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High-Fidelity Telecom Analysis Techniques for Spacecraft Dynamic Events

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Traditional telecom planning is usually limited to single point, worst-case scenario analysis of a static communication link. Communications during spacecraft dynamic events (which are usually critical) like launch, trajectory correction maneuver, and orbital insertion are usually not sufficiently characterized a priori. The lack of high-fidelity simulation of spacecraft dynamic events results in:

1) Limited ability to timely detect and react to spacecraft anomalies. This might lead to loss of encounter opportunities or even loss of mission.
2) Limited ability to plan and analyze mission communication design and operation strategy during the design phase. This might lead to insufficient information to quantify operation impact and subsystem interaction, resulting in bad onboard design, inefficient telecom resource usage, and reduced science return.

In this paper we describe a systematic approach to support telecom planning and analysis for spacecraft dynamic events. This approach involves 1) a standard interface with the NAIF SPICE data to input spacecraft trajectory and attitude information, and 2) a set of attitude heuristic models that simulate the spacecraft attitude in the normal mode and in the safe mode. These techniques are currently implemented in the operational telecom forecaster predictor (TFP) link analysis tool. The TFP tool was used to support the DS1 high-gain antenna pointing activities in the absence of the stellar reference unit (SRU). The TFP tool was also used to support the planning and execution of the Mars Odyssey orbital insertion (MOI) critical event on August 28, 2001. This tool is now being used to support the Space Infra-Red Telescope Facility (SIRTF) launch scenario analysis using DSN and non-DSN stations.

The rest of this paper will describe in details how we apply the above techniques to support telecom planning and analysis of the mission dynamic and critical events.

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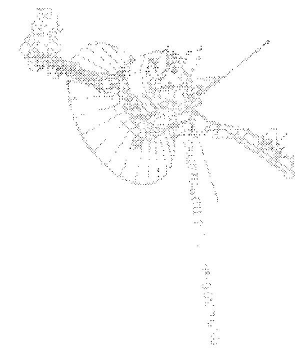

ecom Analysis Techniques
raft Dynamic Events

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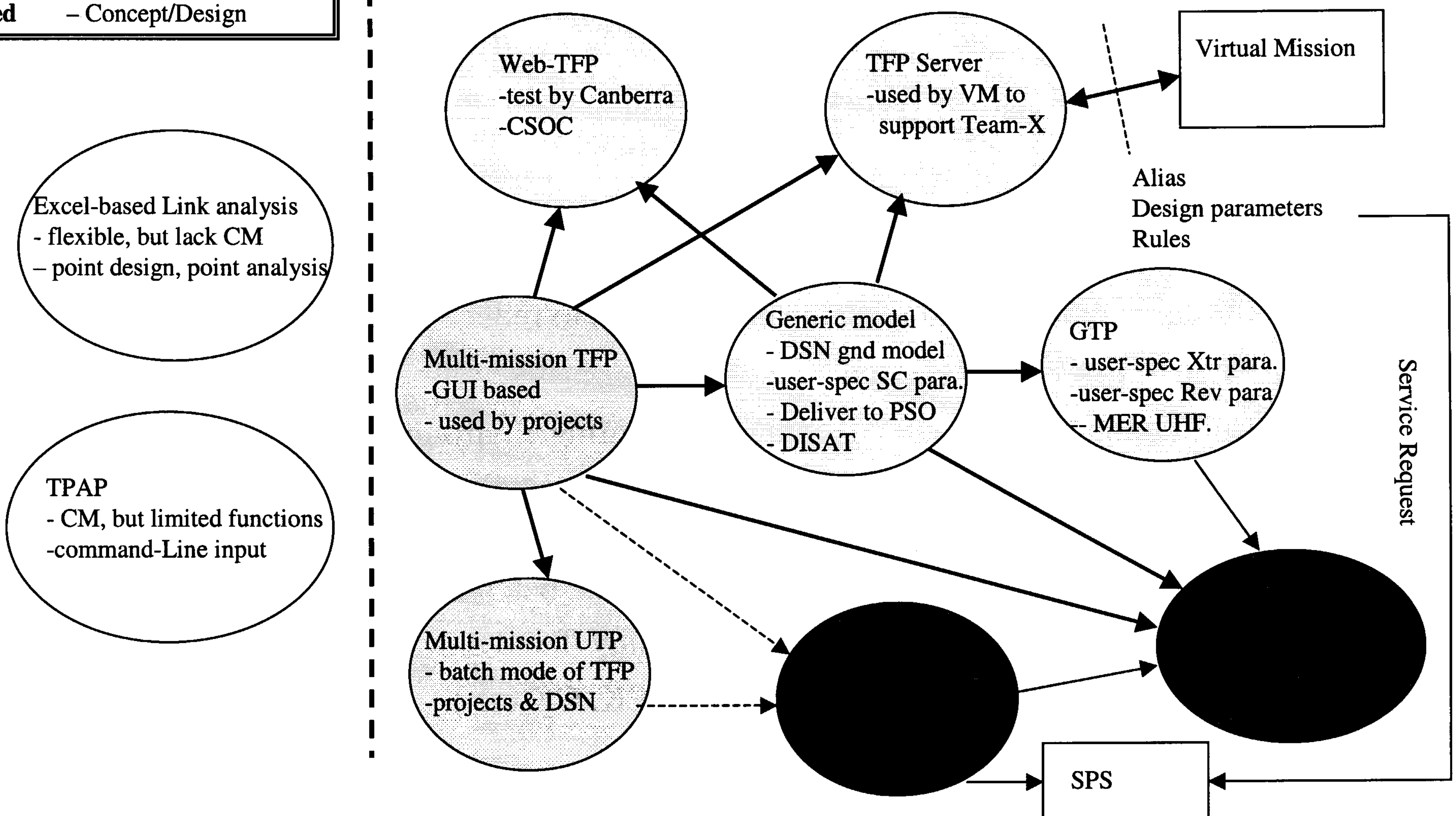
Outline

