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Using Quality Attributes to Bridge Systems Engineering Gaps: A Juno Ground Data System Case Study

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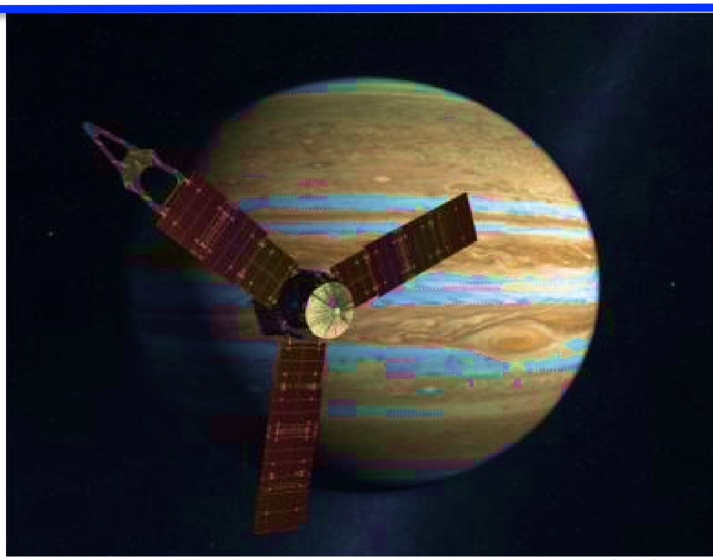
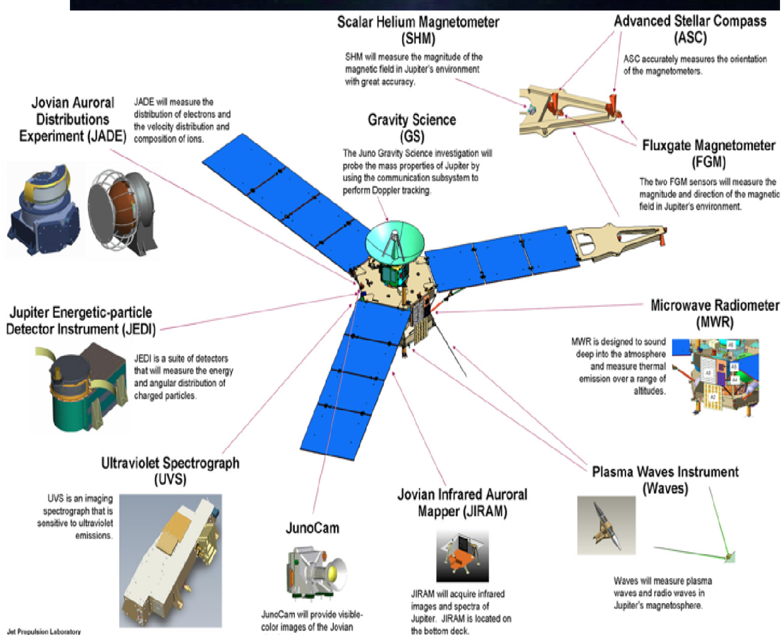
Juno Mission Background





- *Juno is a New Frontiers, Class B Mission*
- *First solar-powered mission to the outer planets*
- *Polar orbiter spacecraft*
- *Launch August 5, 2012*
- *Jupiter Orbit Insertion in July 2016, 1 year Science Operations*
- *Elliptical 11 day orbit swings below radiation belts to minimize radiation exposure*
- *Key Juno partners: SwRI, JPL, ASI, LM-Denver and GSFC*

GRAVITY SCIENCE & MAGNETOMETERS (ASC, FGM)
Study Jupiter's deep structure by mapping the planet's and gravity magnetic fields

