

James Webb Space Telescope –L2 Communications for Science Data Processing

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ABSTRACT

JWST is the first NASA mission at the second Lagrange point (L2) to identify the need for data rates higher than 10 megabits per second (Mbps). JWST will produce approximately 235 Gigabits of science data every day that will be downlinked to the Deep Space Network (DSN). To get the data rates desired required moving away from X-band frequencies to Ka-band frequencies. To accomplish this transition, the DSN is upgrading its infrastructure. This new range of frequencies are becoming the new standard for high data rate science missions at L2. With the new frequency range, the issues of alternatives antenna deployment, off nominal scenarios, NASA implementation of the Ka-band 26 GHz, and navigation requirements will be discussed in this paper. JWST is also using Consultative Committee for Space Data Systems (CCSDS) standard process for reliable file transfer using CCSDS File Delivery Protocol (CFDP). For JWST the use of the CFDP protocol provides level zero processing at the DSN site. This paper will address NASA implementations of Ground Stations in support of Ka-band 26 GHz and lesson learned from implementing a file base (CFDP) protocol operational system.

Keywords: L2, DSN, Deep Space Network, JWST, CCSDS, Ka-band

1. INTRODUCTION

The James Webb Space Telescope (JWST) is a large aperture infrared space telescope with a 5-year mission, 10-year design goal. It is currently planned to be launched in 2013 from French Guiana aboard an Ariane 5 launch vehicle. JWST is designated to succeed the Hubble Space Telescope (HST) and Spitzer space telescope as part of the NASA Great Observatories program. JWST will continue the HST tradition of advancing breakthroughs in our understanding of the origins of the earliest stars, galaxies, and the very elements that are the foundations of life. The JWST team, partially shown in Figure 1, includes several partners at multiple locations: (1) Project management located at Goddard Space Flight Center (GSFC), (2) Observatory Prime Contactor (Northrop-Grumman Space Technologies (NGST)), (3) Integrated Science Instrument Module (ISIM) located at GSFC, (4) Near-Infra Red Camera (NIRCam) (University of Arizona and Lockheed Martin), (5) Near-Infrared Multi-Object Spectrometer (NIRSpec) built in Europe, (6) Mid-



Figure 1 - JWST Team at the Goddard Space Flight Center.

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Infrared Instrument (MIRI) build by a US and European team, (7) Flight Guidance System (FGS) built in Canada and (8) Science and Operations Center located at the Space Telescope Science Institute (STScI) located in Baltimore MD.

The JWST spacecraft from a ground system perspective is a fairly traditional science mission. For operations, the JWST will be located at the second Sun-Earth Lagrange Point (L2), see Figure 2, that provides JWST with a naturally cold environment with no solar eclipses and an unobstructed view of the earth for communications. After launch and commissioning, normal operation will involve a single 4-hour contact per day to allow the uploading of commands, monitoring of real-time engineering telemetry, and downlinking of recorded engineering and science data. The ground processing of the recorded science data is done overnight so the products are available to the users the next day. The engineering data is dumped first and sent to the analysis system near real-time to determine any back orbit out-of-limit conditions.

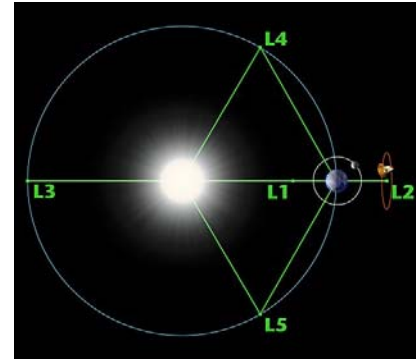


Figure 2 - Lagrange Points.