- **Multi-mission TFP and UTP Overview**
- **TFP Support on Dynamic Event Analysis for DS1**
  - "Telecom-in-the-Loop" HGA Pointing during DS1 SRU Anomaly
- **TFP Support on Dynamic Event Analysis for Mars Odyssey**
  - High-fidelity telecom simulations to support high-dynamic events like launch, safing, and orbital insertion

TFP Development Roadmap

Green – Operational
Yellow – Development/Prototype
Red – Concept/Design



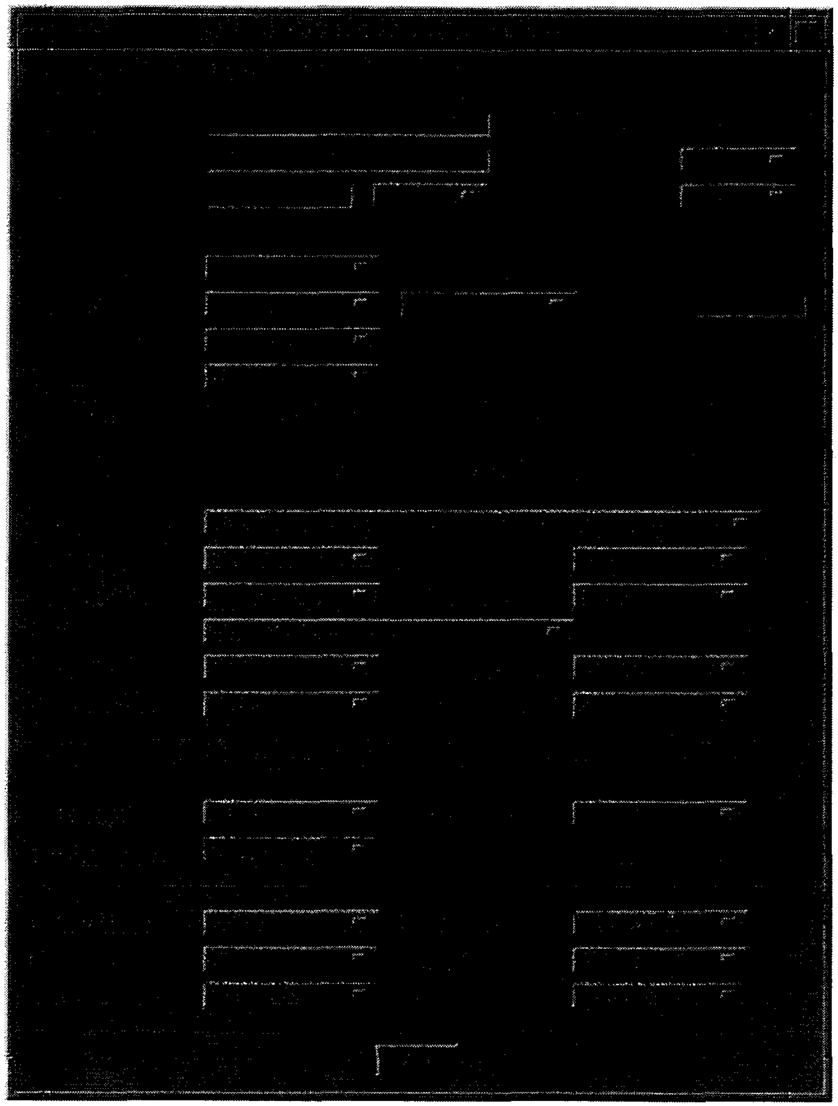
Overview

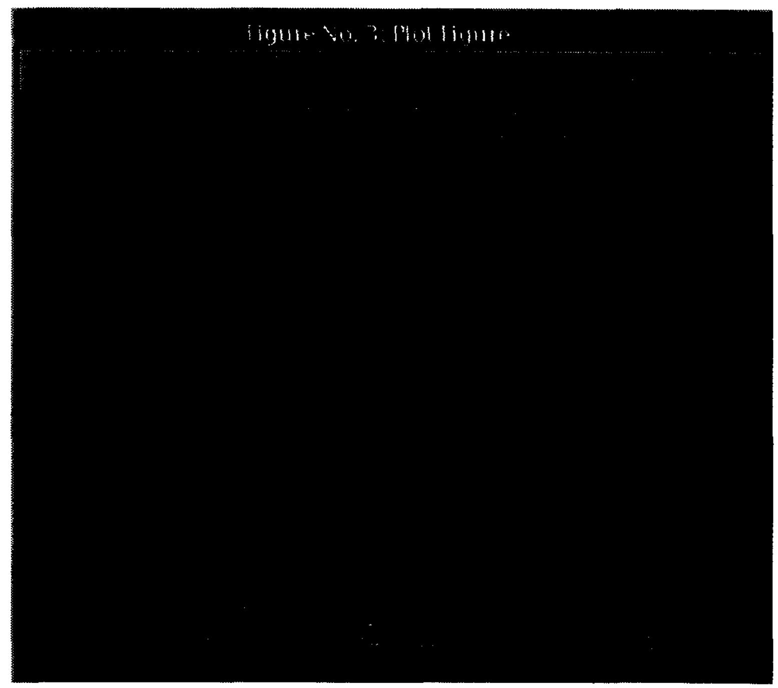
- **TFP is an operational multi-mission GUI-based telecom link analysis software for mission planning and operation (Phase C/D, E)**
  - Unlike prior link analysis tools (e.g. Excel spreadsheets) which only provide static analysis of best/worst case scenarios, TFP contains high-fidelity models and interfaces to support high-dynamic scenarios analysis
  - Contains modular and reusable components to reduce development cost
- **Multi-mission architecture**
  - Build upon MATLAB - a technical computing environment for high performance numeric computation and visualization
