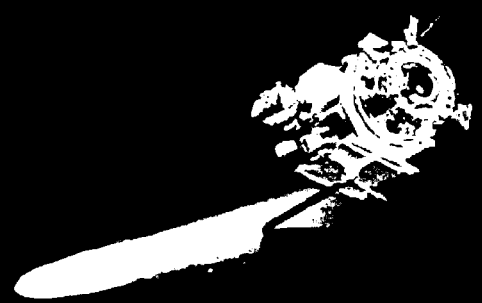
An Overview of Beacon Monitor Operations

i-SAIRAS '97

Tokyo, Japan

July 14, 1997



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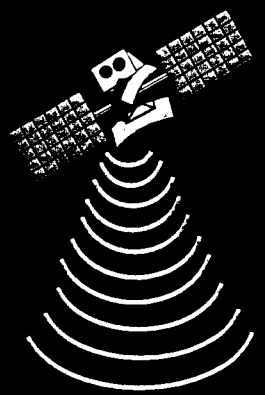
USA

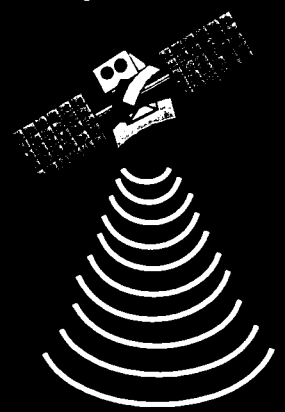
- Operational Concept
- Key Components
  - Tone Monitoring System
  - Onboard Engineering Data Summarization
- DS-1 Implementation and Technology Validation
- Future Work

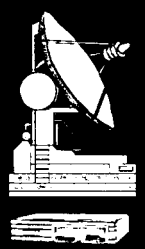
- Need to reduce ops cost for mission to Pluto
- Arose out of NASA vision for "darkening the skies"
  - Need to reduce loading on DSN antennas
  - Need to reduce the size of ops staffing and complexity of operations
- New Millennium Program
  - Selected for flight validation on Deep Space One

Beacon Tone

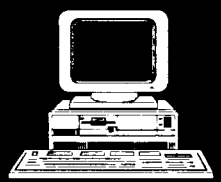


Telemetry Downlink

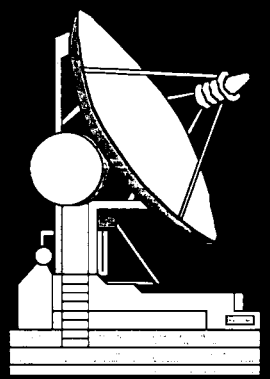




Weak Signal Detector



Smart Antenna Scheduler



Intelligent Data Summaries

Pager Notification

On-Demand Ops Team

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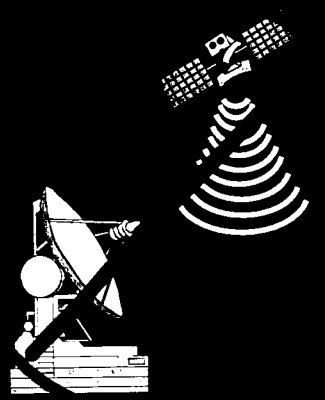
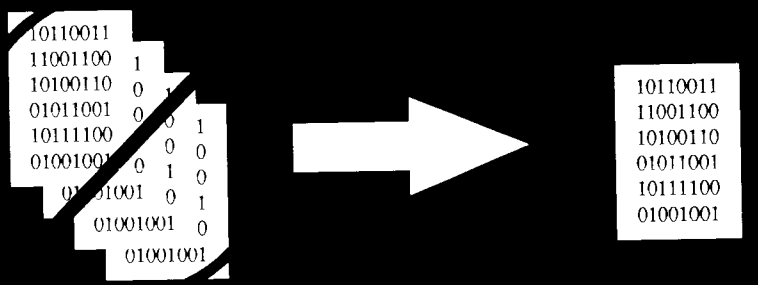


Objective: Reduce frequency of tracking for routine telemetry

Advantages: Reduces the loading on ground antennas

Reduces workload on operations team

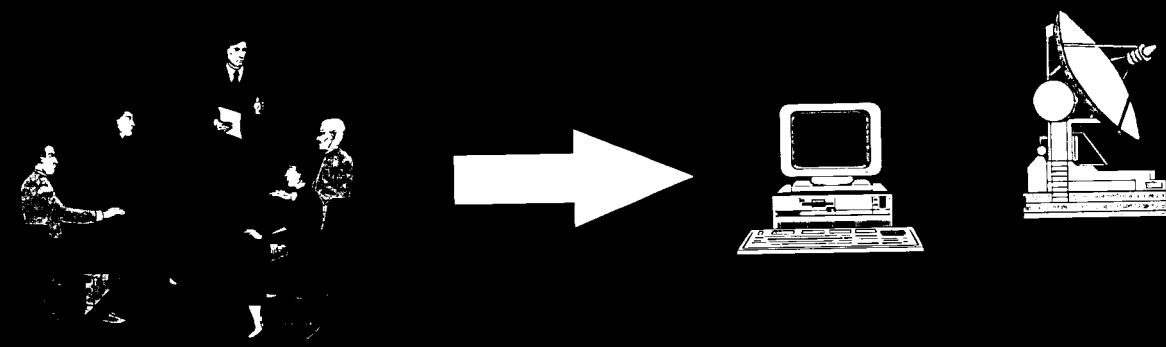
Approach: Replace TLM with a signal that provides assurance of spacecraft health but is detectable with simpler (and lower cost) ground resources