The JWST system includes the typical systems for most science missions. This starts at the science investigator proposal and ends with the science data and associated products delivered to the science investigator. The earlier development and I&T ground systems are based upon the final operational system. The overall high-level ground system is depicted in Figure 3. The main components of the JWST ground system that support the science planning, data collection and processing are:

- Proposal Planning Subsystem (PPS) – Provides the proposal solicitation, processing and planning functions required to generate the science program and to generate the observation plan.
- Operations Scripts Subsystem (OSS) – Provides the tools necessary to assist in the development, validation and management of onboard scripts.
- Flight Operations Subsystem (FOS) - Provides the command data uplink and telemetry capture functions, performs telemetry processing necessary to monitor observatory status, monitors observatory and ground status, and detects and notifies operations personnel in the event of an anomaly.
- Project Reference Database Subsystem (PRDS) – Comprised of the project reference database as well as database tools. It is the repository for all JWST data and information required for observatory operations, such as telemetry descriptors, commands, parameters, algorithms, and characteristics. It provides the configuration management, change process management, and data distribution functions required to provide operational data to the other components of the ground system.
- Data Management Subsystem (DMS)/Science Archive – Provides the data processing, archive, catalog, calibration, distribution and analysis functions required to support the science program and maintenance of observatory performance. One of the primary components of this system is the science pipeline. The science pipeline provides an automated means of low level processing the science data and associated engineering data.
- Wave Front Sensing and Control (WFS&C) Software Subsystem (WSS) – Stores and processes science and engineering data obtained to measure wavefront error. Produces commands that will be uplinked to correct the optical figure of the telescope.
- Flight Dynamics Facility (FDF) - Provides the mission's orbit determination and tracking and ranging support.
- Deep Space Network (DSN) – Provides the flight to ground communication portion of the mission.
- NASA Integrated Services Network (NISN) – Provides the telecommunication services needed for the transfer of data between the other ground elements.

Covering a larger time-span than most missions required taking operational considerations early in the life cycle. The major themes in JWST operations are:

- Using the same I&T system for operations,

- Separating project reference database from T&C system,
- Using standards and open source XML and XTCE,
- Maximizing the use of NASA institutional services – FDF, DSN, CFDP, and
- Addressing autonomy of only 4 hours contact by using an event driven scheduler.

This paper will summarize these operability themes.

2. SAME SYSTEM FOR I&T AND OPERATIONS

Implementing lessons learned from EOS and GSFC SMEX programs, JWST decided to use a COTS product for the command and telemetry system for both I&T and operations. The JWST has a project requirement to use the same ground system in science instrument and spacecraft development through I&T that will be used in mission operations. The intent of this requirement is to follow the ‘test-as-you-fly’ philosophy, to identify problems very early in the project lifecycle and to reduce the risk in operations. The first step is to determine the scope of the ground system for operations and the subset that will be used for the I&T system. The consideration of the various ground system choices had to not only provide the best technical solution but also the best business solution that would be acceptable with the prime contractor and various international partners. This meant using a COTS product rather than a home grown product. As shown in figure 3, the first system modified for the science processing for JWST was the C&T system used in development. As the program transitioned to the I&T phase, the science flow included the WFS&C, analysis systems, and operational scripts. Lastly, in the operational system the proposal planning system is the last piece added to complete the science data flow from user input to science data processing. Using this incremental development for the science data processing allows users to correlate the early science calibration data with that obtained during operations without any modifications.