  - Separation of DSN common models (core) and mission-specific models
  - Client/server architecture to support GUI and batch mode
  - Support time-series analysis and fixed range/fixed elevation analysis
  - Standard NAIF library and interfaces (SPK, CK etc.)

Overview (Cont'd)

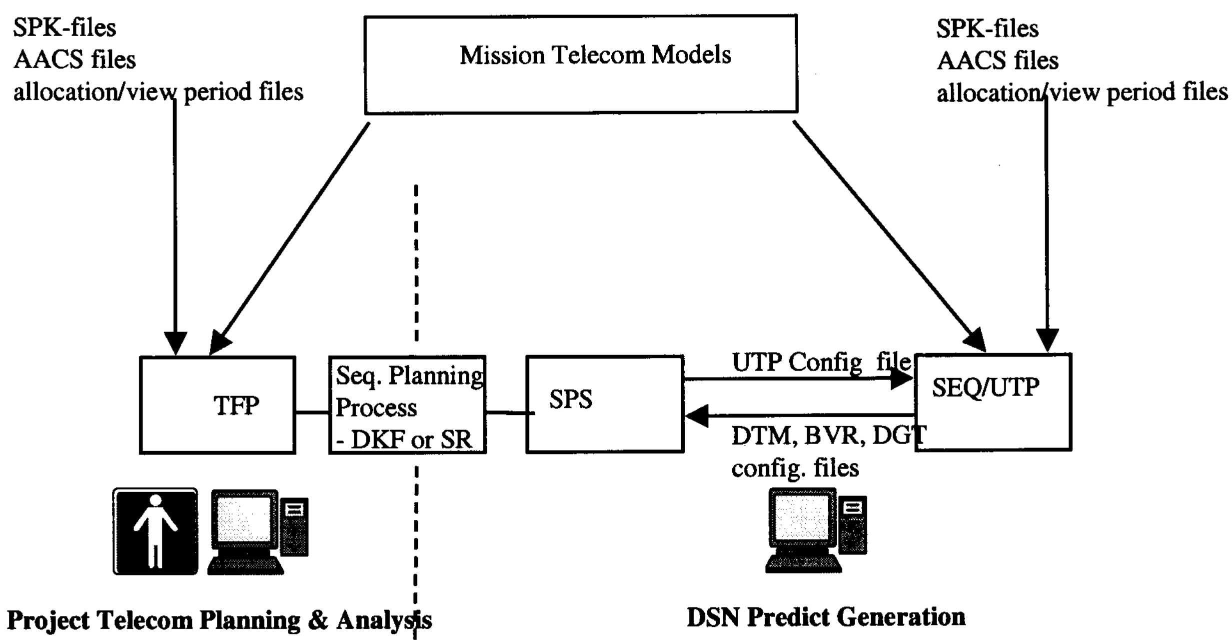
- **Modeling/simulation capabilities**
  - High-fidelity DSN common models (810-5 compliant, multi-mission)
  - High-fidelity mission telecom models (mission-specific)
  - C-kernel interface and attitude heuristics modeling to simulate telecom performance during spacecraft dynamic events - launch, safing, TCM, and orbital insertion
- **Software capabilities**
  - Trace model using model tree
  - Edit model using editpar
  - Over-ride formal delivered models with user-customized models using 'add-path'. Support fast-turn-around analysis (used at your own risk)
  - Save GUI setting (GUI-state file) for future use
  - View and process time-varying variables with Matlab native commands or workspace visualization tool