Objective: Reduce the amount of downlinked engineering data per telemetry pass

Advantages:
- Necessary to deal with bandwidth limitations
- Reduces the duration of telemetry passes
- Reduces workload operators

Approach: Provide reusable software modules to perform engineering data summarization above the state-of-the-art



Objective: Schedule TLM tracking based on demand rather than pre-negotiated agreements

Advantages: Necessary for DSN support of beacon monitor operations to be viable

Saves DSN operations costs by automating DSN antenna scheduling process

Approach: Use automated scheduling software to perform spacecraft-initiated scheduling of DSN antennas

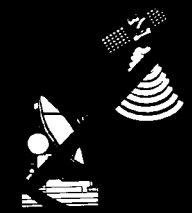
Galileo-class Ops
~ 200 people

Pluto Mission Ops
< 10 people

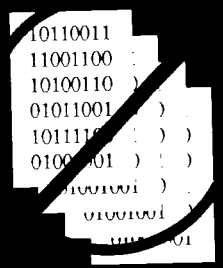
Objective: Provide innovative staffing solutions

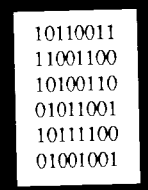
Advantages:
- Reduce size of ops team to lower mission cost
- Better allows ops teams to support multiple simultaneous missions

Approach:
- Automate tone message handling & reporting
- Provide capabilities for visualizing summary data
- Send tone continuously to avoid scheduling tone tracks
- On-demand ops teams



- **Reduce frequency of tracking for routine telemetry**

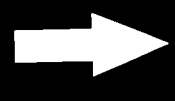




- **Reduce the amount of engineering data per telemetry pass**

- **Schedule telemetry tracking based on demand rather than pre-negotiated agreements**

Galileo-class Ops
~ 200 people



Pluto Mission Ops
< 10 people

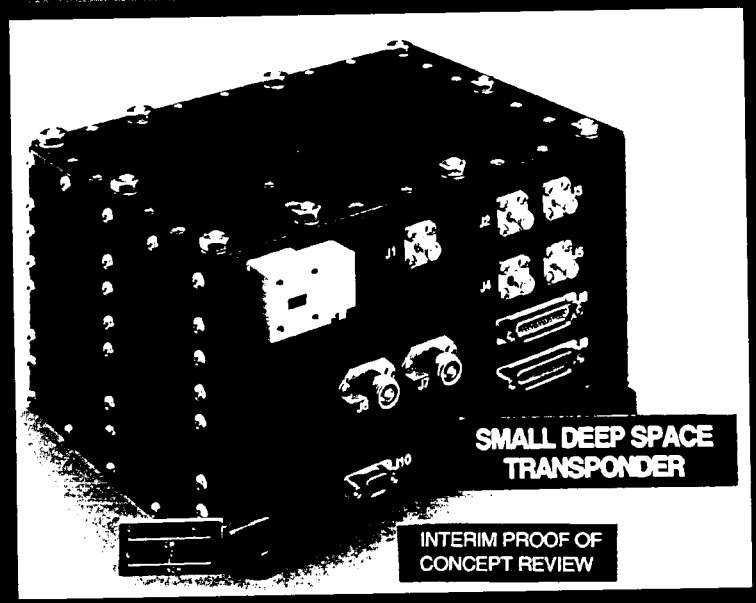
- **Provide innovative staffing solutions for shared and on-demand operations teams**

- Reduction of work processes = cost savings
- Reduces the workload at the antenna site
  - Reduces the complexity and number of configuration tasks (no bit synch, telemetry frames, or complex decoding schemes to contend with)
  - Eliminates telemetry data handling (no routine data recording, logging, recall, staging, distribution)
  - Reduces link & error modelling, analysis, ancillary data capture, logging, reporting, and distribution
- Reduces the workload for the flight project team
  - Antenna scheduling and coordination
  - Routine engineering telemetry analysis
  - Spacecraft state management
  - Spacecraft-to-ground coordination functions
  - Status reporting
  - Sequence of events generation

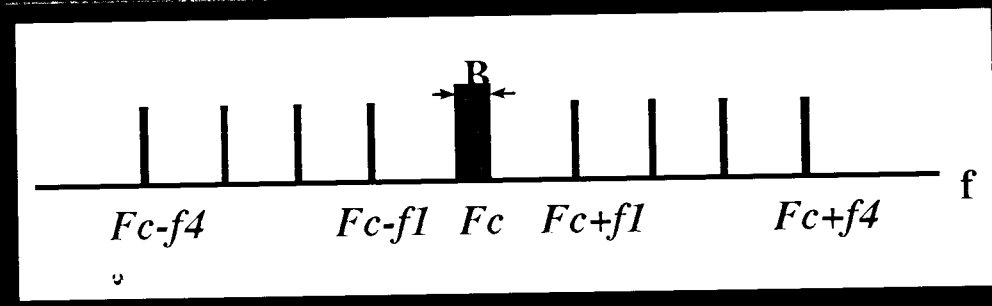
- Operational Concept
- Key Components
  -
  - Onboard Engineering Data Summarization
- DS-1 Implementation and Technology Validation
- Future Work