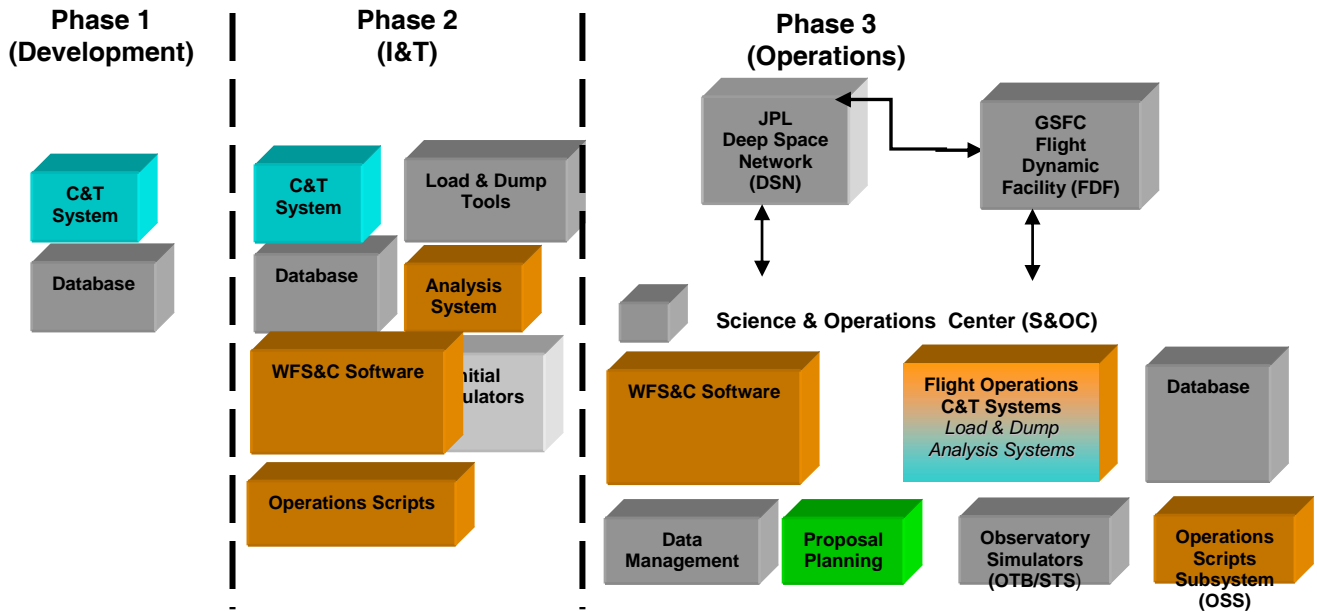


Figure 3 – Ground System Development Phases.

After the selection of JWST prime contractor a trade for selection of the command and telemetry system was made. The trade included GSFC and NGST personnel from both the JWST and NPOESS projects. The Raytheon Eclipse product, used on EOS, was chosen. This was a major commitment on NGST’s part as they replaced their existing legacy home grown C&T system with a COTS system. The C&T system is the first element to be enhanced for JWST science

processing. The C&T system is being modified for handling of CFDP commanding to the spacecraft as well as keeping the operators informed on the status of the CFDP transactions

For I&T, JWST is an international program with the assembly of the observatory occurring at the prime contractor's facility in Manhattan Beach, California, with cryo testing occurring at Johnson Space Center (JSC), and launching from French Guiana. To use the same ground system in all these locations requires a system that is easy to set up, secure, networkable, and provides the processing of the science data as it will be done in operations.

Providing an I&T system 10 years prior to launch created an opportunity to design into the ground system upgrade paths and take advantage of upcoming technologies. Most missions have a short (less than five (5) years) between the time they start development and launch. The common practice is to take "what" we used before, use a command and telemetry system and tailor the entire mission operations around it. JWST decided to take a different approach, and address 'new' concepts for mission operations, by having a 'real' modular plug and play components and using the operational processing of the data, including the science data.

3. JWST DATABASE XML AND XTCE

It was recognized that JWST database is key to the different systems exchanging information, migration of ground system components, and reducing testing needed for each database release.

At first, the choice of XML was not widely accepted. Many meetings and reviews were held to discuss the advantages and disadvantages of XML. XML was a departure from the traditional use of relational databases such as Microsoft Access or Oracle for spacecraft databases. XML was selected as it was an emerging standard.

The next key decision point was whether to structure the database as one large file or to have each command and telemetry item exist as a separate file. The JWST team chose to have each command and telemetry item exist as a separate file in order to facilitate identification of changes, reduce the regression testing needed on the databases, and to visually separate the various spacecraft PRD elements in to subdirectories.