MICROWAVE RADIOMETER (MWR)
Probe Jupiter's deep atmosphere and measure H/O

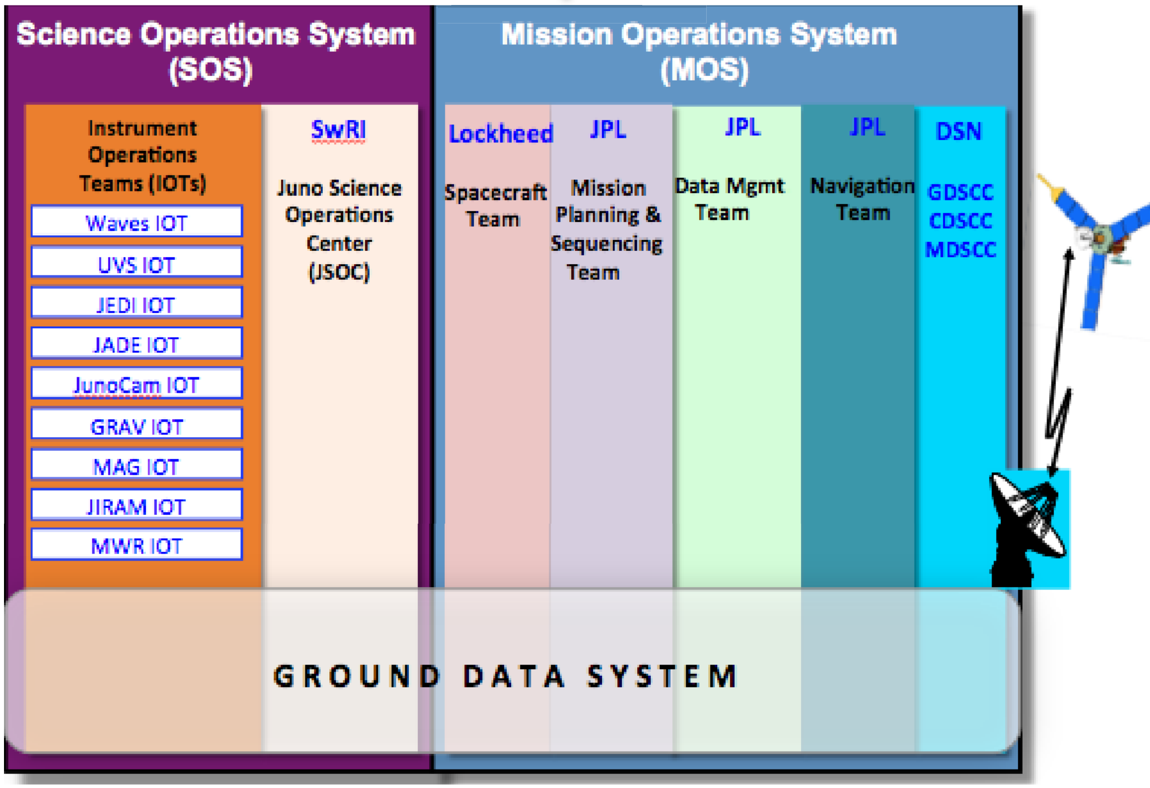
JEDI, JADE & WAVES
Sample particles, electric fields and radio waves around Jupiter to determine how the magnetic field inside the planet is connected to the atmosphere and magnetosphere – especially the auroras

UVS & JIRAM
Take images of the atmosphere and auroras, , along with the chemical fingerprints of gases there with ultraviolet and infrared cameras.

JUNOCAM *Take spectacular close-up, color images*

JUNO GDS Overview

Scope



- ✧ The Juno Ground Data System (GDS) spans the MOS and SOS
- ✧ The GDS provides the software, hardware, networks, and information services required to conduct mission operations
- ✧ The GDS delivers instrument engineering data and raw science data to the IOTs at their home institutions and to JSOC

Heritage

- ✧ Juno Flight System heritage is from the Mars Reconnaissance Orbiter (MRO) also built by LMSS
- ✧ Juno GDS heritage is based on JPL's Advance Multi-Mission Operations System (AMMOS), also used by MRO
- ✧ Heritage assumption: Flight/Ground Interactions similar to MRO
- ✧ Both Juno and MRO use CFDP to capture and deliver instrument product telemetry

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System Engineering Problem Statement

Key & Driving Data Processing Requirements

- ~3.5 gigabits per 8 hour pass at 120 Kbps
- Science data products available within 15 minutes from receipt by the DSN for initial instrument turn-on and calibration activities
- Quick Look science data products available within 15 minutes of the end of the corresponding DSN pass

