



How a Spacecraft Mission is Developed

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Agenda

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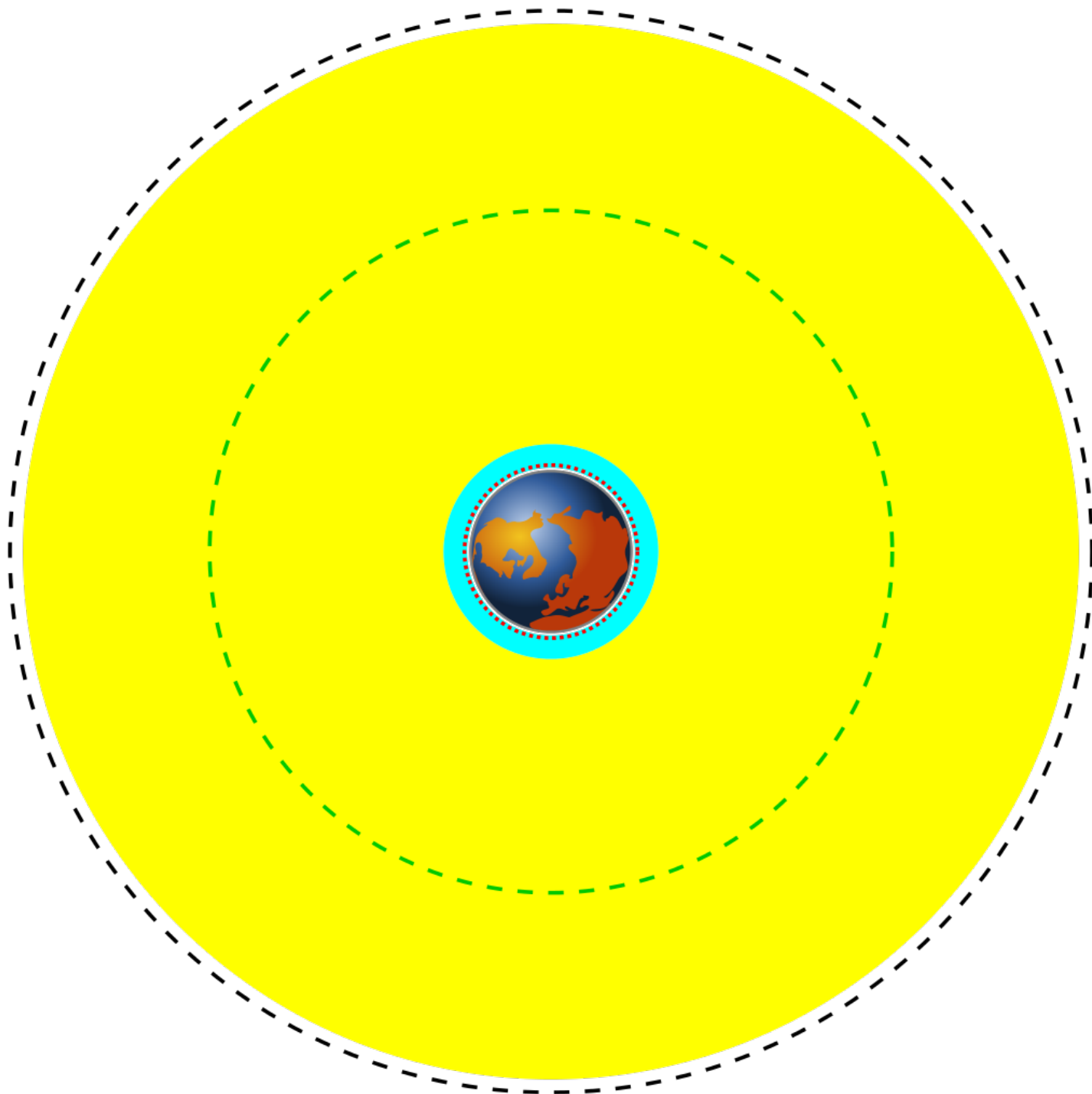
Introduction

- A satellite is made up of two parts that communicate with each other, then to/from the communications site and then to/from the ground
 - A spacecraft bus
 - Science Observatory
- Types and Costs of missions
 - Observatory Class - \$1 billion and more
 - Medium Class (MIDEX) - \$180 to \$240 million
 - Small Explorer (SMEX) - up to \$120 million
 - University Class (UNEX) – up to \$15 million
 - CubeSat – up to \$1 million
- Communications to and from the satellite
 - Tracking and Data Relay Satellite System (TDRSS)
 - Deep Space Network (DSN)
 - Mission specific ground station
 - Commercial ground station