TFP Graphical User Interface





- **The Unified Telecom Predictor (UTP) uses the same models as TFP and generates telecom predicts to configure and operate DSCC telemetry subsystems to track ongoing and future missions (SPS D1, 2004)**
- **UTP generates data rate capability file to support sequence planning**
  - Used in DS1with Plan-It
  - Support MER-APGEN interface



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A Snapshot of DRCF file (30 min interval for 7 days)

Choose optimal site for up/down comm for resource mapping.
Indicate station overlap to plan handover & arraying
Provide DSN antenna pointing data
View period generation

Elv. of DSN sites

up/down Data rate capabilities for each station and for each configuration

LowGain Antenna :																	
											ul 34m BWG	ul 34m BWG	ul 34m BWG	ul 34m BWG	ul 34m BWG	ul 34m BWG
											dl 34m BWG	dl 34m BWG	dl 34m BWG	dl 34m BWG	dl 34m BWG	dl 34m BWG
											ul NO mod	ul NO mod	ul NO mod	ul NO mod	ul NO mod	ul NO mod
											dl NO mod	dl NO mod	dl NO mod	dl NO mod	dl NO mod	dl NO mod
								Canb	Madr	Gold	Canb	Canb	Madr	Madr	Gold	Gold
date/time	calendar	range	range	owlt	lgax	lgaz+	sc ant	elevation	elevation	elevation	max uplink	max downlink	max uplink	max downlink	max uplink	max downlink
yyyy-doyThh:mm:ss	date	km	AU	sec	to earth (deg)	to earth (deg)	best LGA	angle (deg)	angle (deg)	angle (deg)bit ra	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)
)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)	bit rate (bps)			
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1999-202T06:00:00	7/21/99	181711050	1.215	606.12	45.54	93.6	(U/L)lgax (D/L)l	56.8	NaN	NaN	15.625	NaN	NaN	NaN	NaN	NaN
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1999-202T07:30:00	7/21/99	181763682	1.215	606.3	45.54	93.59	(U/L)lgax (D/L)l	57.5	NaN	NaN	15.625	NaN	NaN	NaN	NaN	NaN
1999-202T08:00:00	7/21/99	181781399	1.215	606.36	45.54	93.59	(U/L)lgax (D/L)l	54.8	NaN	NaN	15.625	NaN	NaN	NaN	NaN	NaN