NOMINAL	All functions are performing as expected. No need to downlink engineering telemetry
INTERESTING	Establish communication with the ground when convenient to obtain data relating to an event. Examples: device reset due to SEU
IMPORTANT	Spacecraft needs servicing within a certain time or spacecraft state could deteriorate or critical data could be lost. Examples: solid state memory near full, non-critical hardware failure
	Spacecraft emergency. A critical component has failed. The spacecraft cannot adequately recover. Ground intervention is required immediately
No Tone	Beacon mode is not operating, telecom is not earth-pointed, or a spacecraft anomaly prohibited tone from being sent

- Missions determine mapping of spacecraft state to urgency of ground response
- Mapping resides in a simple look-up table
- Tones transition only to a more urgent state until reset by ground command



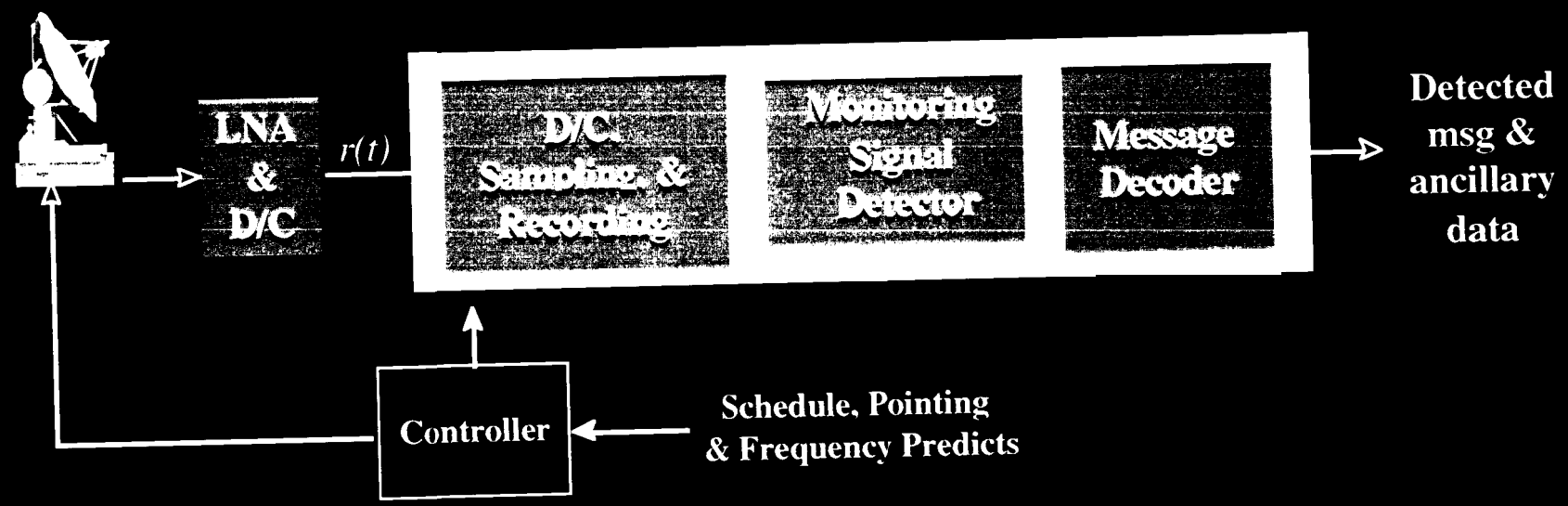
Small Deep Space Transponder



- Each message is represented by a pair of tones, centered around a suppressed carrier
- Use of tone pairs reduces the probability of incorrect detection caused by interference or frequency drift

Small deep space transponder tone generation capabilities:

- Meets a detection requirement for 8 simultaneous spacecraft, each with four tone frequencies (32 possible tones)
- Frequency range for tones is 500Hz - 10kHz