Introduction (Continued)

- Earth Orbits
 - Low Earth Orbit (LEO) 100 to 1200 miles
 - Medium Earth Orbit (MEO) 1250 to 22,000 miles
 - High Earth Orbit (HEO) 22,200 to 26,000 miles
 - Geosynchronous (GSO) 26,200 miles
 - Geostationary (GEO) 26,200 miles
- Lagrange Orbits 932,00 miles from earth
 - L1
 - L2
 - Station Keeping about every 22 days
- Moon Missions
 - LRO, Lunar Prospector
- Deep Space Missions
 - Cassini, Galileo, JUNO, numerous Mars missions



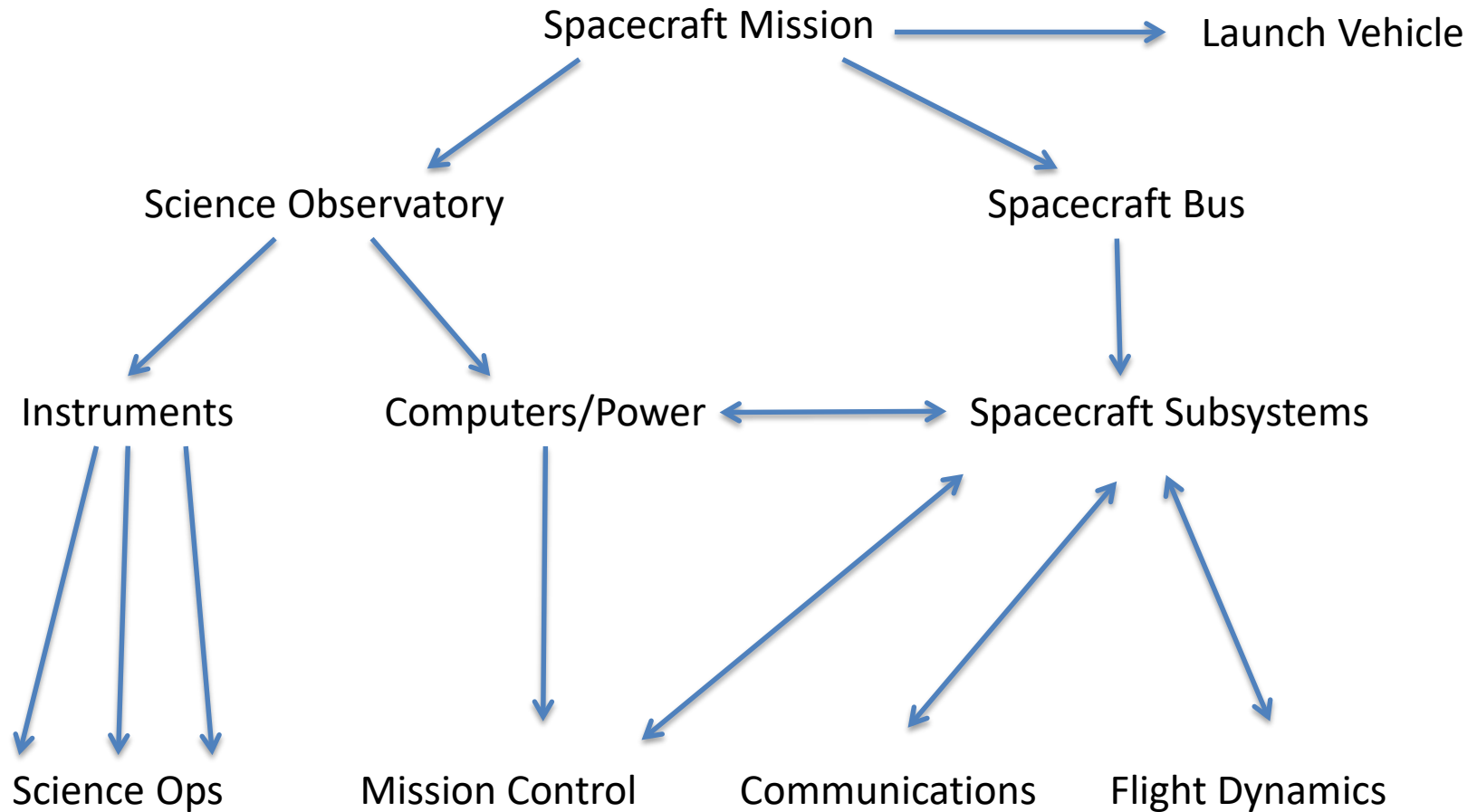


Initial Concepts for a Spacecraft Mission

- The ideas for a mission can come from a variety of places
 - NASA Headquarters as an Announcement of Opportunity (AO) or a Response for Proposal (RFP)
 - NASA Center scientists
 - JPL scientists
 - University scientists
 - Private industry scientists
 - European Space Agency (ESA) and other foreign space agencies in contact with NASA headquarters
 - NOAA scientists for weather and earth observing