1999-202T08:30:00	7/21/99	181799198	1.215	606.42	45.54	93.59	(U/L)lgax (D/L)l	51.1	NaN	NaN	15.625	NaN	NaN	NaN	NaN	NaN
1999-202T09:00:00	7/21/99	181817075	1.215	606.48	45.53	93.59	(U/L)lgax (D/L)l	46.7	NaN	NaN	15.625	NaN	NaN	NaN	NaN	NaN
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1999-202T16:30:00	7/21/99	182088694	1.217	607.38	45.51	93.54	(D/L)lgax	NaN	44.7	NaN	NaN	NaN	15.625	NaN	NaN	NaN
1999-202T17:00:00	7/21/99	182106559	1.217	607.44	45.51	93.54	(D/L)lgax	NaN	45.2	NaN	NaN	NaN	15.625	NaN	NaN	NaN
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1999-202T18:00:00	7/21/99	182142041	1.218	607.56	45.51	93.53	(D/L)lgax	NaN	43.3	NaN	NaN	NaN	15.625	NaN	NaN	NaN
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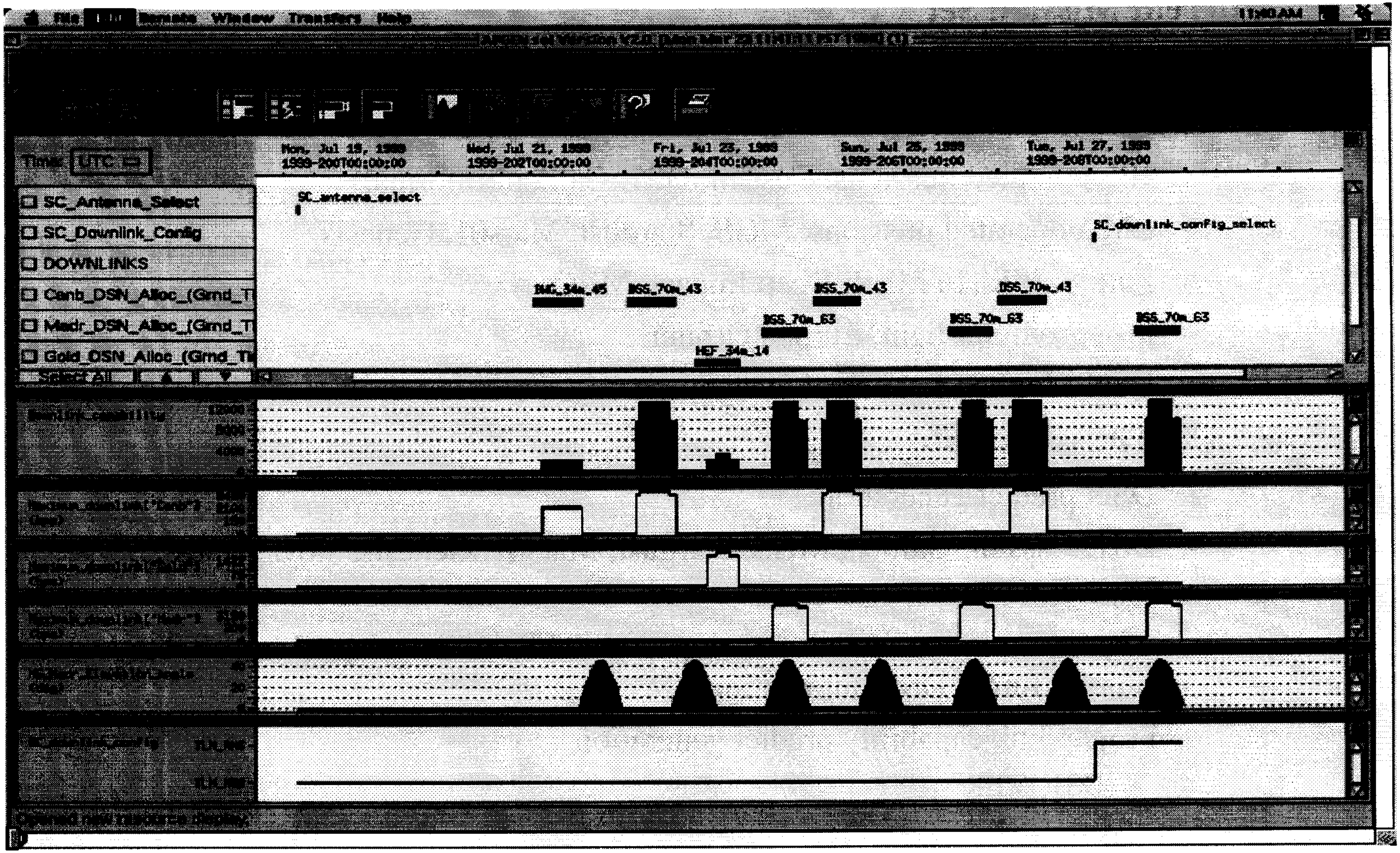


Current Mission Set

- **TFP mission suite**
  - JPL operated missions: Cassini, DS1, Galileo (informal)
  - LMA operated missions: MGS, Stardust, Mars01, Genesis
  - Future: SIRTF, MER, Deep Impact, MRO
  - Proposed: Starlight, Europa Orbiter
  - DSN Monitor & Control System
- **UTP mission suite**
  - DSN predict generation
  - DS1, Cassini, Galileo, MGS, Stardust, Mars01, Genesis, Voyager 1&2, Ulysses, Chandra
  - Any new mission models developed for TFP will be adapted for UTP to support future DSN automation
  - Project link capability predict generation
    - DS1, MER

"Telecom-in-the-Loop" HGA Pointing during DS1 SRU Anomaly

- **DS1 Stellar Reference Unit (SRU) failed in November 1999. In the absence of SRU, DS1 could not maintain an attitude for HGA downlink**
- **DS1 develop an interim 3-axis pointing concept (HGA activity) to support**
  - Return of valuable science data already stored onboard at the time of failure
  - Maintenance of reasonable uplink and downlink communications in the interim
  - Upload several megabytes of new flight software at a high rate
    - The new software operates the science camera to generate star data for onboard pointing control