Heritage Based Assumptions

- MRO demonstrated with a data rate of 6 Mbps that the as-is ground system could sustain product generation
- MRO Yearly CFDP Product Generation

Year	2008	2009	2010
Num CFDP Products	~124,000	~88,000	~129,000

- Juno expected to fit within this envelope

System Engineering Gap

- Gap emerged between Juno GDS data delivery requirements and the assumptions behind the heritage flight-ground interactions
- Heritage design of the Juno Instrument Data Pipeline was unable to meet instrument team data delivery expectations

Unexpected Instrument & GDS Behavior

- *Surprise:* during first two months of ATLO payload integration, Juno generated ~525,000 CFDP products, which translated into 1.575 million CFDP files in the GDS
- Unexpected: Instruments generated large volume of small products.
- Instruments favored small products to minimize instrument memory constraint
- Instrument used separate packet telemetry for different science types
- Heritage GDS Instrument Data Pipeline unable to meet latency requirement

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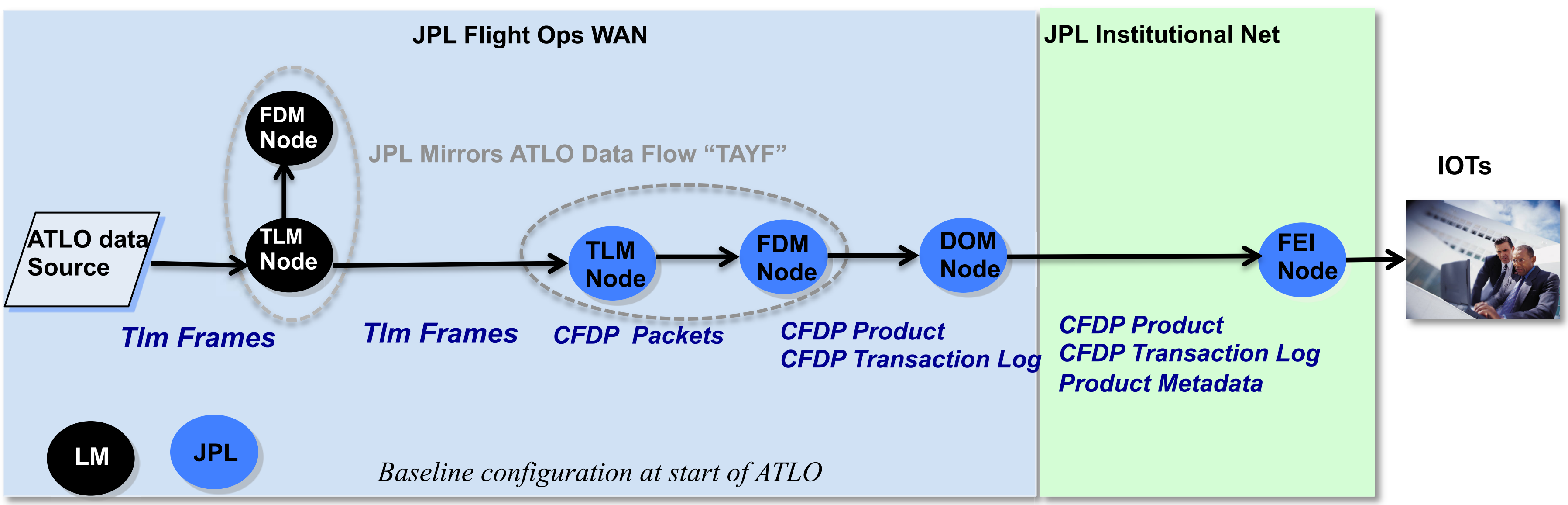
Juno Instrument Data Pipeline

The IDP processes and delivers raw science data products to the Instrument Operations Teams (IOTs).
Data processing nodes :

- TLM Node: extracts CFDP/PDU packets from telemetry frames and delivers packets to FDM (File Delivery Manager) Node.
- FDM Node: builds CFDP products (.out files) and transaction logs (.dtl files) from CFDP/PDU packets and publishes them to the project database, aka DOM (Distributed Object Manager).
- DOM Node:: builds meta data (.hdr) files from CFDP product and transaction files, and publishes all these to the FEI (File Exchange Interface) Node.
- FEI Node: Archives the raw science data products, generates additional meta data, and delivers products and meta data to the IOTs (subscription-based).

