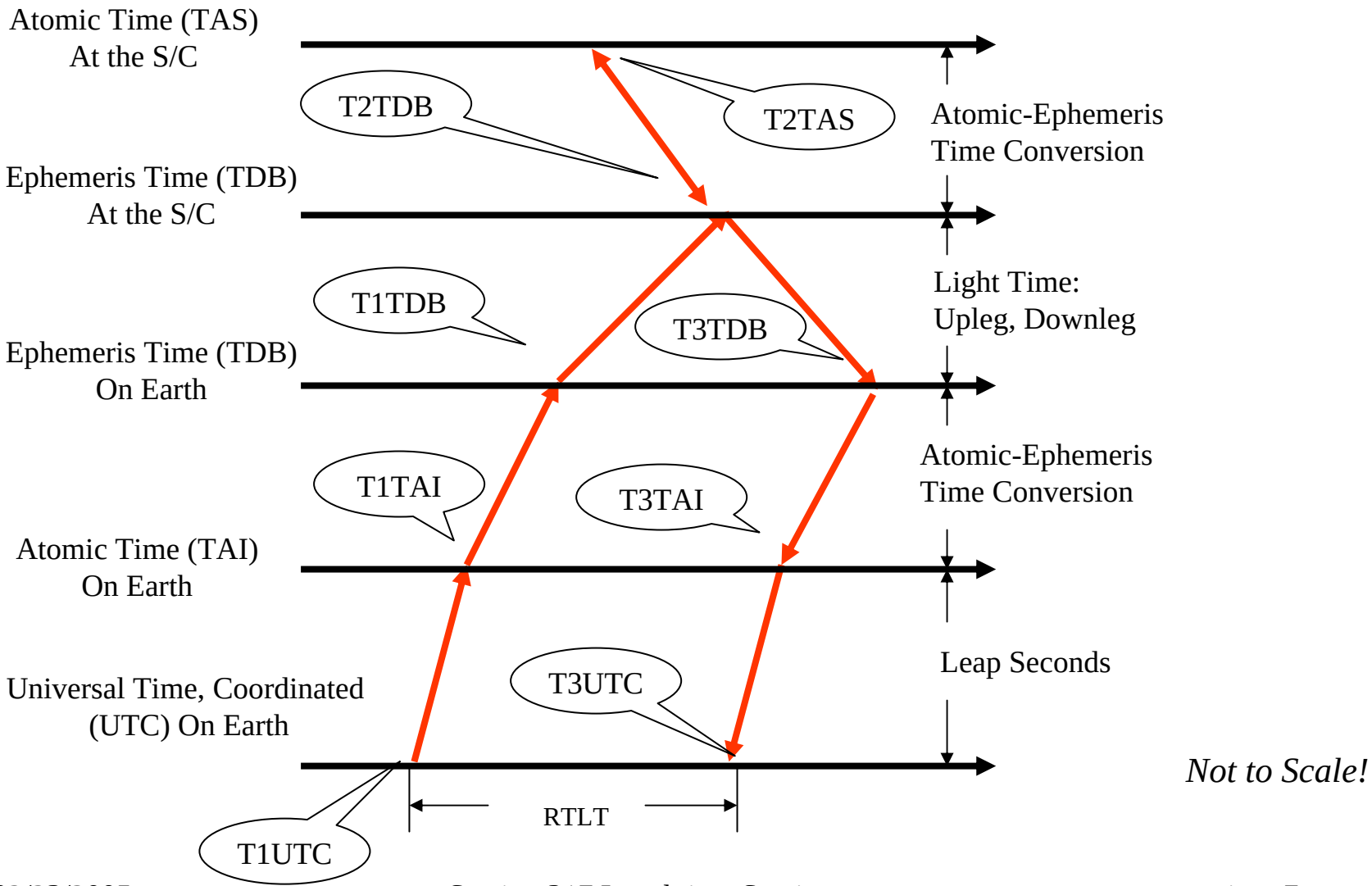
What is the MPG?

- A compute-bound application with a collection of programs that predict pointing angles, frequencies, and view period events related to tracking spacecraft
- Predictions are consumed by DSN subsystems that provide mission tracking services
  - Antenna pointing (APA, APC, AMC)
  - Uplink (ULC)
  - Downlink (DCC)
  - VLBI (FSPV)
  - Radio science (FSPR)
  - Arrayed antennas (FSPA)
  - 26M antennas (MPA)
- A modern SPICE-based system that operates directly on SPICE files
- The core processing is coded in C++ on top of SPICE Toolkit and a series of extensions provided by the NAIF group
- Successfully tested through shadow tracks
- Currently a Unix based application targeted to both the Intel and Sparc platforms
- In the SPS, follows the Google paradigm of using Intel-based board farms
- Scheduled for delivery to DSN operations within SPS in 2006

MPG Terms Of Interest - Time

- Times
  - T1 – Earth Transmit Time
  - T2 – Spacecraft Receive/Transmit Time
  - T3 – Earth Receive Time
- Time frames
  - UTC – Wall Clock Time on Earth
  - TAI – Atomic Time on Earth
  - TAS – Atomic Time at the Spacecraft (unused in MPG)
  - TDB, ET – Barycentric Dynamical Time, Ephemeris Time
    - ET and TDB are used interchangeably in MPG
- Leap Seconds
- Light Times: Upleg, Downleg, Round Trip (RTLT)

What Time Is It?