The JWST database tools allow the various users to locally modify, add and delete database items as part of the JWST flight software and hardware development. The master database is maintained at the S&OC so the users can access a configuration-managed database at any time. Each item in the database has an owner who is responsible for verifying the data item has been tested at various certification levels: by analysis, with simulators, with engineering test units, and with flight hardware units. To date, 15 master databases have been created, and at least 150 databases have been created at the local sites.

The commitment to standards called for JWST to work with ESA/ESOC in developing XTCE which became a standard at 2007. JWST is working on defining the standardizing the science data engineering data keywords in XML format that are attached to each science observation. JWST is the leading mission in the US for XTCE and is supporting other projects such as LCDM and Constellation to use XTCE.

4. HIGH DATA RATE WITH 26 GHZ KA-BAND

JWST was the first L2 mission to be defined as a high data rate mission. JWST was also the first mission that pushed the spectrum allocation group to design a new spectra band in the 26 GHz Ka-band to meet data rates of more than 8 Mbps. JWST pushed for enhancements to the DSN capabilities that previously were limited to 5 Mbps. JWST requirements are to downlink 270 Gb science and engineering data every day. One of the main challenges for missions beyond the moon (300,000 km+) is in the spacecraft to earth communications. Geostationary satellites have straight forward satellite to earth communications since they are stationary over the same spot of the earth, Low Earth Orbiting (LEO) satellites have many alternatives with ground stations and the for NASA missions the Tracking and Data Relay Satellite System (TDRSS), but the challenges for the missions to and beyond the moon tend to share the following characteristics:

- Due to the earth rotation each viewing period of a satellite from a given ground station is between 8- 14 hours a day. Communication coverage can vary greatly, based on the satellite's ground track and latitude of ground stations.

- Ranging is required for JWST, using alternate ground stations in the southern and northern hemisphere. For LEO and L2 missions the accuracy of the ranging is dependent on the tracking of the spacecraft across the sky. For the JWSTs L2 orbit, 21 days of tracking equals about 15 minutes of tracking for a LEO spacecraft.

The JWST original concept was to have a daily 8-hour contact using X-band with an 8 Mbps downlink rate. 8 Mbps required an allocation of a 20 MHz X-band frequency. The NASA Spectrum office objected to provide more than the 10 MHz band in X-band range and suggested using Ka-band. JWST project decided to move to K-band and have one (1) 4-hour contact per day for communication and ranging.

The next step was finding the infrastructure to support the 26 GHz Ka-band. JWST performed a lease or buy ground station trade study that recommended leasing rather than buying would be the most cost effective. DSN offered to upgrade its existing 34-meter Beamwave Guide (BWG) assets with Ka-band and JWST would pay by usage. The LRO mission is building one 18-meter 26 GHz Ka-band ground station at the White Sands Test Facility in New Mexico. This antenna will provide high data rate support for recorder dumps of 100 Mbps link from lunar orbit with the link is closed with 40-watts Traveling Wave Tube Amplifier (TWTA). Having a single antenna at one location does not meet the JWST requirements to provide multiple hemisphere contacts and backup capabilities for the contact in case of rain attenuation or antenna maintenance.

Other missions such as the LEO National Polar-Orbiting Operational Environmental Satellite System (NPOESS) and GEO Solar Dynamic Observatory (SDO) also plan to use the 26-GHz band, but due to the nature of GEO and LEO missions they cannot share their resources with Lagrange missions due to limited ground assets.

TDRSS supports 26 GHz Ka-band and will provide communication services for the Crew Exploration Vehicle (CEV) while visiting the International Space Station (ISS). CEV missions to the moon are planned to be supported by a new infrastructure with a combination of ground and lunar relay satellites. CEV planned downlink data rate is 150 Mbps.