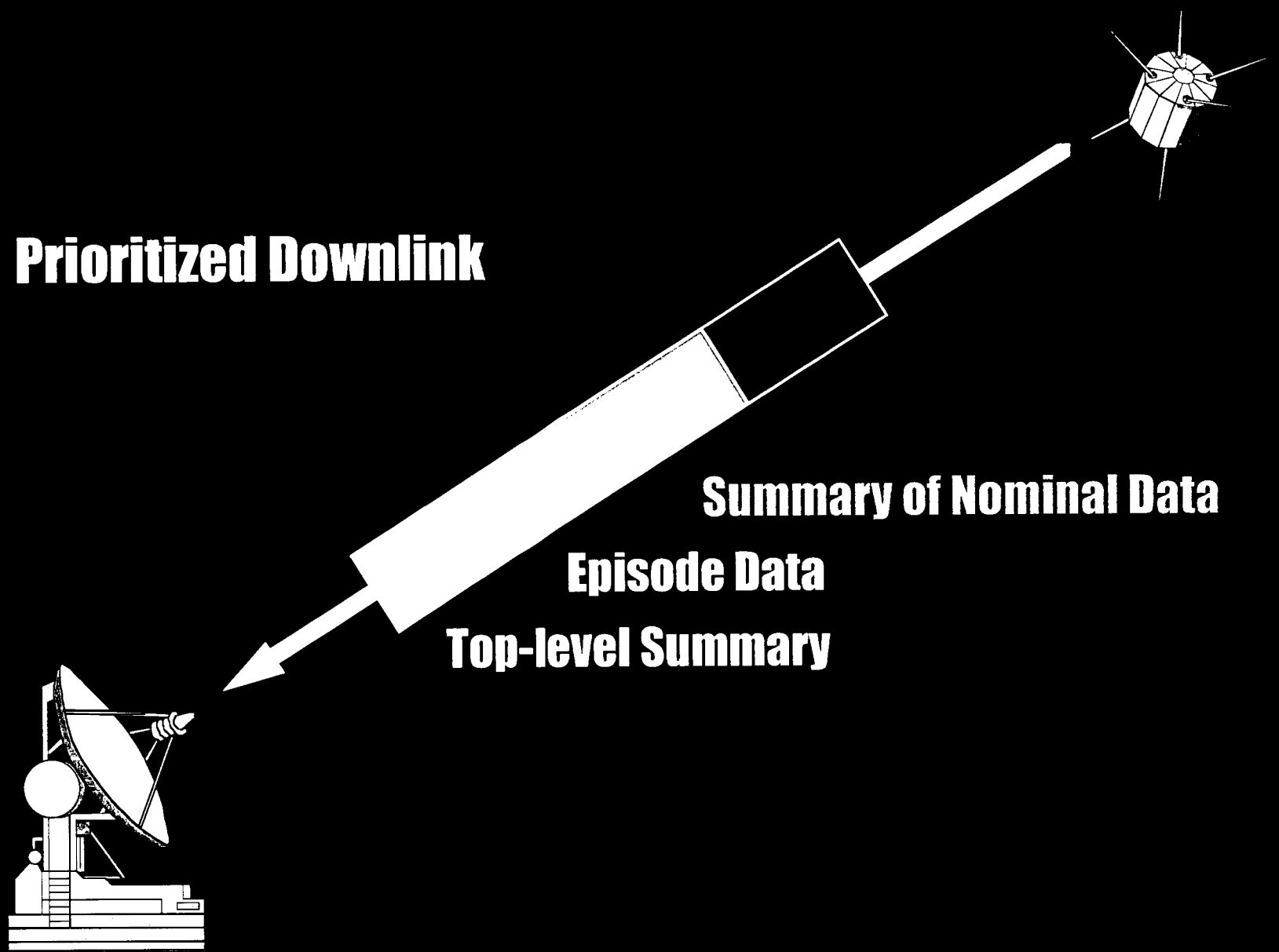


r(t)=received monitoring signal at IF frequency

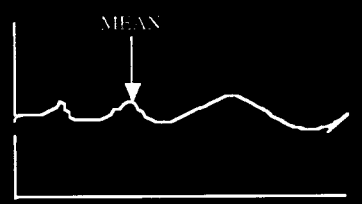
- **Goal is to use a small (4-12m) aperture antennas**
- **Detection time is short (approx. 15 minutes)**
- **Detection is automated and remotely controllable by the flight project operations team at JPL**

- Operational Concept
- Key Components
  - Tone Monitoring System
  -
- DS-1 Implementation and Technology Validation
- Future Work

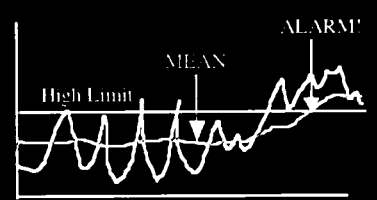
Prioritized Downlink



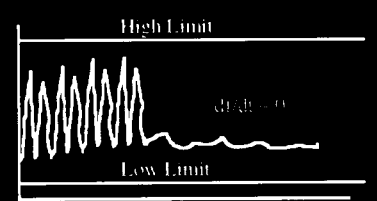
Examples



- **Transforms in the DS-1 Architecture**
  - **Maximum and Minimum Value**
  - **Mean**
  - **1st and 2nd Derivative**



- **Maximum, Minimum and Mean are efficient ways to summarize <u>nominal data</u>**



- **Using transforms to identify <u>episodes</u>**
  - **Mean enables detection based on length of time above or below a threshold**
  - **1st and 2nd Derivative allow detection when a an oscillating signal fails to change but is still within the nominal alarm thresholds (1st & 2nd derivative = 0)**