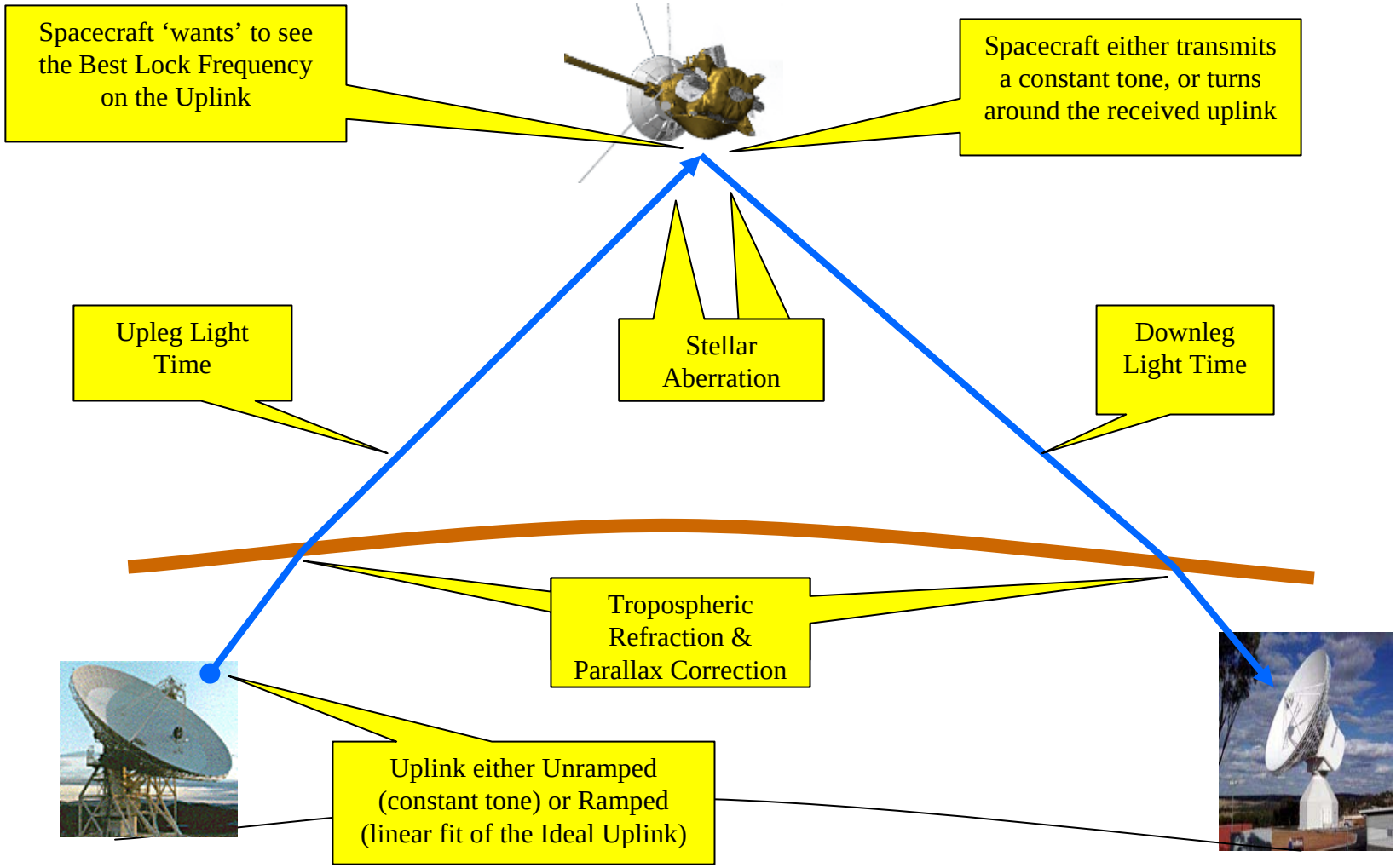


MPG Terms Of Interest - Frequency

- Players
  - Transmitter – Station originates the carrier
  - Transponder – Spacecraft receiver locks on carrier and immediately retransmits at a different frequency
  - Receiver – Station receives the retransmitted carrier
- Doppler Modes
  - 1-way – Signal originates at the S/C. Downlink only
  - 2-way – Signal originates at DSS, turned around by S/C, received at same DSS
  - 3-way – Same as 2-way, except received at a difference DSS
- Other Terms
  - Turnaround Ratio – Ratio of two integers; converts uplink to downlink
  - Coherent – S/C multiplies received frequency by turn around ratio, retransmits
  - Non-coherent – Transmission on S/C is driven by on-board oscillator
  - XA – Ideal Uplink Freq. = S/C best lock (loved) frequency minus Upleg Doppler
  - Bands – Specific Frequency Ranges. MPG can support any band. Current and historic bands include: Ka, X, S, C, or L

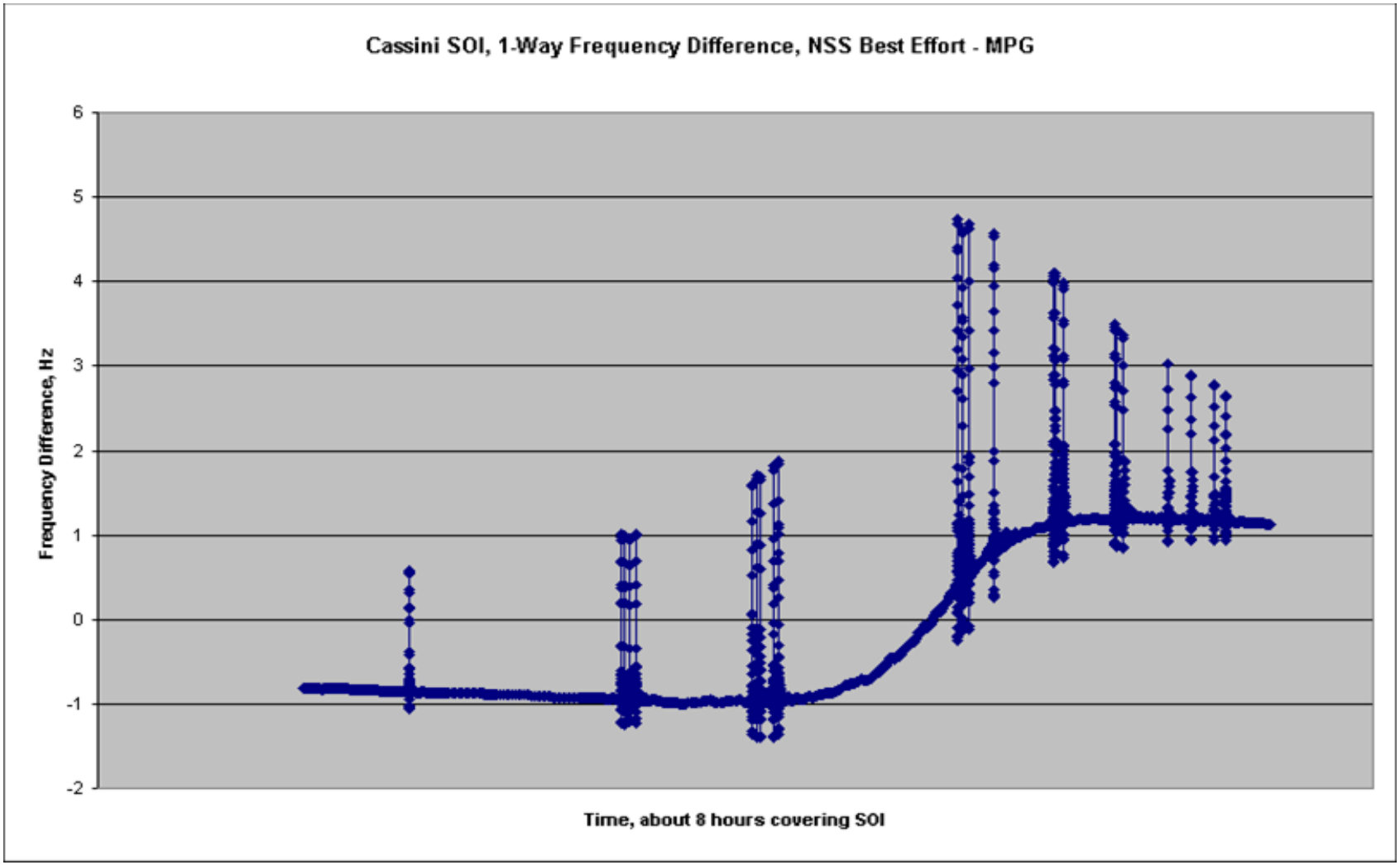
Service Preparation Subsystem

What's the Frequency, Kenneth?