Another consideration is for these types of missions are the signal strength verses coverage. GEO missions can typically use high elevation antenna angles that reduce temperature effect and improves the Gain Over Temperature (G/T). Acquiring the satellite at 10 degrees elevation vs. 20 degree decreases the link margin by 1.2 dB for JWST, however acquiring at this elevation can significantly increase coverage. Also Ka-band is more sensitive to weather than S-band, which will decrease the link margins even more. For the JWST mission, another parameter that will impact the spacecraft to ground station is dependent on the launch time. The launch time will provide a bias either to the northern or southern hemisphere that may further limit the contact time with either Canberra or Madrid. For Lunar missions to provide continuous coverage, excluding the LOS that naturally occurs behind the moon, using 20 degree elevation would require four antenna sites.

As a baseline for planning, JWST suggests using the lower 10 degree antenna elevation and compensating by increasing the spacecraft Radio Frequency (RF) power that may be a mass impact to the spacecraft provider and one high link contact per day using a one 18-meter antenna with G/T of 45 dB or a DSN 34-meter with ground G/T of 55 dB. Many factors need to be considered when planning communication coverage for missions at and beyond lunar orbit. The mission's daily data downlink volume, ground track, ground station location, and concept of operations are some of the things that need to be considered in conjunction with link budget analyses.

At the time JWST was the first mission to use 26 Ka-band, however LRO use of this frequency by 2008 and DSN upgrades by 2011 will provide operational experience and reduce the risk of using 26 Ka-band.

5. CONSULTATIVE COMMITTEE FOR SPACE DATA SYSTEMS (CCSDS) FILE DELIVERY PROTOCOL (CFDP)

The CCSDS standard reduces functionality needed at control center, yet increases the data reliability by providing a reliable file downlink protocol. CFDP has become a standard way of sending recorded files. The Applied Physics Laboratory's Messenger mission was first to use the standard. Its CFDP agents were at the APL operations center. LRO makes extensive use of CFDP and its CFDP agents are at LRO MOC. JWST is the first mission to move the processing to the mission's ground stations. Its CFDP agents are at DSN, allowing the JWST operations center to receive the data as FTP'd files. Dealing with large amounts of data requires planning and smart use of resources. The systems need to address issues such as data priority, multiple instruments collecting data at different times, and variances in speed between components.

The JWST operations concept of one (1) contact per day, and sized for at least one (1) missed contact, requires a relatively large recorder. With a large recorder a method to optimize the use by minimizing maintenance of the fragmentation and allowing for handling of data priorities of data is highly desired. JWST has about 540 Gbits SSR at the beginning of life, with one (1) large partition to collect data from its instruments. JWST will be using the CCSDS File Delivery Protocol (CFDP) to provide reliable file transfer. To keep up with the high downlink, the recorder data gets sent directly to the Ka-band transmitter with the CFDP headers are being inserted by using a field programmable gate array. This implementation was selected as the onboard Command and Data Handling computer (single board PowerPC 750) does not read the file into its internal memory as it would not be able to keep up with the data rate.

The files are transmitted to the ground stations that perform store and forward to these files. The ground station will send the files to the Mission Operations Center (MOC) or by having priority partitions using CCSDS virtual channels (VCIDs). See figure 5 that shows the JWST flow of data, including CFDP. As part of moving to Ka-band, JWST has decided for cost purposes not to have a file system. By contrast, LRO uses a file management system and extracts files by name.

As a part of CFDP and file implementation, note that the file sizes should be relatively large - 256 Mb to 1 Gb. JWST is using one (1) Gb files and the propagation delay from L2 is twelve (12) seconds. For each CFDP file, the C&DH holds pointers and number of pointers grow significantly the smaller the file size. $Pointers = 2 * (data\ rate / file\ size) * propagation\ delay$.