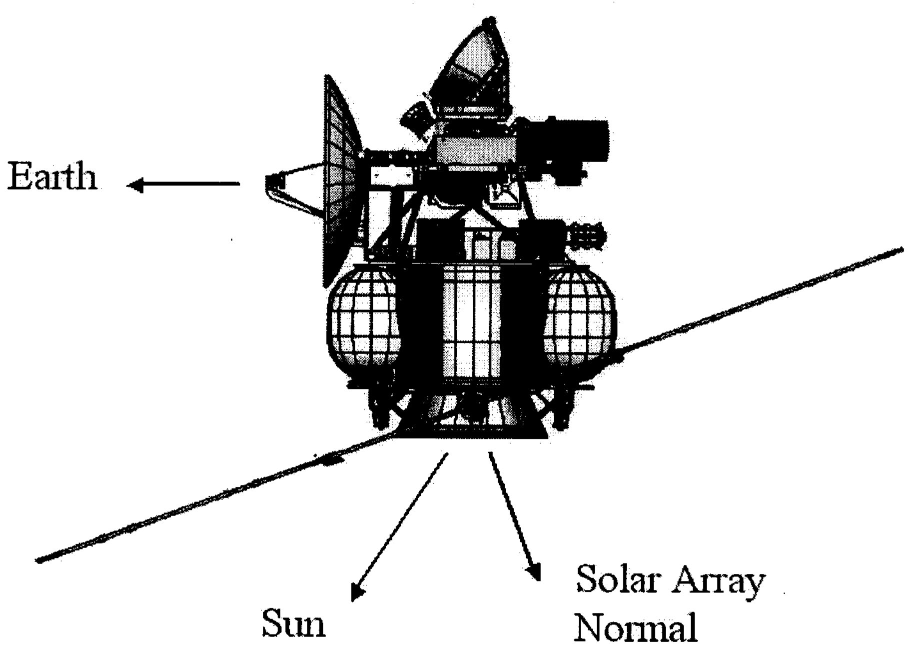
- **New TFP modeling capabilities were developed to support the DS1 HGA activity**
  - Model the telecom performance as a result of the DS1 spinning/coning "safing" heuristics
  - Establish the optimal coning rate that provides a wide enough command window and a fast enough turn-around time
  - Determine the supportable uplink and downlink data rates
- **DS1 HGA activity details**
  - Start from X-to-Sun, spin about X at 1 rev/45 minutes
  - Using sun sensor and gyros only, move X axis by SPE angle amount
  - Stop coning based on time of seeing first peak

- **The DS1 HGA activity demonstrates the right combination of people, process, and tools could enable new mission operation concepts, which sometimes could mean a difference between mission success and early project termination**
- **Reference**
  - "Achieving and Maintaining Deep Space 1 Spacecraft High-Gain Antenna Pointing Control by Data Monitoring and Immediate Corrective Commanding," TMO PR 42-144, October-December 2000, pp. 1-23, February 15, 2001.

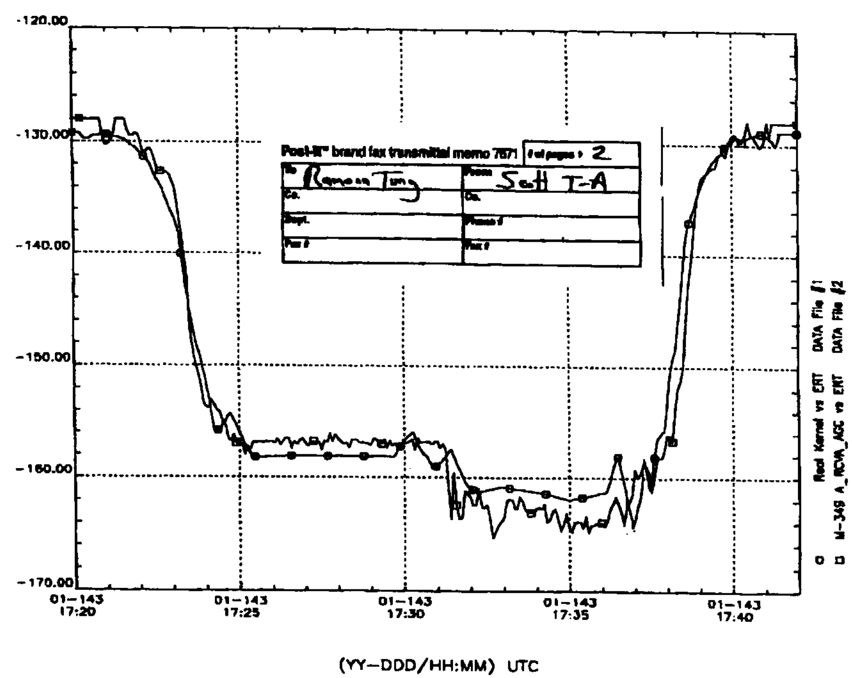
Mars Odyssey TCM-1 Support

- TCM-1 executed on 5/23/2001 for 20 minutes
- LMA telecom team used TFP tool to generate TCM-1 AGC predict
- Predict favorably matches actual in a 30 dB dynamic range during TCM-1
- Project decided to use TFP for subsequent TCM's and MOI planning