ATLO Requirement: Test-As-You-Fly of the GDS



Attacking the Problem

Two-prong approach:

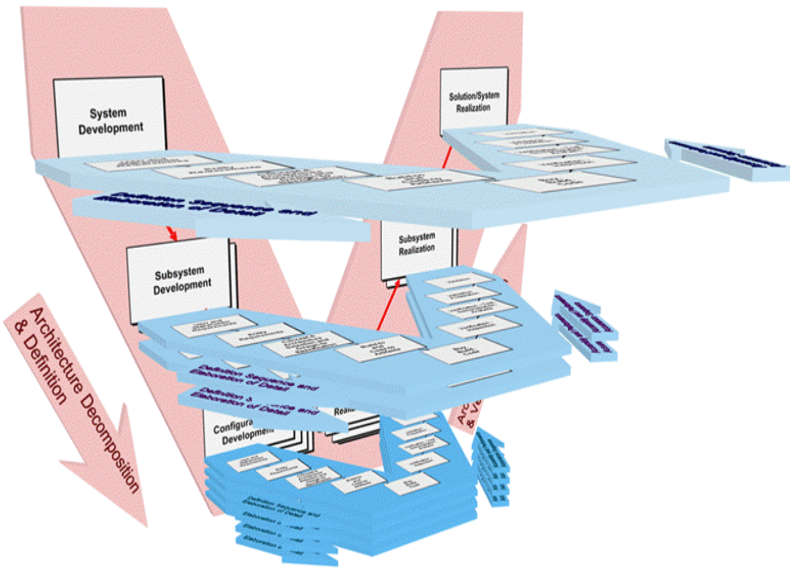
1. Identify and Implement GDS software remediation actions:

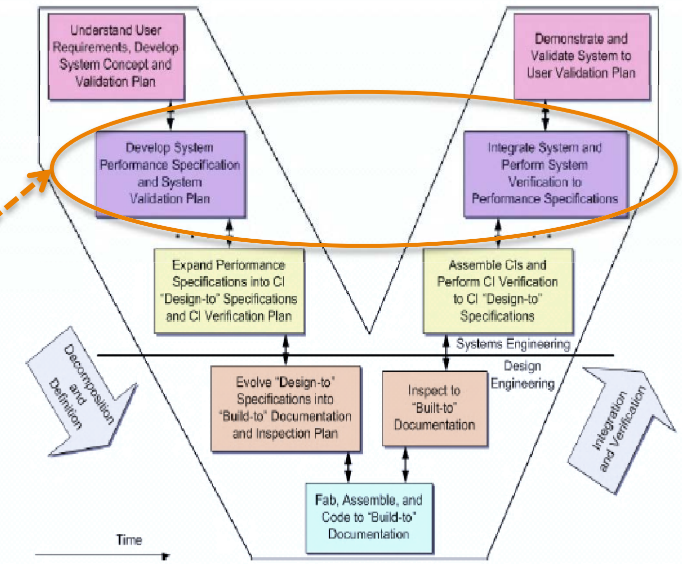
IDP Node	Remediation Actions
FDM	• Added multiple threads of product building per FDM instantiation. Six threads identified as optimum number of concurrent threads. • Three FDM nodes: one for JIRAM, one for JEDI and one for all other instruments • CFDP Timer adjustments
DOM	• Network Appliance storage system parameters adjusted • Unix system max file descriptors increased from multi-mission default
FEI	• Science orbit-based storage structure for raw science data archive (deferred post-launch)

2. Apply system engineering rigor to verify that changes to as-is design meet requirements by characterizing system performance through the use of quality attributes. To accomplish this, the following innovation was necessary:

   - Definition of a monitoring service architecture that was needed to provide the data to measure quality attributes
   - Definition of a new systems engineering activity that tied in the rapid system development approach of the monitoring service to the process of bridging the systems engineering gap

Revisiting the System Engineering Process





- ✧ Juno GDS Sys Eng approach consistent with Forsberg-Mooz Dual Vee Architecture
- ✧ Identification of gaps is part of the systems engineering process represented in this model
- ✧ This Sys Eng model ties verification planning to requirement analysis, emphasizes entity validation as input into system validation, and provides for early problem identification and resolution

Introduced new GDS Systems Engineering Activity:

1. Identify Quality Attributes needed to validate that the revised architecture bridges the systems engineering gap
2. Identify software performance metrics to measure the Quality Attributes
3. Use deployed system to mine ground truth and extract performance metrics
4. Use Quality Attributes to verify that the system architecture meets GDS requirements and to validate that the deployed system meets customer expectations
5. Identify updates to GDS subsystem level requirements

Identification of Quality Attributes

Rationale behind identification of QAs:

- Need to assess and qualify operational behavior of the IDP
- ATLO and Mission Operations stakeholder expectations in combination
- Theme of "follow the product"

Predictability

- ✧ Based on known science operations scenarios, instrument users need to predict when their products will arrive at their home institution and the GDS users need to predict where the product is in the pipeline

Reliability

- ✧ Both instrument and GDS users rely on continuity of IDP operations. A key function of the monitoring service is to provide visibility into the operational status of each of the pipeline nodes

Traceability

- ✧ GDS users need to verify the processing history and location of the instrument products by "following" the product along the pipeline

Recoverability

- ✧ Instrument product reconstruction at each of the IDP nodes is a high priority in the case of any pipeline node failure. Recovery of the pipeline requires resumption of product processing

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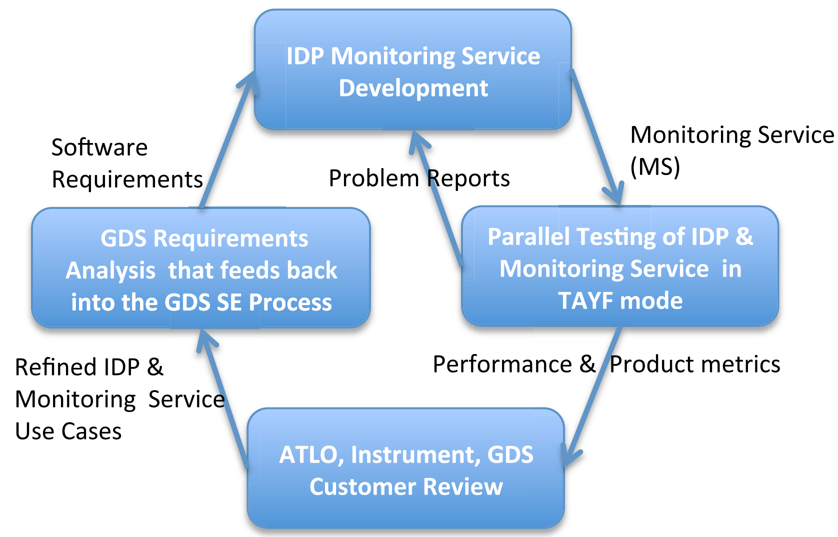
Developing the IDP Monitoring Service to Measure QAs

IDP Monitoring Service driving requirements:

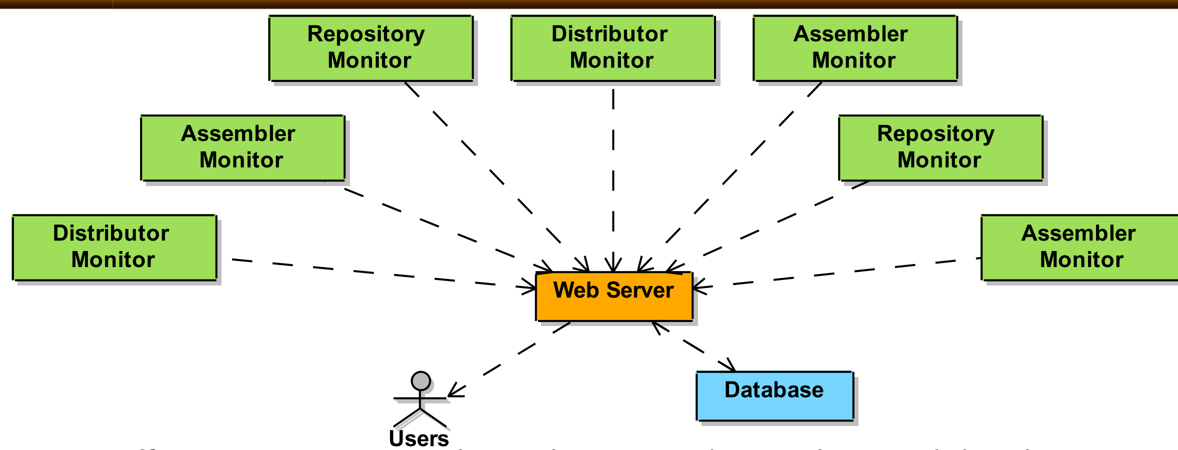
- Mine metrics available from IDP node logs
- Capability to compare products built locally in ATLO to those built by the flight operations pipeline
- Non-interference with pipeline performance
- Provide first-level of metrics analysis
- Provide web-based remote access to “follow the product” and metrics
- Continuous operations with auto-detect of pipeline operational status
- Detect pipeline processing errors
- Monitor in real-time
- Reconstruct pipeline processing
- Multiple instances running in parallel

Rapid System Development Approach



Architecture

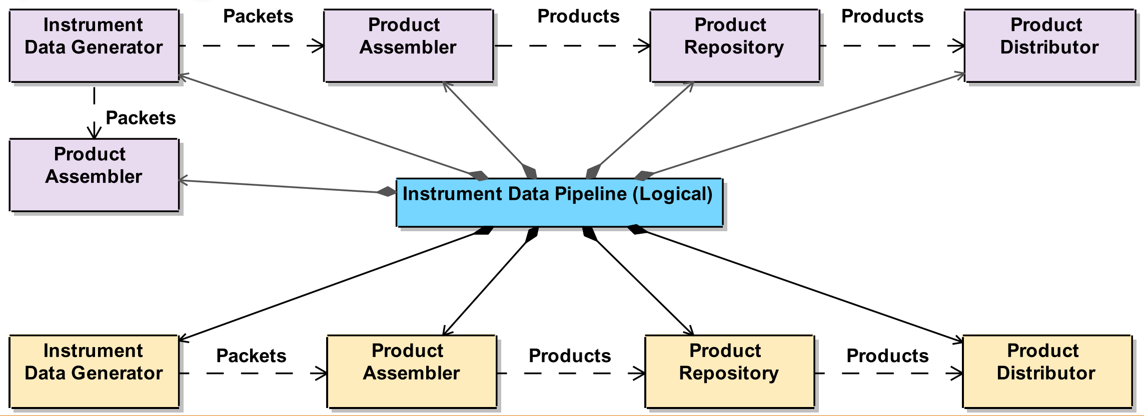
- The Monitoring Service architecture is characterized by plug-n-play monitoring agents; and open source web server and database framework