Initial Concepts for a Spacecraft Mission (continued)



Other Facilities also



Initial Concepts for a Spacecraft Mission (continued)

- Spacecraft Bus components
 - Power -- solar panels, Radioisotope Thermoelectric Generator (RTG), long term batteries
 - Communications -- High gain and low gain antenna's
 - Star Trackers -- optical device pointing to a star(s) and locks on to maintain directional control which measures the position of stars
 - Thermal blankets -- keeps component systems within acceptable temperature ranges
 - Gyroscopes -- provides spacecraft stabilization and control
 - Recording Devices -- saves data for later downloads
 - Batteries -- used after launch until the solar arrays are deployed
 - Propulsion -- hydrazine fuel or ION engines (electric propulsion)
 - Main and backup computers -- this is the On Board Computers (OBCs)
- Space qualified parts are used which may seem “out of date” by the public but are important for a successful mission
 - Legacy equipment versus new equipment

Initial Concepts for a Spacecraft Mission (Continued)

- Observatory
 - Main computer that connects between the spacecraft bus and the instrument(s)
 - One or more science instruments
 - Computer for each instrument with software to communicate not only with the instrument(s) but also with the main observatory computer
 - High Voltage and Low Voltage power supplies
 - Any additional sensors for fine pointing or for adding additional data for the instrument

Peer Review Process

- One or more scientists on the mission concept will provide a presentation to other scientists on a panel not involved in the mission; those scientists on the panel will present detailed issues including pro's and con's for this mission concept
- This presentation will give a detailed explanation of what the mission will accomplish and what value it has to the overall science
- A detailed cost model for the mission will be developed and presented which also includes the cost of the spacecraft bus and more importantly what type launch vehicle that may be needed and very importantly its cost
- Science drivers versus engineering constraints
- Trade Studies are presented
 - The mission objectives versus the constraints such as the instrument power required, the technology required (Technology Readiness Level #9 to #1) and the budget/time needed
 - Identification of commercial of the shelf components (COTS) that can be used both for the observatory and for the ground systems



TRL 9

- Actual system “flight proven” through successful mission operations

TRL 8

- Actual system completed and “flight qualified” through test and demonstration (ground or space)

TRL 7

- System prototype demonstration in a space environment

TRL 6

- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5

- Component and/or breadboard validation in relevant environment

TRL 4

- Component and/or breadboard validation in laboratory environment

TRL 3

- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2

- Technology concept and/or application formulated

TRL 1

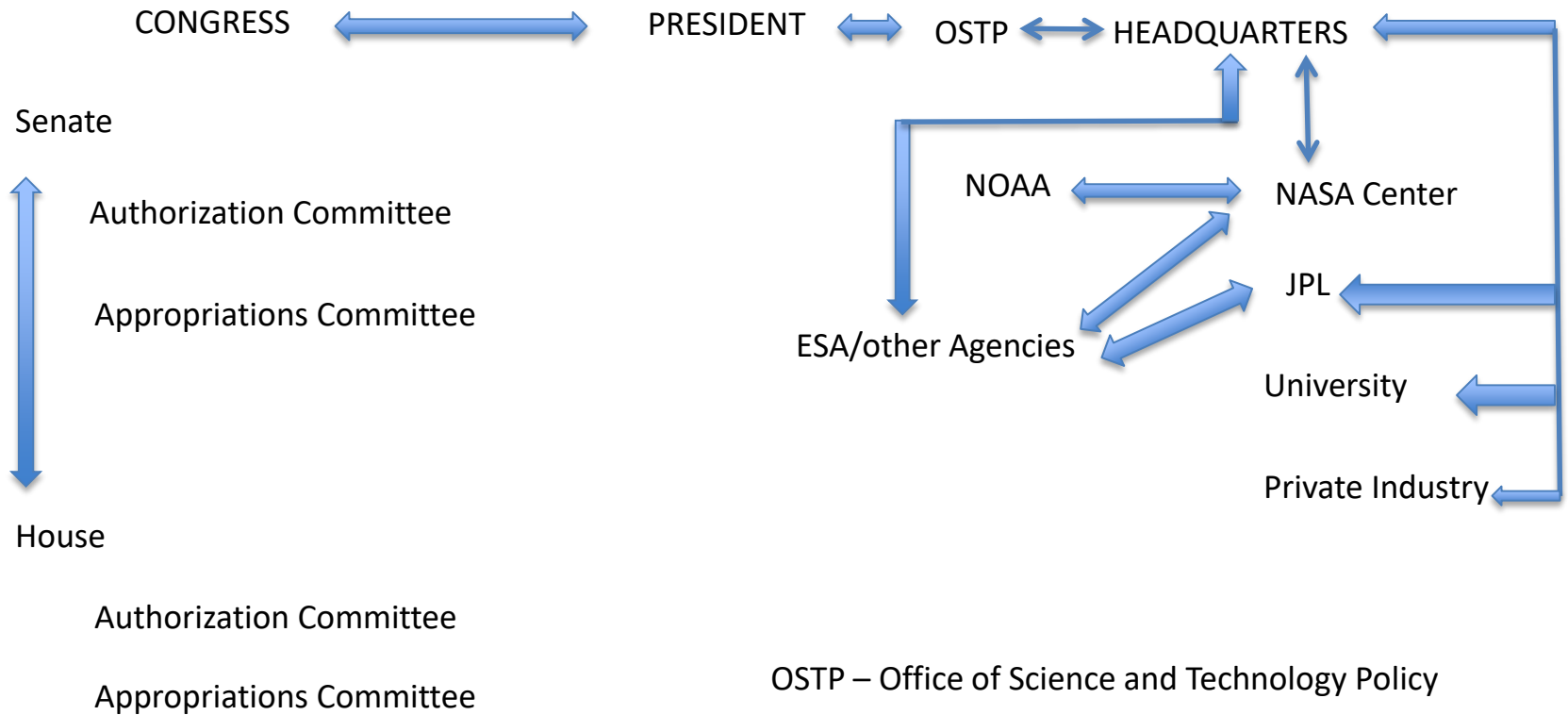
- Basic principles observed and reported