CRUISE CONFIGURATION - NORMAL



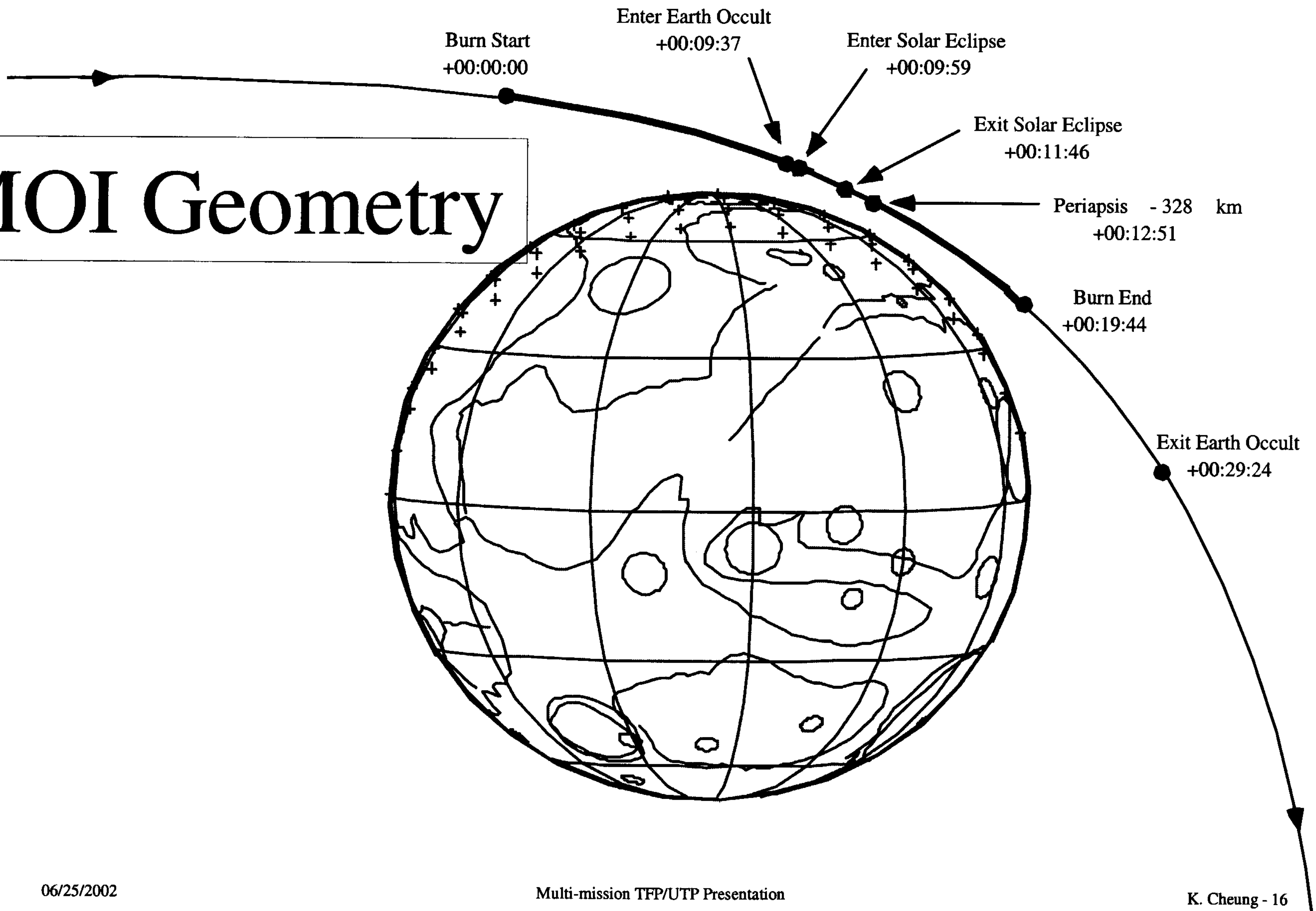
Odyssey TCM1 AGC Actual / TFP Predicted using Real ck



Mars Odyssey MOI Support (10/23/2001)