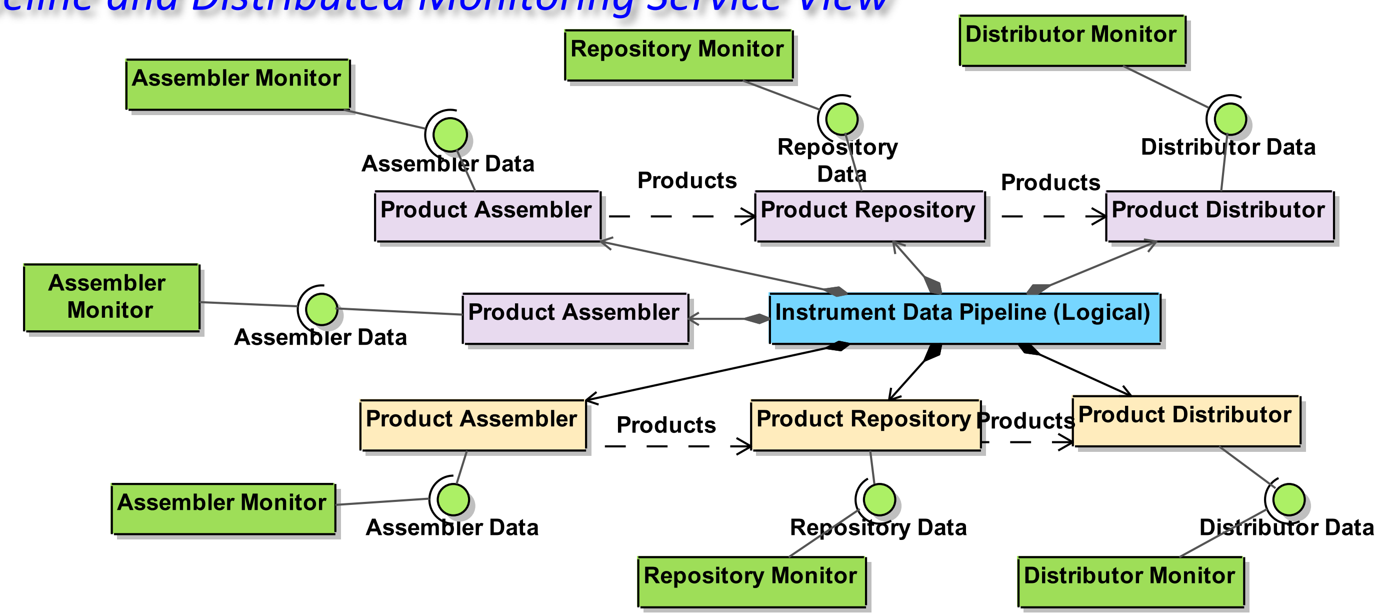
- Model-Based Systems Engineering was effective in capturing the architecture during the rapid development mode

Other Architecture Views of the IDP-MS

Instrument Data Pipeline Logical View



Integrated Pipeline and Distributed Monitoring Service View



Quality Attributes Close the SE Gap

The IDP-MS provided the necessary metrics to measure the QAs, thus, resulting in a successful GDS V&V outcome and a solid qualitative assessment of the IDP performance against requirements

Predictability: 100% assuming nominal ops

- ✧ The Jupiter polar orbit with close perijove science scenario was tested repeatedly in ATLO
- ✧ The IDP metrics gathered provided consistent instrument product statistics and matched IOT latency expectations

Reliability

- ✧ Demonstrated to meet MTBF requirement of no less than 1 month and recovery within 24 hours

Traceability: 100%

- ✧ Both in real-time and in batch mode, the monitoring service demonstrated the availability and immediate access to product metadata at each IDP Node

Recoverability: 100%

- ✧ Resumption of product processing was demonstrated consistently when any of the nodes encountered a problem
- ✧ Persistence of both product data and processing information was demonstrated at each node