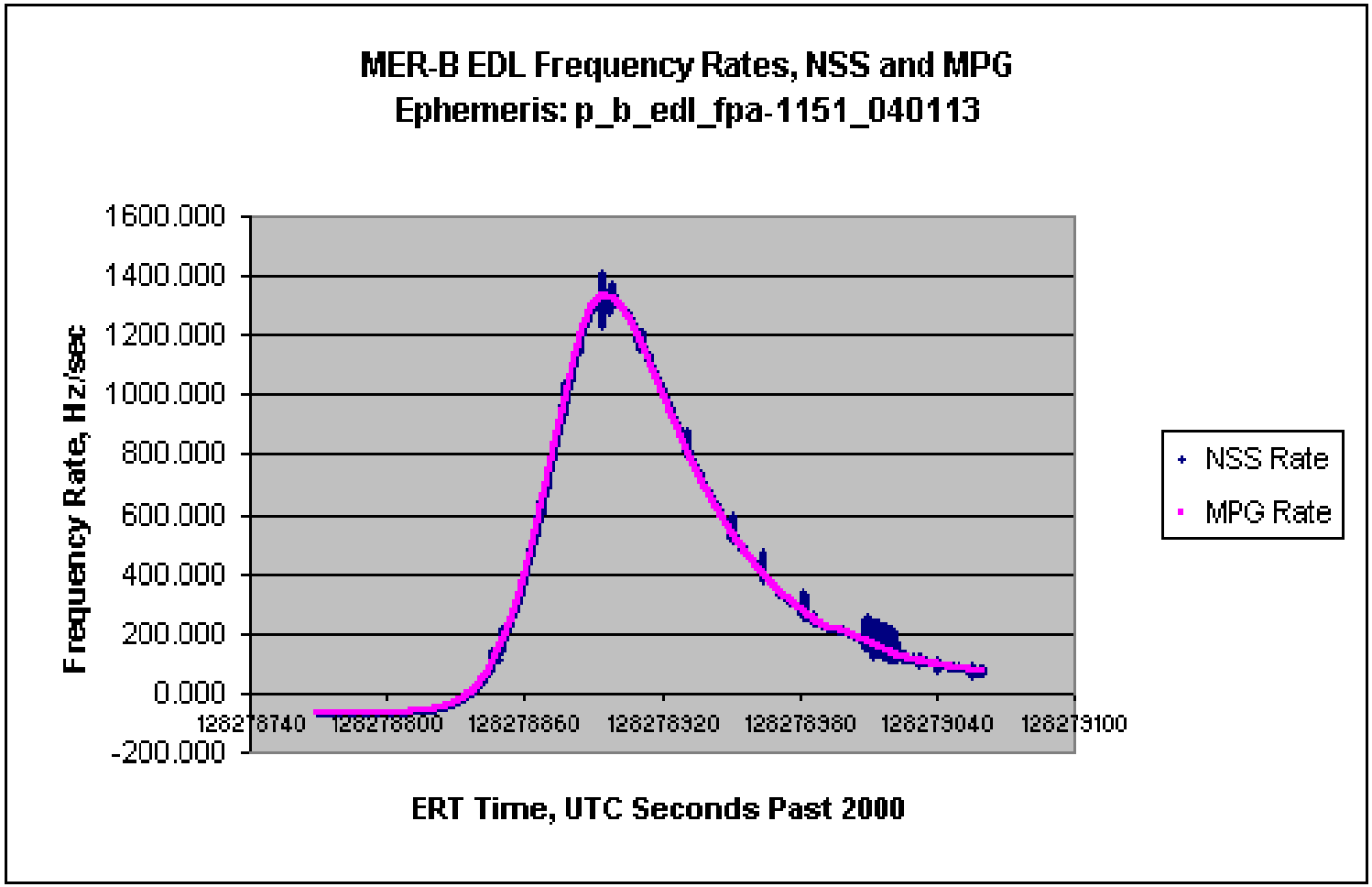
Service Preparation Subsystem

NSS vs. MPG, Cassini SOI,



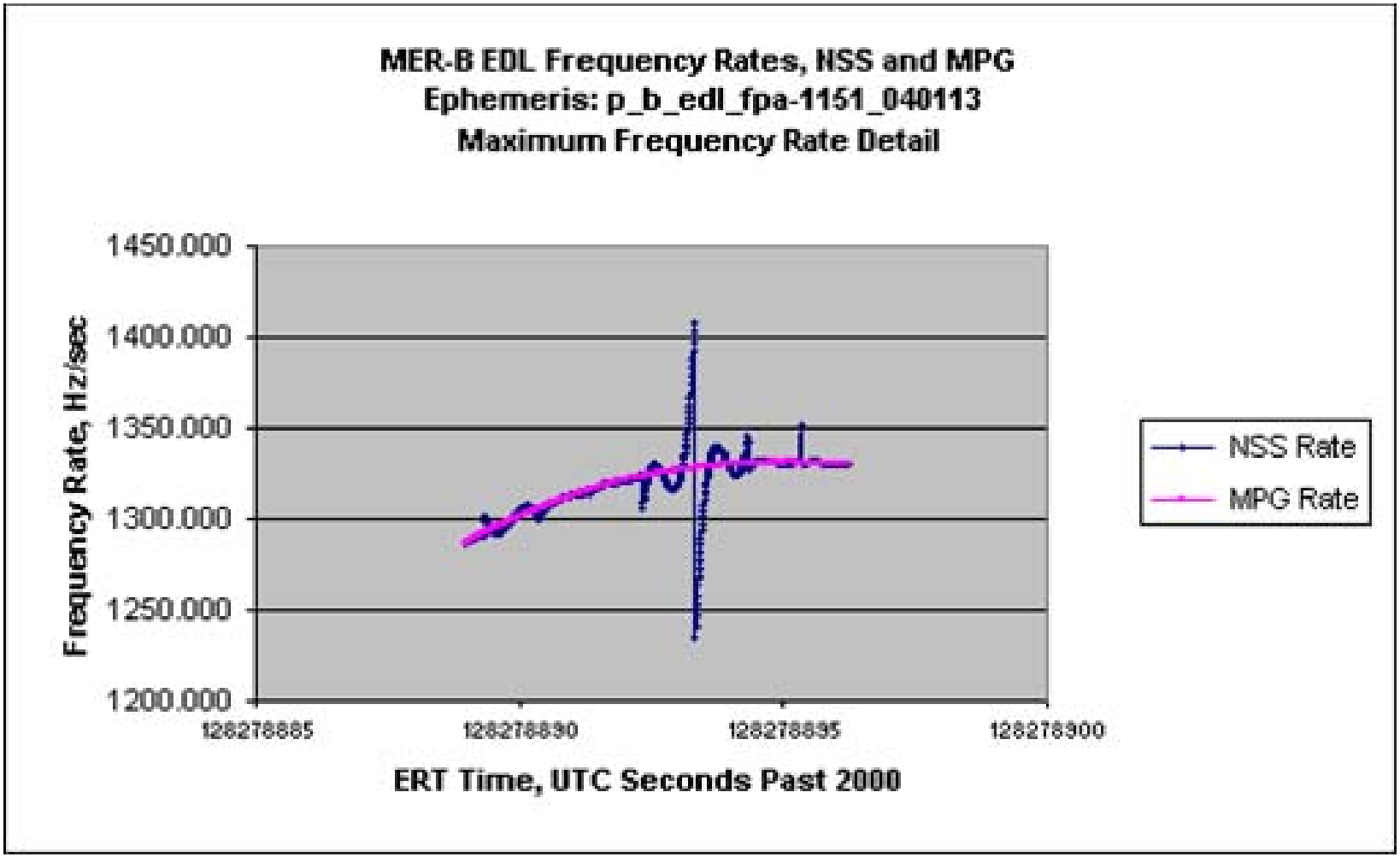
Service Preparation Subsystem

NSS vs. MPG, MER-B EDL



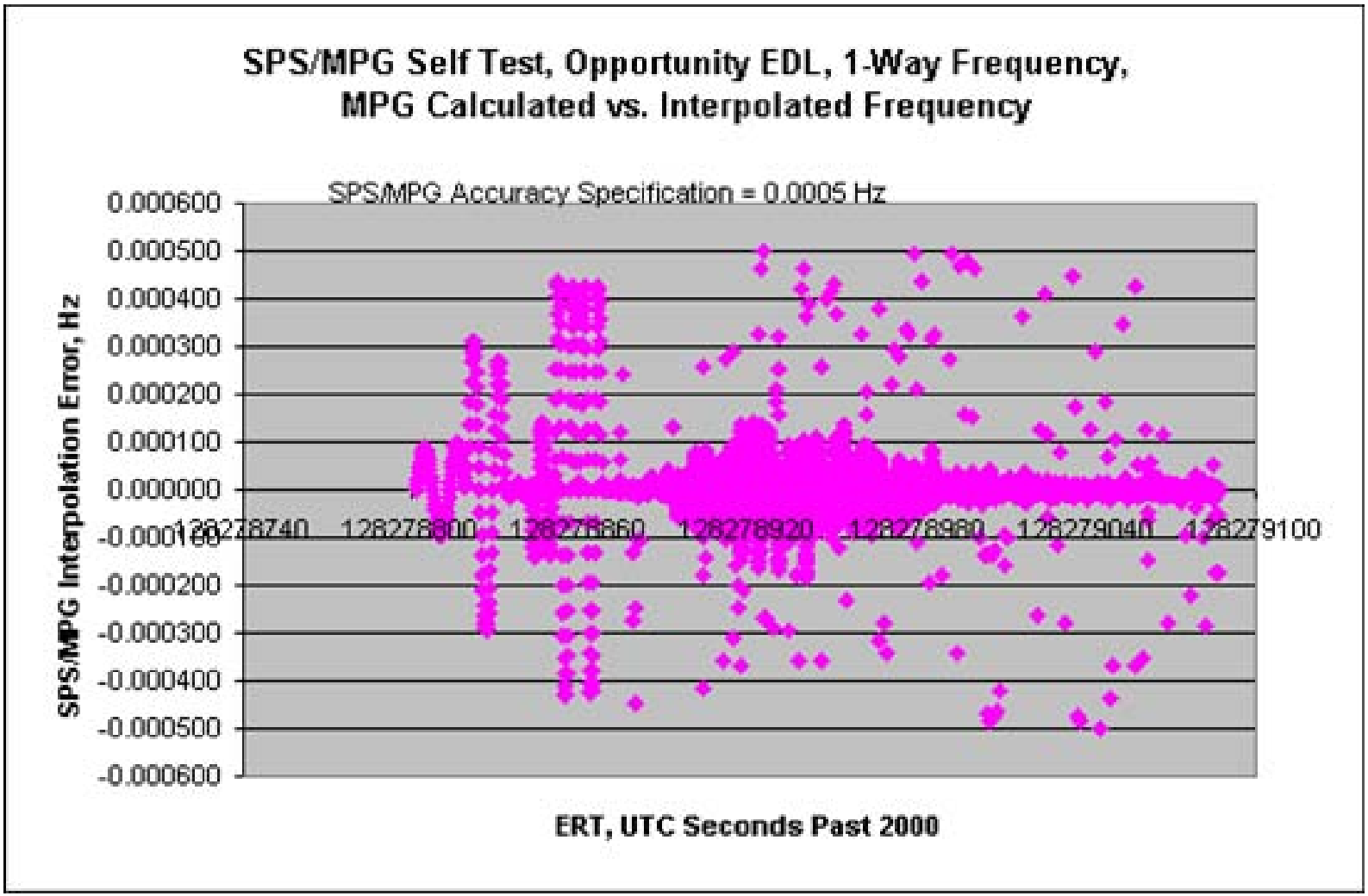
Service Preparation Subsystem

NSS vs. MPG, MER-B EDL Max Freq Rate



Service Preparation Subsystem

MPG Self Test, Opportunity EDL

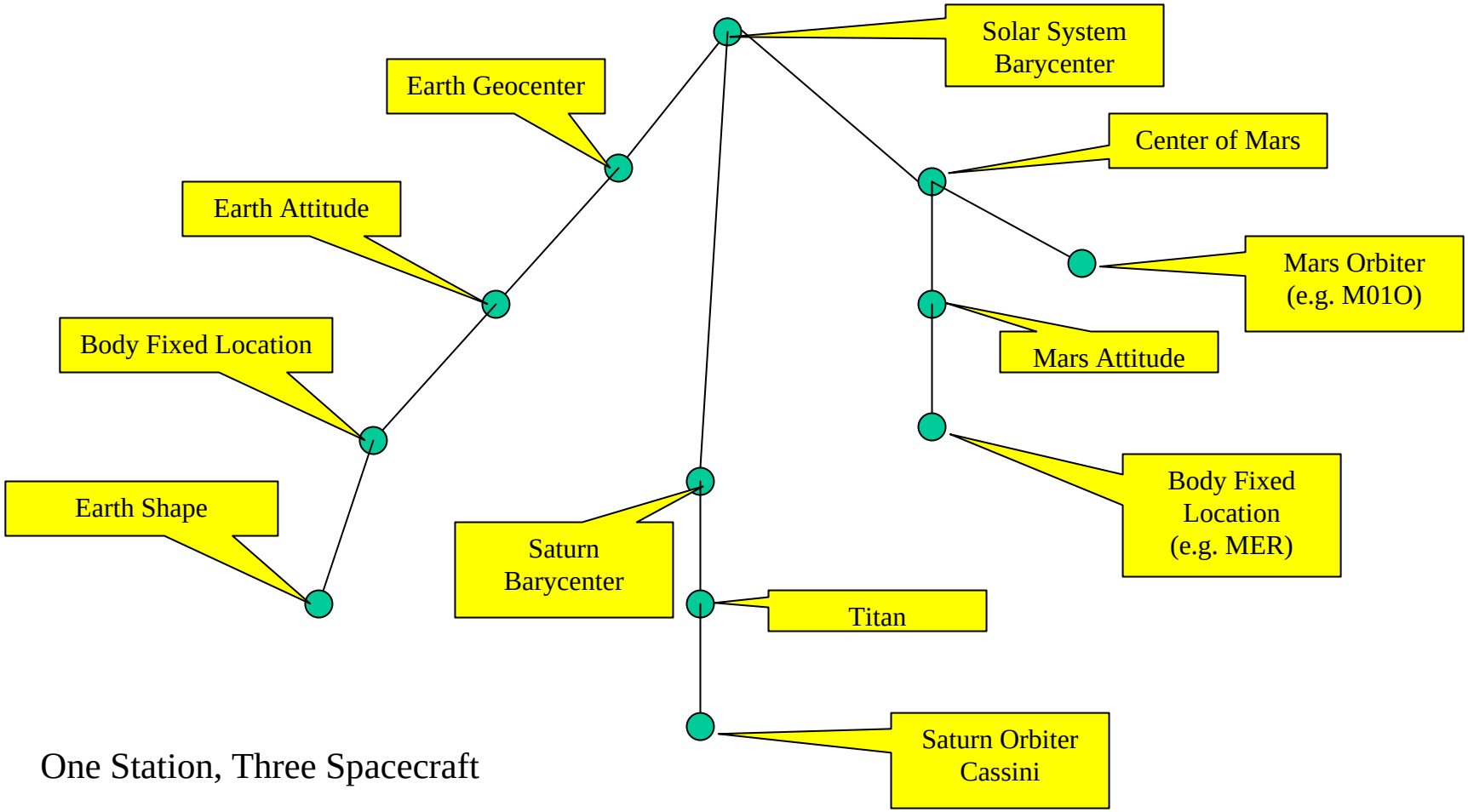


Location, Location, Location

- Station Location and Topocentric Reference Frame:
  - Location of the Center of the Earth