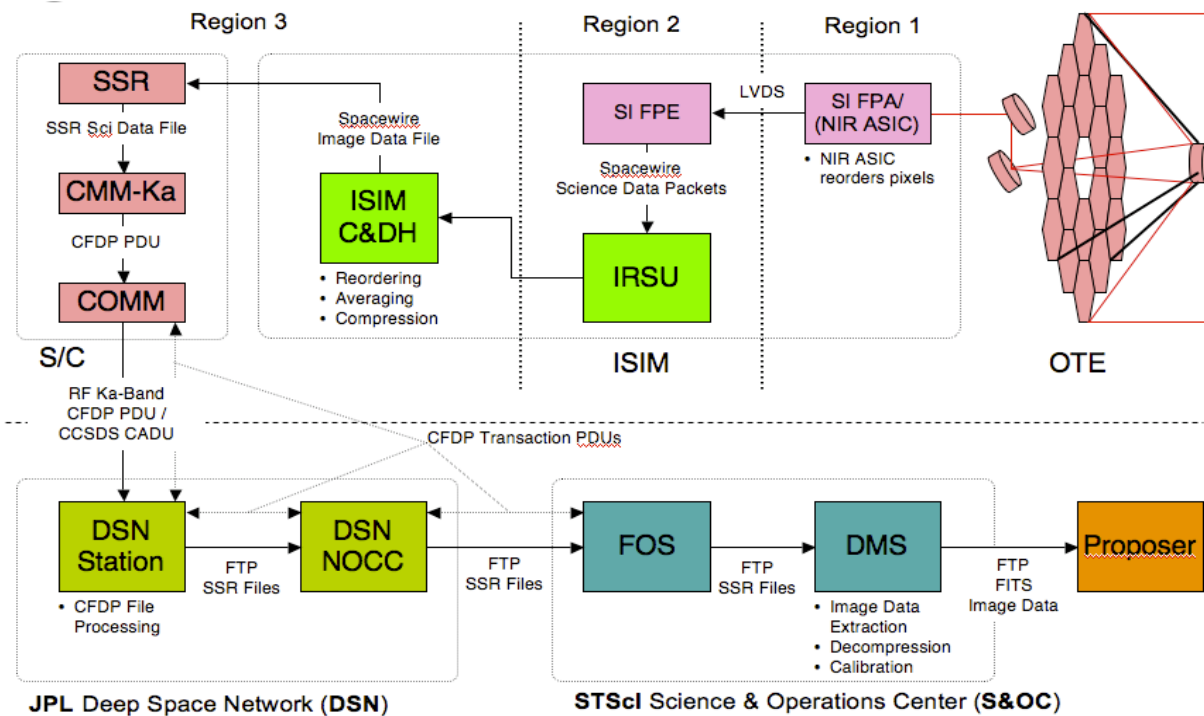


Figure 5 - JWST Data Flow.

In summary dealing with these high data rates requires close coordination with C&DH and a smart design that optimizes the use of resources.

6. SUMMARY

Solutions for the JWST communications from L2 for large volumes of science data has been provided. As systems are developed and tested the various elements will determine whether the proposed solutions meet reality. As covered in the paper the JWST science flow will be using standard protocols and downlinks, that at the time JWST was in the concept phase, had not been implemented. Also to further reduce risk the JWST is using the same standard protocols in the I&T

system, including the processing of the science data into the format that will be used in operations. JWST has successfully implemented the I&T systems that will migrate to the operational system, using XML/XTCE databases that are independent of the C&T system and science data processing following operational processes. Also the I&T test program will be using the operational event driven scripts so all flight products are verified during the I&T program.

For long term missions like JWST, being at the forefront of standards and technology during the concept and development phase reduces the likelihood of becoming obsolete during the mission phase. The impact of the upcoming standards and technologies can not always be forecast when they are first emerging, such as the internet and web standards, but the risks often are overcome by the benefits even if the standard does not catch on or has limited life. This is evident in the JWST science data, large amounts of science data using guaranteed data delivery products that is verified during I&T.