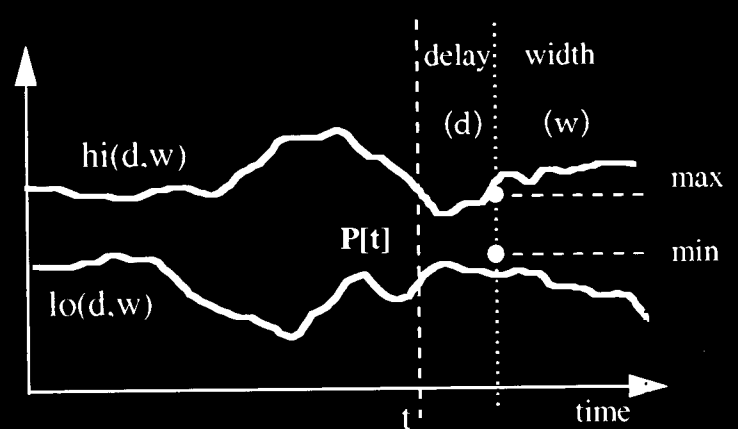
Concept

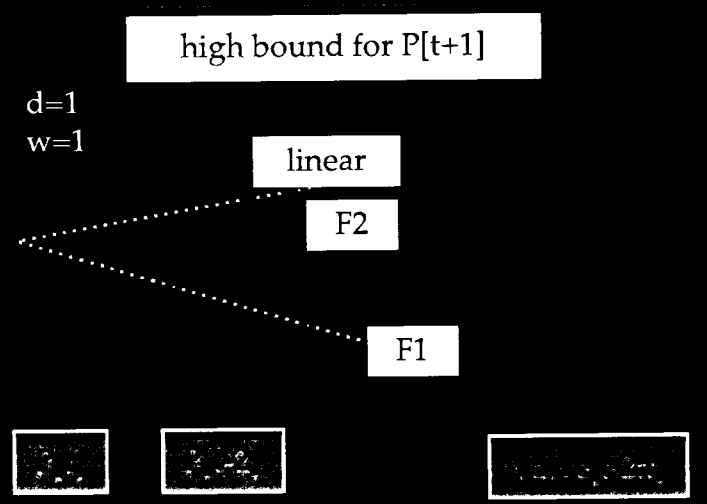
- Method for replacing hard limits with adaptive "learned" limits

Major Advantages

- More precise episode identification
- More accurate anomaly detection
- Trains on Nominal Engineering Data

ELMER: Envelope Learning and Monitoring using Error Relaxation





DS-1 Implementation

- Can switch between ELMER and traditional limits
- Adaptive limits not linked to spacecraft fault protection

PI: Dr. Dennis Decoste

- Operational Concept
- Key Components
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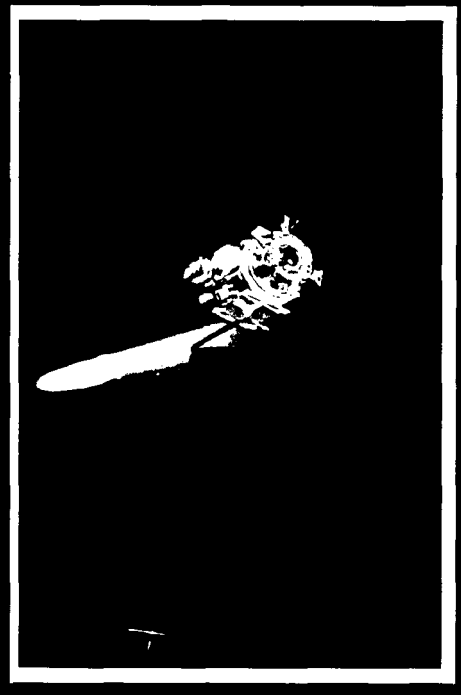
-
- Future Work



- Mission includes encounters with an asteroid, Mars, and a comet
- Main objective is to flight validate new technologies
- Mission Use
  - Summary data available to operators
  - Tone system can help maintain thrust profile

STATUS:

- All components of the beacon monitor technology are being developed/integrated for flight validation
- Use of tone system is planned for portions of mission cruise phase
- DSS-26 (34 m) antenna has been secured for beacon monitor operations

Beacon Tones

- Generation - demonstrate correct mapping of spacecraft state to tone state
- Transmission & Detection - demonstrate an end-to-end tone system

Engineering Summary Data

- Generation - demonstrate that summaries are accurate reflections of onboard conditions
- Visualization - demonstrate efficient methods for viewing engineering

Multi-mission Ground Support

- Tone message handling & reporting - demonstrate a low-cost process for relaying tone state to the flight team
- DSN track scheduling - demonstrate viable demand-based scheduling of DSN antennas for telemetry tracks

Operations Concept

- Verify that beacon monitor operations can reduce flight project operations cost and redcue the loading on DSN antennas

- Architecture is adaptable to both highly autonomous and more rudimentary flight systems
- Spacecraft design must reflect beacon monitoring requirements early
  - Pluto Express example
  - DS-1 severely power constrained
- Operational risks associated wtih "Darkening the skies" approach not yet endorsed by all project engineers at JPL

- **Telemetry management architecture**
  - Should be capable of prioritizing downlink
- **Pointing requirements**
  - To secure tone link
  - Must know situations when off earth-point
- **Power**
  - Continuous tone transmission enables tone tracks to not be scheduled
  - Transponder power directly affects ground antenna size
- **Onboard storage**

- Operational Concept
- Key Components
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-