  - Earth Attitude: Precession, Nutation, Polar Motion
  - Location of the Antenna: Latitude, Longitude, Altitude
  - Earth Shape: Oblate spheroid, Geodetic Latitude
  - Ephemeris to Local Time Conversion
- Apparent Spacecraft Position
  - Geometric Location of Spacecraft
  - Light Time Correction
  - Stellar Aberration
  - Gravitational Deflection
  - Atmospheric Refraction
  - Parallax Correction to the Atmospheric Refraction

Service Preparation Subsystem

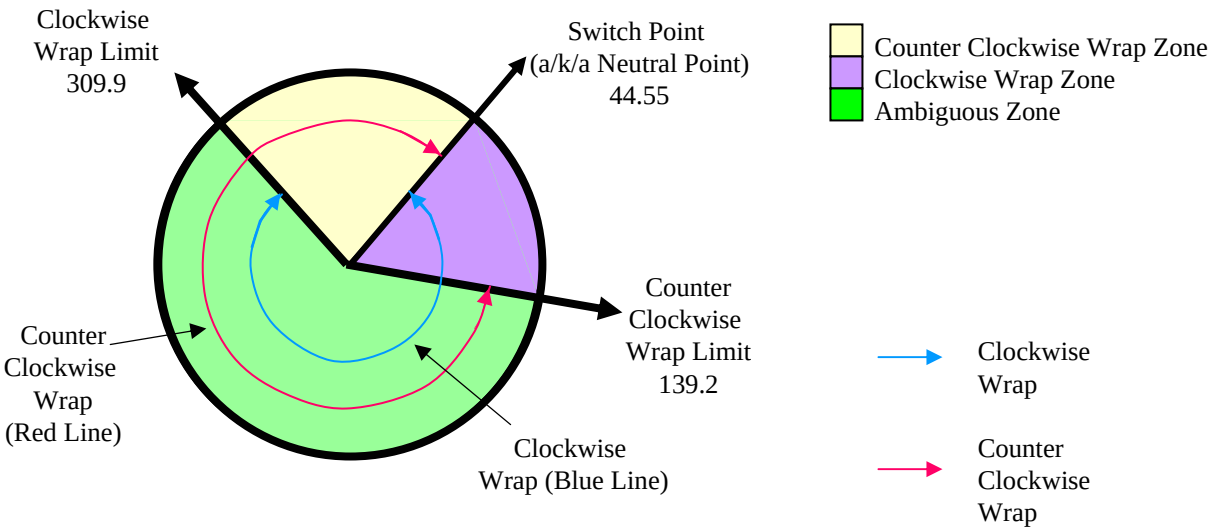
Where are you? Which Way Is Up?