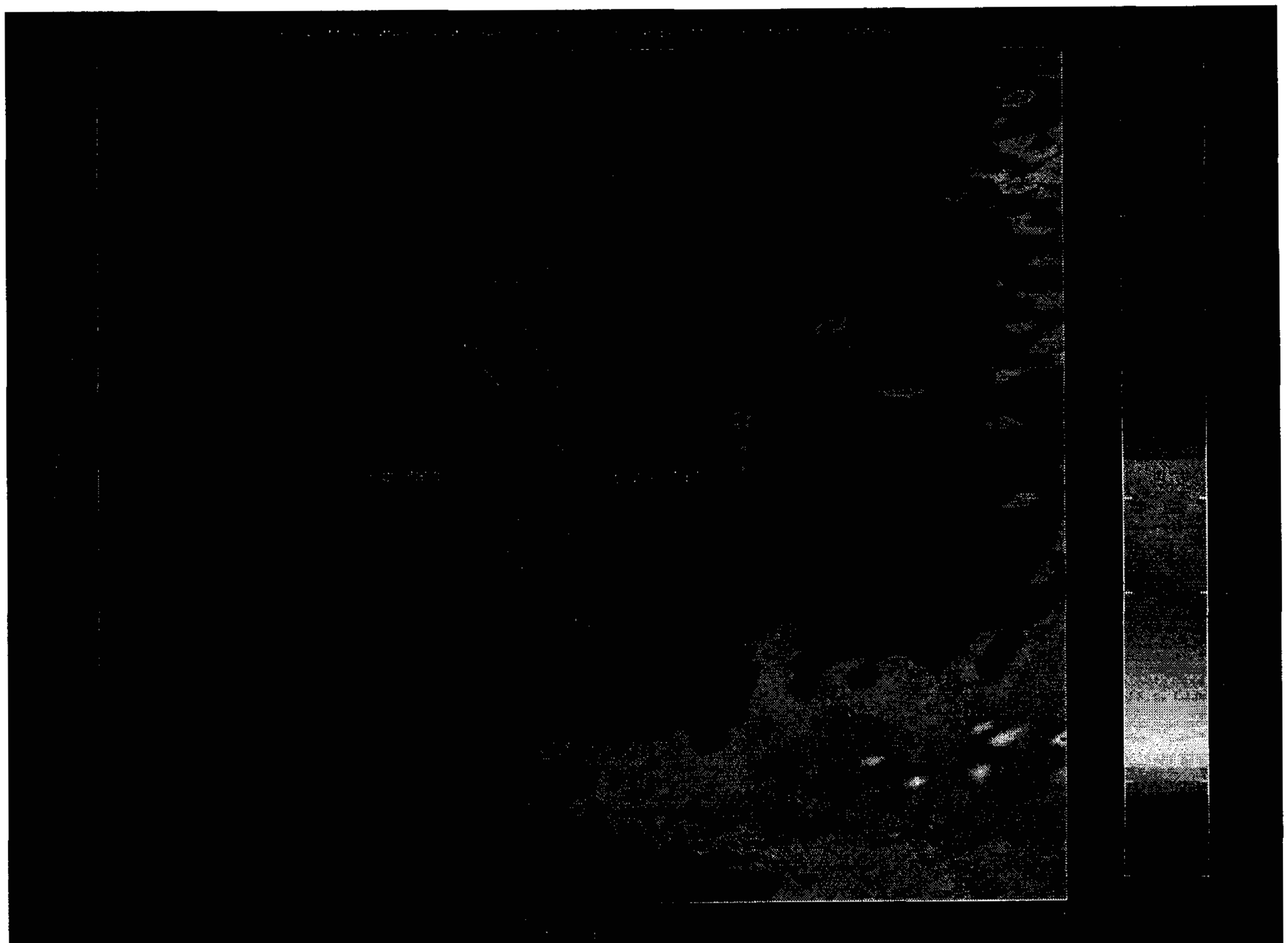
- **Two month before MOI, the TFP was used to plan the MOI maneuver**
  - The cone/clock swaths for the MOI burn that results from different roll angles were plotted on a contour plot of the non-symmetric MGA pattern
  - The most favorable roll angle was selected to maximize gain
- **During MOI, the actual AGC observed at DSS-14 matches favorably with the predicts in a 30 dB dynamic range of MOI (except for a brief 4 minutes outage), confirming in real-time that the MOI was executed correctly**
- **During the playback sequence, the spacecraft attitude data were queried and fed back to TFP. This verified that the unexpected loss of lock during MOI was due to the wide carrier bandwidth, and not because the spacecraft attitude was different than expected. This validation process was done in near real-time, and took less than 10 minutes**

MOI Geometry



MOI Roll Angle Choice to Optimize Link

- **MOI Tracks in MGA Radiation Pattern**



Note: Each track starts at the right-most point (MOI Start) and moves to the left, ending at Earth Occultation. A Roll Angle of 75 degrees was chosen for MOI.

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