5 yrs	10 yrs	15 yrs
HIGHLY AUTONOMOUS SPACECRAFT	OBSERVING & DISCOVERY PRESENCE ONBOARD	WIDESPREAD PROJECTION OF HUMAN AWARENESS
REQUIRE FEWER OPERATIONS STAFF	HANDLE MORE UNCERTAINTIES	ENABLE NEW SCIENCE
SELF-MANAGING EXPLORER	COORDINATED PLATFORMS	COOPERATING FLEET
Self-directing Spacecraft	**Trainable Object Recognition**	**Multiple Interacting Heterogeneous Assets**
Self-Preserving Spacecraft	**Knowledge Discovery**	**Sustained Presence**
Self-Mobilizing Spacecraft	**Close Maneuvering at Target**	**Science Alerts**
Beacon Operations		

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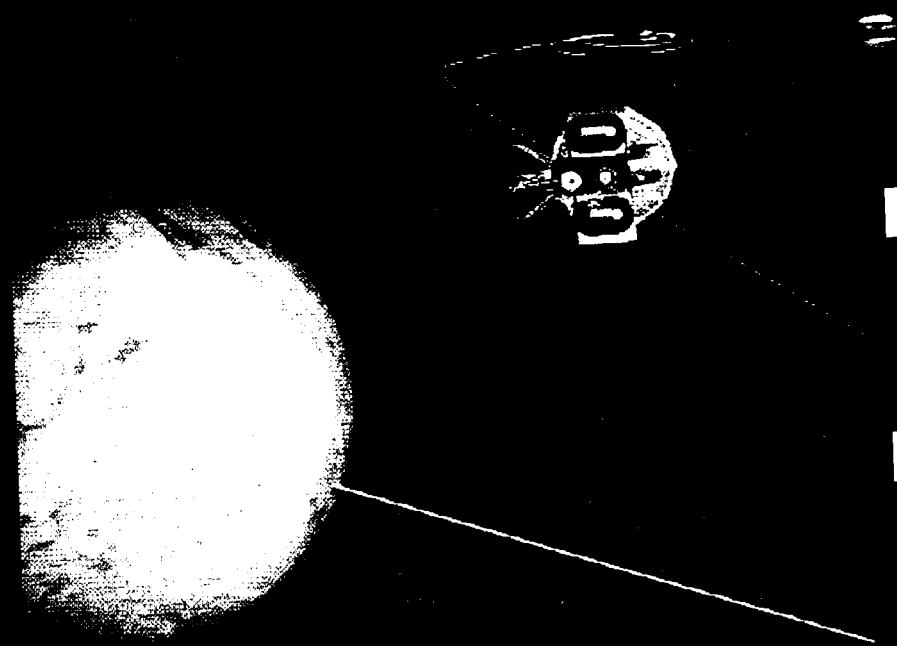


Beacon Ops baselined for:

- Pluto Mission
- Europa Orbiter Mission

Potential Applications:

- Deep Space 4 (Champollion)
- X2000 Bus Missions

Deep Space Missions	Earth Orbit Missions
Signal Delay	Near-instantaneous Signals
Weak Signals	Strong(er) Signals
Long Passes	Short Passes
"Constant Hazards"	Periodic Hazards
Sequential Operations	Periodic Operations
Long Cruise Periods	High-use Duty Cycle
Robust Performance	Optimized Performance

Earth Orbit Beacon Work:

Stanford Space Systems Development Laboratory
U. Colorado Space Grant Consortium
STRV in collaboration with NASA MOCA and U. Colorado LASP

Innovation	Rationale
Mapping of spacecraft state to urgency of ground response	Four levels of urgency map best into the ops decision space
Suite of techniques for onboard engineering data summarization	Needed for fast response and solves bandwidth limitations
Advanced Scheduling software	Supports demand-based scheduling of telemetry tracks
Automated tone message handling & reporting	Shortens response time, lowers cost, and utilizes personnel most effectively
Detection of weak signals with unknown freq., freq. drift, and phase noise	Allows use of small antennas for beacon monitoring

INNOVATORS

- John Carraway
- Bruce Crow (ret.)
- Richard Doyle
- Jay Wyatt

DEVELOPMENT TEAM

- Jay Wyatt
- Tim Fogarty
- Mike Foster
- Rob Sherwood
- Alan Schlutsmeyer
- Miles Sue