One Station, Three Spacecraft

Service Preparation Subsystem

Basic Cable Wrap Diagram

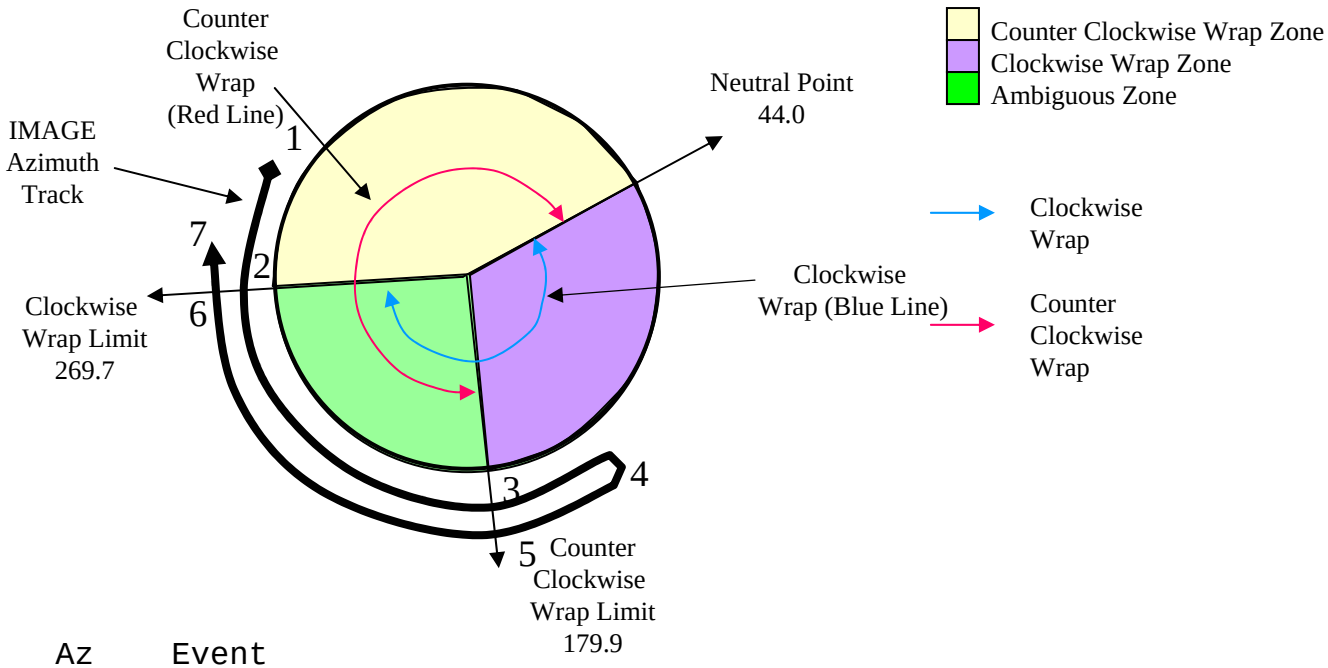


Example: DSS14 Cable Wrap Parameters

Zones are derived from these values

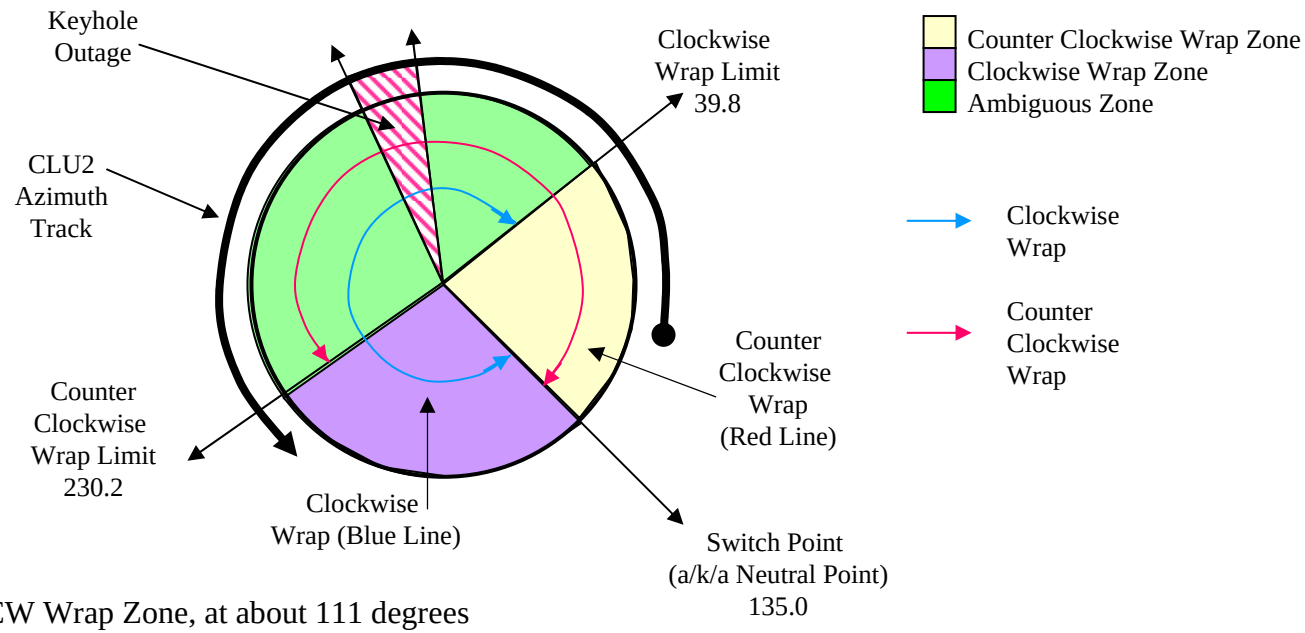
- Counterclockwise Wrap Zone
  - Azimuths that can only be reached in the Counterclockwise Wrap
- Clockwise Wrap Zone
  - Azimuths that can only be reached in the Counter Clockwise Wrap
- Ambiguous Zone
  - Azimuths that can be reached in either CW or CCW Wrap

IMAGE DSS34 DOY 356 Cable Wrap



•	Time	Az	Event
1.	11:26:33 -	313.2	Rise
2.	11:43:27 -	269.7	CW Cable Unwrap
	12:25:00 -		Beginning of Activity (BOA)
3.	14:18:21 -	179.9	CCW Cable Wrap Limit
	14:40:00 -		End of Activity (EOA)
4.	19:21:39 -	147.7	Azimuth Reversal CCW to CW
5.	21:19:21 -	179.9	CCW Cable Unwrap
6.	22:33:37 -	269.7	CW Cable Wrap Limit
7.	00:32:41 -	303.7	Set

Keyhole: CLU2 DSS43 DOY 321 Cable Wrap



- Significant Events:
  - CLU2 Rises at in the CCW Wrap Zone, at about 111 degrees
  - CLU2 Crosses into Ambiguous Zone at 39.8 degrees
  - CLU2 Crosses Above the Maximum Elevation at 351.8 degrees
  - CLU2 Crosses Below the Maximum Elevation at 323.4 degrees
  - CLU2 Crosses into CW Wrap Zone, at 230.2 degrees
  - CLU2 Sets at in the CW Wrap Zone, at about 209 degrees
- What is the correct course of action for the SPS/MPG?
  - Start in CCW Wrap, Switch to CW Wrap at CCW Wrap limit (230.2) – Favors start of pass
  - Start in CCW Wrap, Switch to CW Wrap at CW Wrap Limit (39.8) – Favors end of pass
  - Start in CCW Wrap, Switch to CW Wrap at start of keyhole (351.8) – Minimizes outage
  - Delay start of track until CW Wrap Limit valid; Stay in CW until Set – Eliminates 360 degree slew
  - Start in CCW Wrap, End track before reaching CCW Wrap Limit (230.2) – Eliminates 360 degree slew

What's involved in Metric Prediction Calculation

- The sun, the planets, and other natural bodies
  - Position and velocity
  - Body shape and atmosphere
  - Highly accurate model of earth attitude
- Deep space stations
  - Location, modeled as a point on the surface of a body
  - Mount type, slew rate limits, cable wrap limits, elevation limits
  - Horizons (actual horizon, transmitter horizons, auxiliary)
- Spacecraft
  - Modeled as a point in space, or on the surface of a planet
  - Position and velocity
  - Best lock frequency
  - Turnaround ratios

Major MPG Algorithms

- Curve Fitting
  - Measured Containment Interval Error (MCIE)
    - 12th Degree Chebyshev fit, to generate required 5th Degree Everetts
    - Dynamic Step Size to reduce number of Everetts
    - Function Discontinuity and gap fitting without "ringing"
    - Virtual Sampling
    - Function and derivative interpolation and inverse interpolation
  - Ramp Fit (Piecewise Linear Fit)
- SPICE Toolkit Extensions, provided by NAIF
  - Break point determination
  - Relativistic light time
  - High precision time (TAI <-> TDB) conversions
  - High Precision Earth Model
  - EOP file extension

Major MPG Algorithms (cont.)