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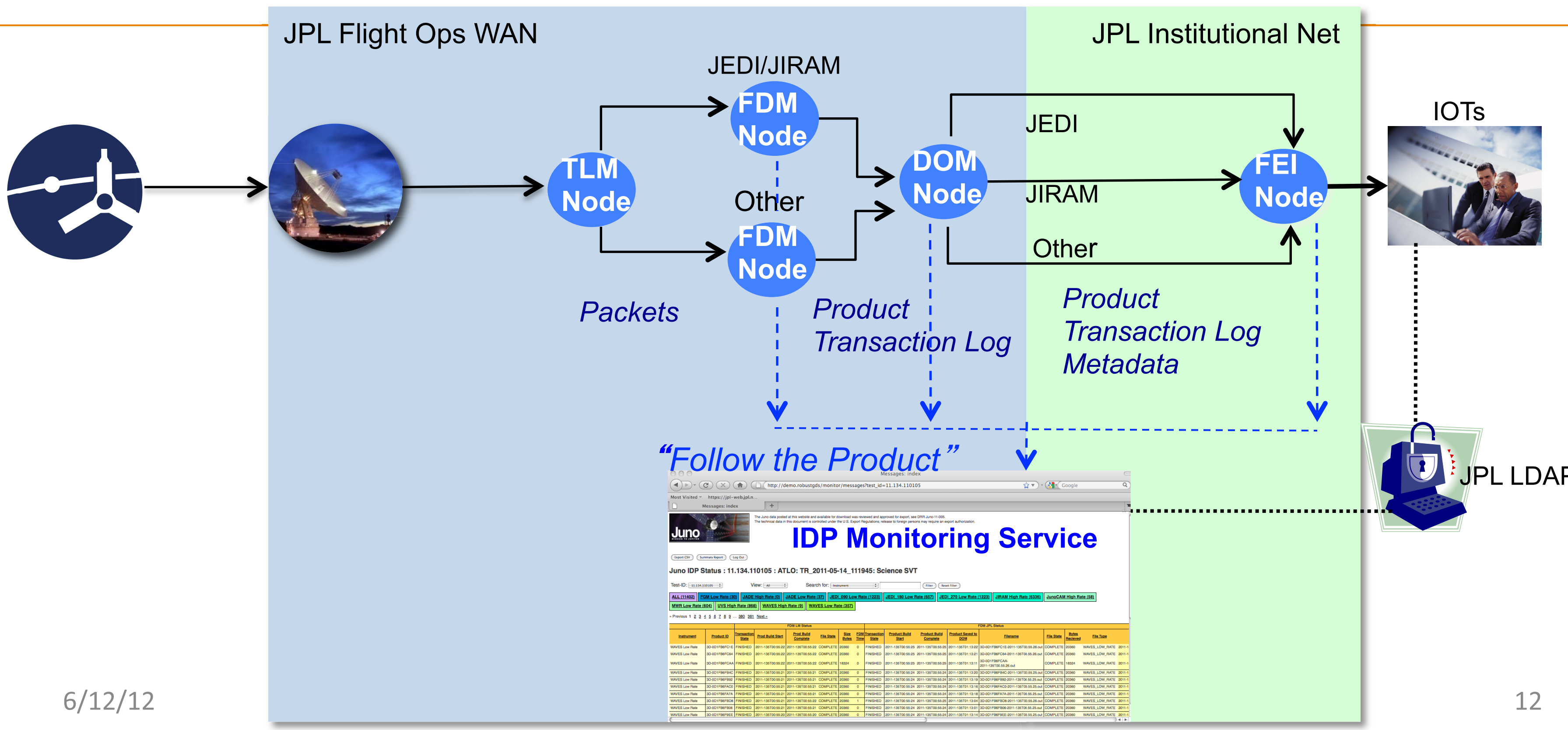
Summary

- ✓ The Quick Look requirement was met for products generated and transmitted in real-time
- ✓ Given that the ATLO tests were conducted at 1.6 Mbps (instead of the 120 Kbps flight rate), it was demonstrated Quick Look requirement would be met for the end-of-pass playback of the orbit data set. Challenge here is that the playback of data for instruments generating the larges volume of products occurs during the last two hours of the pass
- ✓ Juno ORR presentation of IDP metrics was well received
- ✓ Quick Look requirement met during instrument checkout



Lessons Learned

- GDS needs to probe and understand impact of payload/spacecraft bus interactions on flight/ground interactions
- Benefits to be gained from infusing system level quality attributes definition and measurement into the GDS development life-cycle
- Effectiveness of model based systems engineering approach to capture and iterate an architecture in a rapid system development environment
- One useful view of the GDS is as a network of processing nodes can be used to harvest behavior and performance metrics, as the GDS evolves during development and transitions to operations

- Two By-Products from the work described:
  - A quantified performance characterization of multi-mission instrument data pipeline components that can be added to the as-is design specifications
  - A monitoring service architecture that is extensible to all nodes of GDS data processing , which has been captured in a re-usable model (in SysML) for the next mission

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