SPONSORS

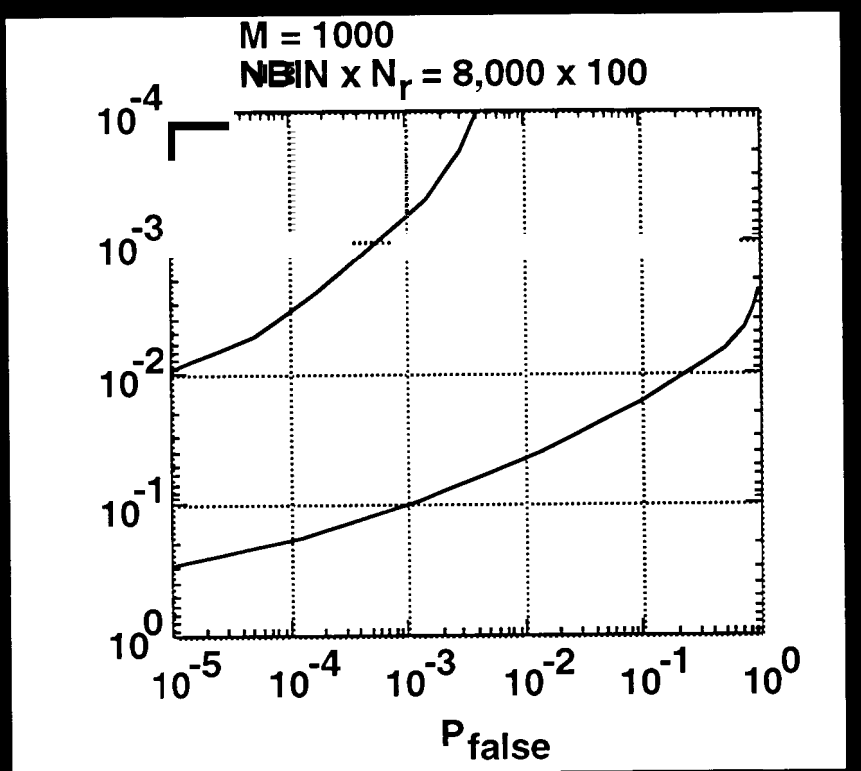
- NASA Autonomy and Operations Program
  - Mel Montemerlo - NASA HQ
  - Richard Doyle - JPL
- JPL Multi-mission Ground Systems Office Continuous Improvement program
  - Bob Wilson - JPL Program Element Mgr.
- JPL Telecommunications and Mission Operations Directorate Advanced Development Program
  - Chad Edwards - JPL Program Mgr.

BACKUP SLIDES

- Frequency drift and phase noise limit coherent FFT integration time (T) to about1 sec.

- Non-coherently summing thousands of FFTs after de-drifting with appropriate models dramatically reduces $(P/N_0)T$ requirement

- Parameters used:
  M=No. of FFTs
  NBIN=No. of FFT bins
  N_r=No. of drift rates
  P_{false}=prob. of false detection
  P_{detect}=prob. of dettection

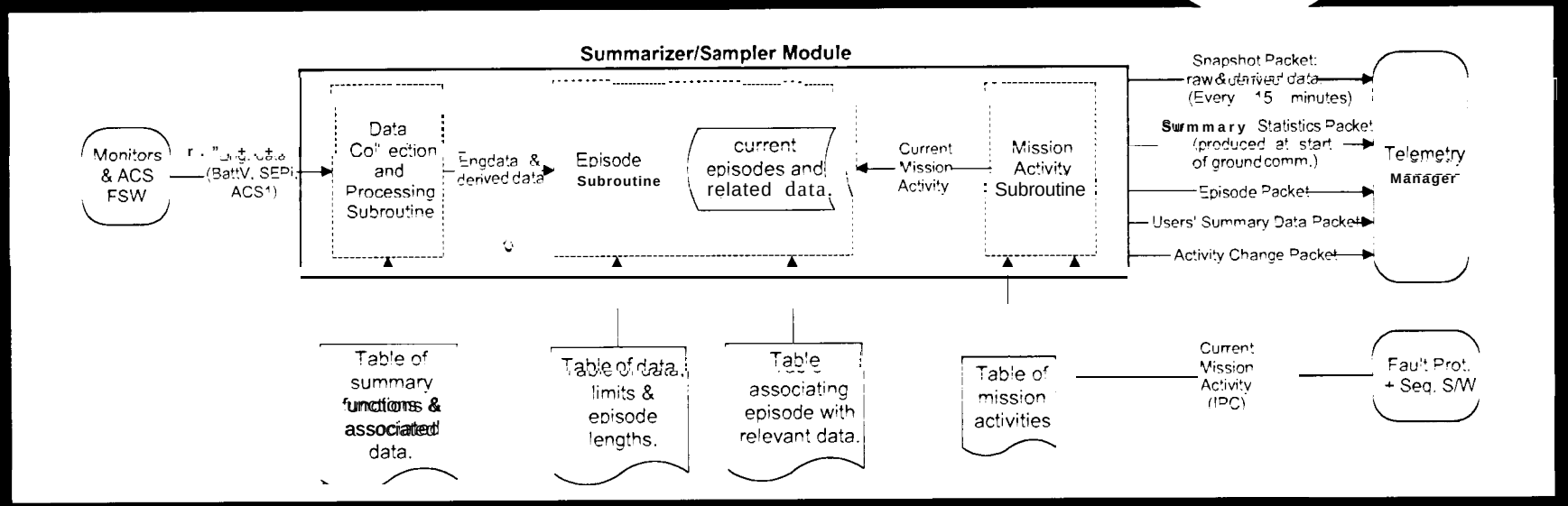


Telemetry Type	Description	Output Frequency and Duration
	Documents changes in mission activity	One packet is produced each time the activity changes
	Records a "snapshot" of every raw and summarized data channel	Regular interval (e.g. 15 min), scales with mission distance
	Records general data about an out-of-limits data condition	One per episode
	Records specific data about a single data channel's behavior during an episode	One or more per episode
	Records summary data about a single channel's behavior since the last downlink	One for each channel out of limits since the last downlink
	A user-specified packet containing raw and/or summarized data previously specified by the user	Duration specified by the user