- View Period Event Metric Functions
  - Meridian Crossings, Azimuth Reversals
  - Elevation: Abs Min/Max, Local Min/Max
  - Slew Rate Limits and Cable Wrap Limits
  - Occultation, Shadow (umbra/penumbra), (uses Triaxial Ellipsoid Model)
  - Apsis Events
  - Mask evaluation: Horizon, Low/High-Power Transmitter, User Supplied
- View Period Event Summarization
  - Pass number resolution (merges, limits passes, revolution #s)
  - Mutual Viewing Opportunities (2- and 3-Way)
  - Cable Wrap Summary (new)
  - Visibility Summary (new)

Major MPG Algorithms (cont.)

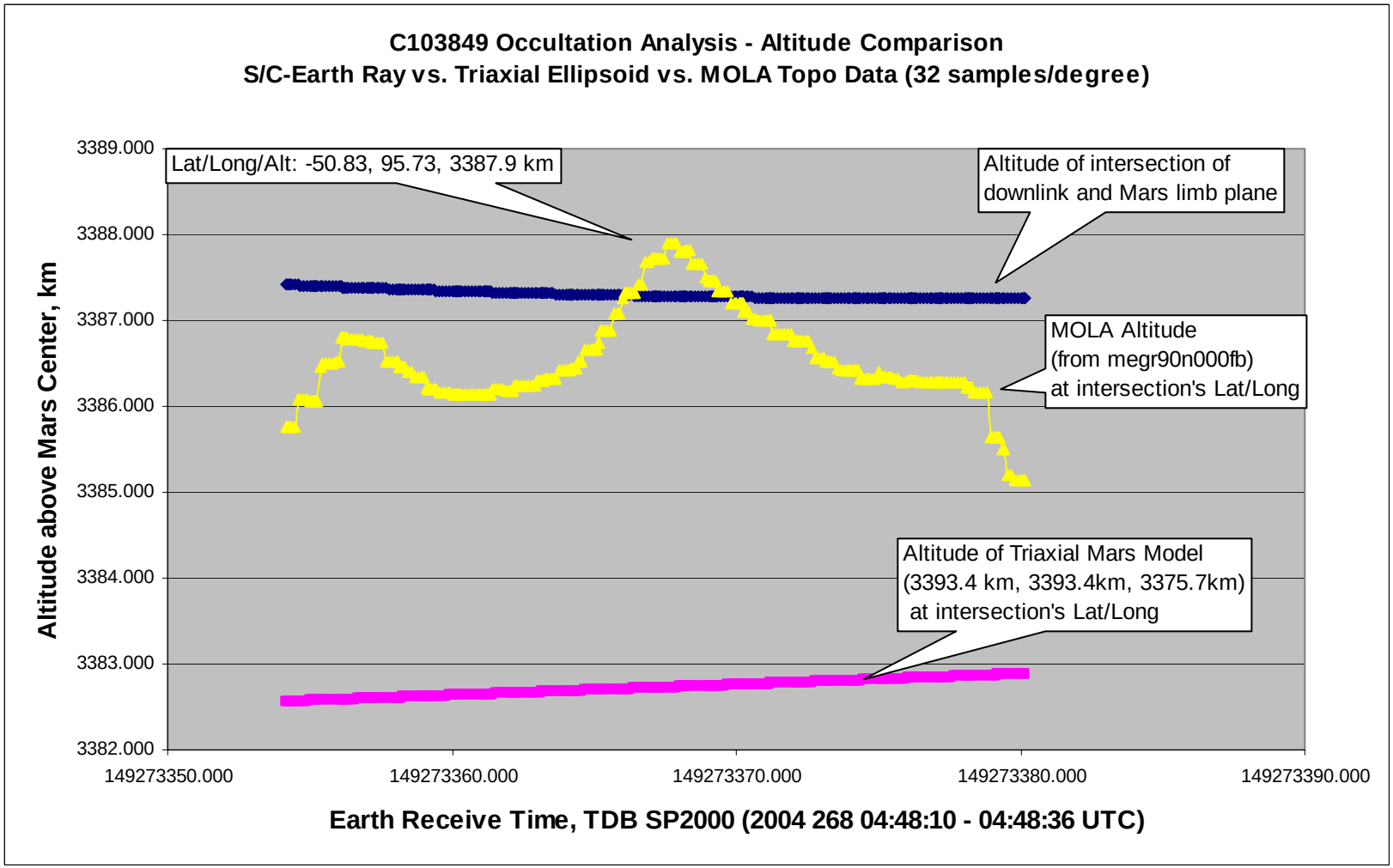
- Pointing
  - Stellar aberration
  - Gravitational Deflection
  - Atmospheric Refraction (for Event Detection)
  - Parallax Correction (for Event Detection)
  - Cable wrap selection
- Frequency
  - Tropospheric Delay
  - Ray Path Delay, including general relativistic effects

Occultation Season

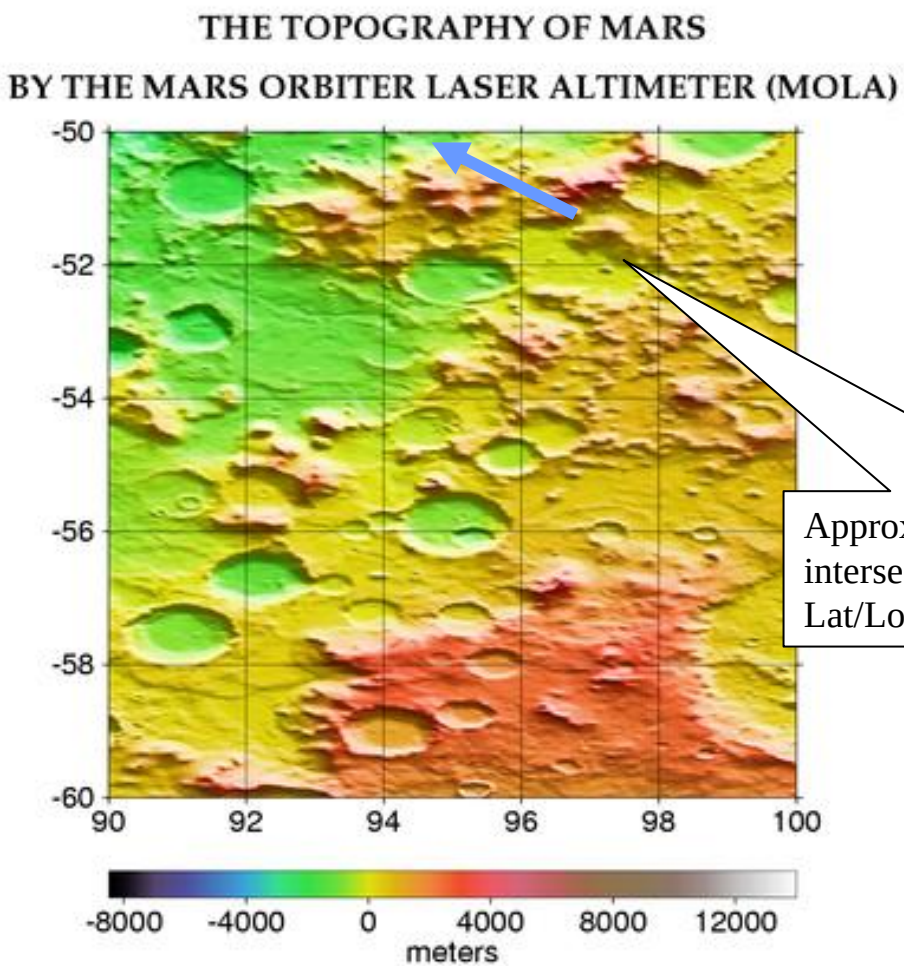
- M01O recently entered Occultation Season, moving from a season with no Occultations to a season when Occultations do occur
- Predicted Occultation times depend upon the model of the planet
  - Spherical vs. Oblate Spheroid vs. Triaxial Ellipsoid
  - Predicted occultation times or even their existence vary
- Announced start of Occultation Season preceded by at least one unexplained loss of receiver lock, leading to DR C103849
- Analysis shows time of DR coincides with time of closest approach of downlink to limb of planet (3.5 km vs Triaxial Model)
- Further analysis using MOLA topographic map data verifies brief occultation (3.6 sec) of downlink by a surface feature of Mars coinciding with time of DR C103849
- Analysis also shows 21 other periods of occultation prior to the start of Occultation Season