Summary Results

Example Data Key

BattV = Battery Voltage
SEPi = SEP current
ACS1 = ACS rate data



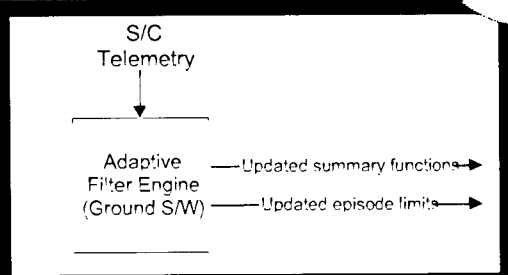
min(BattV)
max(BattV, SEPi, ACS1)
avg(SEPi)
d'(BattV,ACS1)
d''(ACS1)

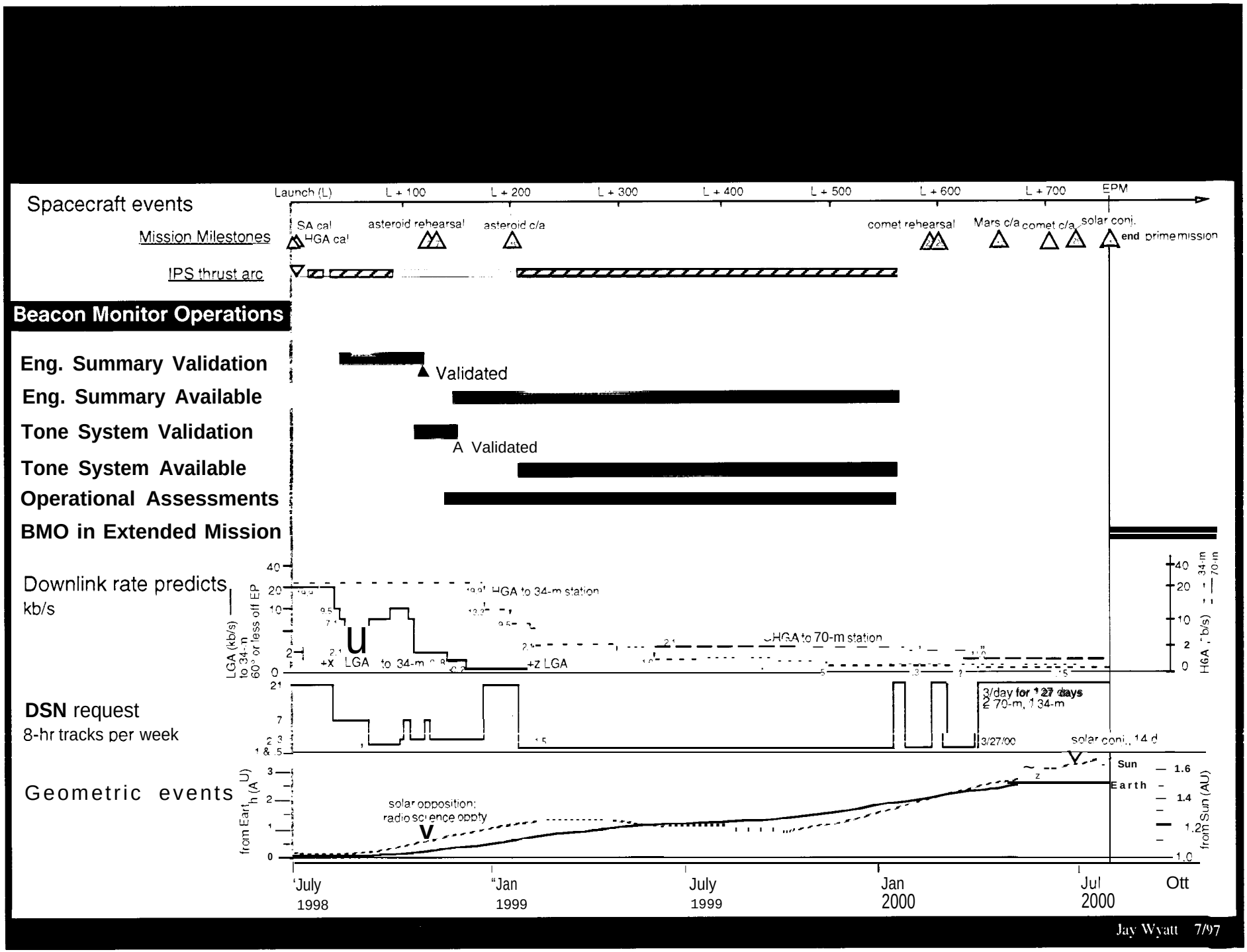
Mission Mode: MANEUVE
Mission Mode: SEP

Data ID	Hi Limit	Lo Limit
BattV	55	40
d'(ACS1)	3	-
avg(SEPi)	50	45

Episode Name	Relevant Data
BattV	BI1, B12, BT
d'(ACS1)	BattV, etc.
avg(SEPi)	max(SEPi), SEF

IPC Message	Mode
SEP_THRUST_ON	SEP
EXEC_TURN	MANUEVER
etc.	





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