Service Preparation Subsystem

Mountains On Mars



Mountains On Mars (Map)



Approx. trace of footprint of intersection in vicinity of Lat/Long/Alt: -50.83, 95.73, 3387.9 km

from Plate grd 010123

Metric Prediction Requirements

- Accuracy:
  - Frequency: 0.5 milliHertz (derived from 1 milliHertz differential error for arraying)
  - Range: 1 nanosecond (about a foot)
  - Pointing: 0.5 millidegree
- Execution Time: 5 minutes (SPS requirement, MPG gets a portion)
- Operability: Must run without intervention; Must not require a PhD to run
- Prediction Format: Must produce usable predict
- Trajectories: All trajectories past, present, future
- Scalability: More spacecraft and vastly more stations, stations on other planets

Primary Requirement:

Cannot be the constraining factor in Operations.

Additional Material

Trajectory Scenarios MPG Supported

- Types of Mission Trajectories and Their Challenges
  - Launch - High angular and frequency dynamics
  - Earth Orbiters - High angular and frequency dynamics
  - Interplanetary Cruise Mode – Long ephemeris record durations
  - Outside the Solar System – Very Long ephemeris record durations
  - Planetary Orbiters – Short ephemeris records, long duration
  - Planetary Landers – Constant, Body-Fixed ephemeris
  - Entry Descent and Landing - Extremely short ephemeris records, High Dynamic
  - Out of the ecliptic – Continuous View, Out of View, and Transitions
  - Lagrange Points/Orbits
  - Trajectory Correction Maneuvers – Transient Dynamics

And, finally

  - Any other trajectory our current or future customers can imagine

MPG Products: View Periods

- View periods are a series of event lines related to a spacecraft and a network of earth stations
- An event line consists of a time, event type, S/C, DSS, pass #, azimuth, elevation, antenna mount specific angles, round trip light time
- Event types:
  - Rise/Set – based on mask that maps the station's horizons (real/TX/aux)
  - Enter/exit occultation with a body or body atmosphere
  - 0/180 degree azimuth crossings and elevation min/max
  - Slew rate limit warnings
  - Possible cable wrap limit warnings
  - Secondary mask events: 2-way and 3-way start/stop times
- View periods define passes and mapping between viewing opportunities and pass numbers
- Used in mission planning, scheduling, and to drive predict generation

Sample Metric Predictions – View Period

Excerpt from a View Period File - Shows events from two passes

TIME	EVENT	SC	FEA	PASS	AZ	EL	LHA/X	DEC/Y	RTLT
97 080/05:31:04	RISE	058	66	4001	232.2	6.0	80.3	308.2	00:00:00.2
97 080/05:31:04	START HOR 2-W 66	058	66	4001	232.2	6.0	80.3	308.2	00:00:00.2
97 080/05:31:06	RISE	058	63	4001	232.2	6.0	232.2	6.0	00:00:00.2
97 080/05:31:06	START HOR 3-W 63	058	66	4001	232.2	6.0	80.3	308.2	00:00:00.2
97 080/05:58:36	TRX ON LIM LOW	058	66	4001	233.8	10.0	73.4	307.4	00:00:00.2
97 080/05:58:36	START LP 3-W 66	058	63	4001	233.8	10.0	233.8	10.0	00:00:00.2
97 080/05:58:36	START LP 2-W 66	058	66	4001	233.8	10.0	73.4	307.4	00:00:00.2
97 080/05:58:39	TRX ON LIM LOW	058	63	4001	233.8	10.0	233.8	10.0	00:00:00.2
97 080/07:00:09	TRX ON LIM HIGH	058	63	4001	230.6	30.0	230.6	30.0	00:00:00.1
97 080/07:00:09	START HP 2-W 63	058	63	4001	230.6	30.0	230.6	30.0	00:00:00.1
97 080/07:00:09	START HP 3-W 63	058	66	4001	230.6	30.0	47.7	318.0	00:00:00.1
97 080/07:22:03	180 DEG AZIMUTH	058	66	4001	180.0	54.2	35.8	0.0	00:00:00.1
97 080/07:22:03	180 DEG AZIMUTH	058	63	4001	180.0	54.2	180.0	54.2	00:00:00.1
97 080/07:22:38	MAX ELEVATION	058	66	4001	174.6	54.3	35.6	3.1	00:00:00.1
97 080/07:22:38	MAX ELEVATION	058	63	4001	174.6	54.3	174.6	54.3	00:00:00.1
97 080/07:25:56	CCW WRAP LIM	058	63	4001	140.2	48.2	140.2	48.2	00:00:00.1
97 080/07:29:10	TRX OFF LIM HIGH	058	63	4001	113.5	30.0	113.5	30.0	00:00:00.1
97 080/07:29:10	END HP 2-W 63	058	63	4001	113.6	30.0	113.6	30.0	00:00:00.1
97 080/07:29:10	END HP 3-W 63	058	66	4001	113.6	30.0	34.7	52.5	00:00:00.1
97 080/07:32:58	SET	058	66	4001	96.5	6.0	47.3	81.1	00:00:00.1
97 080/07:32:58	END HOR 2-W 63	058	63	4001	96.5	6.0	96.5	6.0	00:00:00.1
97 080/07:32:58	END HOR 3-W 66	058	63	4001	96.5	6.0	96.5	6.0	00:00:00.1
97 080/07:32:58	SET	058	63	4001	96.5	6.0	96.5	6.0	00:00:00.1

MPG Products: Pointing Predictions

- Overall accuracy spec: 0.0005 degree
- Directional cosine and range predictions (types: PX6, DOR)
  - Predicts: cosX (zenith), cosY (east), cosZ (north), and range in km
  - Topocentric: relative to a specific station
  - Continuous: uses Everett's form w/ 2nd & 4th central differences
  - Sole remaining binary predict format, XML version in planning
  - Highest accuracy pointing predict: used for deep space missions
- Geocentric 'planetary' predictions (type: GEO)
  - Predicts: Geocentric Right Ascension, Declination and RTLT
  - Discrete: Time and Value Format
  - Can sometimes be used in place of directional cosine predicts
- State vectors (types: MPA and TTY)
  - Predicts: Geocentric Position (X, Y, Z) and Velocity (X', Y', Z')
  - Lower accuracy: used by the 26-meter subnet to track earth orbiters
  - Discrete: Time and Value Format

Sample PX6, GEO, and MPA Types

TIME SECONDS	TIME HH:MM:SS	SOURCE NAME	CABLE WRAP	UT1-UTC SECONDS	FUNCTION	VALUE	SECOND DIFFERENCE	FOURTH DIFFERENCE
36396	10:06:36	VSOP	CW	-0.26513672	X	+0.1024565697	-0.0023193359	-0.0009557009
					Y	-0.5706981421	-0.0020264387	-0.0005180836
					Z	-0.8147431612	+0.0021333694	+0.0003460646
					RANGE (km)	25145	-123	-146
36996	10:16:36	VSOP	CW	-0.26513672	X	+0.1296293736	-0.0016913414	+0.0008221865
					Y	-0.5675970316	-0.0016084909	+0.0004807711
					Z	-0.8130373955	+0.0017185211	-0.0001350641
					RANGE (km)	25458	-92	146

Excerpt from a PX6 Predict – Two ‘difference lines’ with 10 minutes of pointing and range predictions

```
*[                                                                                  ]
*[  AVG TIME    UT1-UTC   EQUINOX      X         Y                                  ]
*2  01:00:00   0.13441  -1.08972   -0.05680   0.25524
[                                                                                   ]
[ DATE/TIME         RA         RADOT      DEC           DECDOT      RTLT           ]
00/300 00:00:00 04:46:07.45  -3.70290E+01 +21:29:39.5  -7.27429E+01  1:03:47.170709
00/300 08:00:00 04:45:55.07  -3.72991E+01 +21:29:15.2  -7.33532E+01  1:03:45.672050
00/300 16:00:00 04:45:42.59  -3.75668E+01 +21:28:50.6  -7.39618E+01  1:03:44.200499
00/301 00:00:00 04:45:30.03  -3.78321E+01 +21:28:25.9  -7.45684E+01  1:03:42.756254
```

Excerpt from a GEO Predict – One subset covering one day

```
*1 IIRV TIME = 94/026 15:35:18.000
XPOS   -000001662708;
YPOS   -000006378225;
ZPOS    000002244402;
XVEL    000006421.188;
YVEL   -000000560.806;
ZVEL    000003038.198;
*1 IIRV TIME = 94/027 22:13:45.000
XPOS   -000004407258;
YPOS   -000004119566;
ZPOS    000003394504;
XVEL    000004319.529;
YVEL   -000005583.398;
ZVEL   -000001248.940;
```

Excerpt from an MPA Predict – Two State Vectors

MPG Products: Frequency Predictions

- Uplink Frequency Predictions (type: ETX)
  - Predicts: Linear approximation of the ideal uplink freq (XA)
  - Discrete: Time and value format
  - Used for all uplink activities (except 26-meter)
  - May be Unramped (constant freq) or Ramped (non-constant freq)
- Downlink predictions (type: DLF)
  - Predicts: 1-way, 2-way, 3-way, and XA Frequency, and 2-way Range
  - Predicts: Non-coherent, Coherent, and Dual Mode Non-Coherent (CONTOUR) modes
  - Continuous: uses Everett's form w/ 2nd & 4th central differences
  - Accuracy specification: 500 microhertz (freq), 1 nanosecond (range)
  - Used for all downlink activities (except 26-meter)

Sample ETX and DLF Types

```
** ETX_PRDX   S/C=077, DSS14, START=96/312 19:23:05, END=03:54:06, GLLO_LEG3
*1 CREATED=88/121 00:41:01
*2 TSF=    2001023040.00000
*2 PASS=   3
*2 FILE_NAME=MP_PDX:[077]077140003.ETX;1
*2 NUM_ULF_POINTS=   8
*2 NUM_XA_POINTS=  14
*2 BAND=X
*@ END OF HEADER
YEAR 1996;
DAY  312;
*ULF
#     TIME        FREQUENCY(HZ)
P 19:23:05        2001026277.05323;
P 20:17:26        2001025187.96271;
P 21:13:27        2001024215.60539;
P 22:21:26        2001023201.99919;
P 23:52:26        2001022035.75761;
P 02:11:21        2001020379.60380;
P 03:32:23        2001019287.38557;
P 03:54:06        2001018966.62503;
*XA
#     TIME        FREQUENCY(HZ)
P 19:23:05        2001026287.05323;
P 19:30:54        2001026120.80511;
P 19:37:24        2001025985.08628;
P 00:43:23        2001021437.47260;
P 01:31:22        2001020863.74074;
P 02:19:22        2001020267.68998;
P 03:07:22        2001019630.84394;
P 03:54:06        2001018956.62503;
*= END =*
```

Complete ETX Predict (Ramped)

```
#
*F X-BAND 1-WAY     START=98/219 13:50:00 END=98/219 14:00:00
#   TIME        FREQUENCY (HZ)      D2N          D2N+1        D4N         D4N+1
#
13:50:00.000000000   7999971178.922      0.291      0.347     -0.018      0.005
13:54:09.822083145   7999971018.650     -0.000      0.001     -0.011      0.011
13:54:22.094640269   7999971010.785      0.015     -0.008      0.000      0.000
13:54:22.926190651   7999971010.255     -0.002      0.000     -0.019      0.002
13:54:33.480707198   7999971003.534     -0.003      0.003     -0.038      0.026
13:54:46.666637659   7999970995.138      0.289      0.335     -0.033      0.032
13:58:33.307557962   7999970850.990     -0.000      0.000     -0.013      0.003
13:58:46.494360394   7999970842.613      0.030      0.037     -0.035      0.016
14:00:00.000000000   7999970795.938
#
*F X-BAND 2-WAY     START=98/219 13:50:00 END=98/219 14:00:00  UPL=JYW_DS1_TEST
#   TIME        FREQUENCY (HZ)      D2N          D2N+1        D4N         D4N+1
#
13:50:00.000000000   8796348401.034      0.104      0.110      0.007     -0.006
13:51:40.372418165   8796348330.573      0.245      0.273     -0.010      0.017
13:54:09.822083145   8796348223.974      0.003      0.003      0.009      0.010
13:54:22.094640269   8796348215.232      0.033     -0.019      0.000      0.000
13:54:22.926190651   8796348214.648      0.001      0.000     -0.000     -0.004
13:54:33.480707198   8796348207.224      0.005     -0.001      0.028     -0.031
13:54:46.666637659   8796348197.950      0.637      0.726     -0.007      0.002
13:58:33.307557962   8796348038.914      0.003      0.002      0.008     -0.001
13:58:46.494360394   8796348029.682      0.070      0.083     -0.050      0.039
14:00:00.000000000   8796347978.268
```

Excerpt from a DLF Predict – Two Subsets:
1-Way and 2-Way

MPG Products: Other Predictions

- Station delay predictions (type: EST)
  - Predicts: Delay between signal arrival at station and at Earth center
  - Continuous: uses Everett's form w/ 2nd & 4th central differences
  - Accuracy specification: 1 nanosecond
  - Initially used by the DGT to support Galileo tracking (arraying)
- Mixed predictions (types: RCV and PFN) - Obsolete
  - Predicts: frequency, angles, range, events, etc
  - Discrete: Time and Value format
  - RCV used by station personnel to monitor tracking activity
  - PFN (Pre-Flight Nominal) used for mission planning
  - Neither are used by station assemblies. For human consumption only
- VSR Predictions
  - Collation of relevant SOE data and DLF predictions

Sample RCV and EST Types

```
TSF=7205556730.00  TSFDOT=   0.000     AT 02:42:31
[
[
EVENT AT 02:42:31 RISE, 62.8, 0.0, 62.8, 0.0
EVENT AT 02:42:31 BOT
[
OBS RTLT=01:03:27.2  COM RTLT=01:03:27.1  GEO RTLT=01:03:27.1  AT 02:42:31
AZ=     62.793    EL=     -0.782    HA=    252.818    DEC=    21.437  APPARENT
[
[  UTC        D1         D2        XA         D3.00      D3.00      D3.00
02:42:31 7413487.43       0.00 7205545264.       0.00       0.00       0.00
02:43:01 7413486.91       0.00 7205545263.       0.00       0.00       0.00
```

Excerpt from an RCV Predict – TSF, Event, Angle & Range, and Doppler Reports

---

```
#
*T
#   TIME            DELAY(NS)       D2N         D2N+1       D4N        D4N+1
#
19:23:05.000000   2215808.6831    -3715.686    -3886.312     -9.62     20.48
19:28:20.936686   2544672.0554   -56068.255   -65313.785    380.79    508.56
19:48:20.936686   3756884.2571   -65315.249   -74076.304    492.89    567.13
20:08:20.936686   4903781.0176   -11875.297   -12409.929      3.19     30.16
20:16:21.253598   5342556.2004   -77431.507   -85380.397    566.24    674.41
20:39:54.000000   6160916.5914
#
```

Excerpt from an EST Predict

Past, Present and Future of DSN Prediction Services

- Hardware
  - Then: Pencil and Paper
  - Now: VAX
  - Soon: Board Farm
- Formats:
  - Then: Graph Paper
  - Now: Mostly Flat Text Files, some binary formats
  - Soon: XML w/ embedded interpolators
- Data Representation
  - Then: Time and Value
  - Now: 5th-Degree Everett Polynomials
  - Soon: 12th Degree Chebyshev