Approval and Funding Process

- NASA center, University, JPL, Private Organization
- Headquarters
- President
- Congress



Approval and Funding Process (Continued)





Headquarters Process

- Headquarters chooses which NASA center, JPL, University or Private organization that will develop, test and operate the mission
- Many times it is a combination of the above organizations
- It depends on what type of mission it is and which organization “bid” for that mission
- Determination is made for the cost and budget for the mission and determines if it matches with the proposal from the science review team
- Headquarters has its own panel of scientists which lay out a decadal set of science and technology projects for the next 10 years

- Announcement of Opportunity (AO) from NASA Headquarters
 - solicits proposals for participation in the NASA-led mission from scientists

- Response for Proposal (RFP)
 - This is a solicitation for a competitive proposal and the response is the proposal
 - It is selected on technical capabilities and on price

Personnel Selection Process

- Program Manager
- Project Scientist and the various instrument scientists
- Project Manager
- System Engineer(s)
- Mission Operations Manager
- Operations Director
- Group Heads
 - Flight Dynamics Engineers
 - Mission Operations Engineers
 - Science Center Engineers
 - Communications Engineers
 - System Engineers for each group
- Contractor companies chosen to develop and support the mission
 - The Flight Operations Team (FOT) is selected and along with the Operations Director to develop the Mission Operations Center (MOC)
 - The contractors also work in the Flight Dynamics Facility, the Command Management, the Scheduler and the Communications personnel

Facilities

- Mission Operations Center (MOC)
 - Receives the spacecraft telemetry
 - Sends the spacecraft commands/observatory commands and command loads to the satellite
- Command Management System (CMS)
 - Develops the command loads based on input from the SOC and the MOC
 - Scheduler prepares the request to the station for a spacecraft support
- Flight Dynamics (FD)
 - There are two different groups – one is the orbital/attitude personnel and the other is the navigation personnel
 - Develops the orbital flight parameters and attitude control for the on-going mission
 - Prepares the navigational parameters for missions
- Science Operations Center (SOC)
 - Receives the science data and separates out each for each instrument
 - Prepares the instrument commands and provides that to the CMS for command loads
- Communications
 - Develops the communications link for TDRSS or DSN or a separate ground station which goes from the satellite to the station(s) and then onto the MOC/SOC
 - Maintains the hardware/software for the communications for all the facilities

Facilities (continued)

- Communications (continued)
 - Deep Space Network: Goldstone, Madrid, Canberra; each separated by 120 degrees
 - Antenna's: each has one 70 meter, several 40 meter and a host of 20 meter antenna's
 - Tracking and Data Relay Satellite System (TDRSS)
 - Location in space: Geosynchronous orbit
 - Present number of satellites: 9 in orbit with another launch this August but will be delayed due to damage to the solar array
 - Dedicated antenna's for a given spacecraft mission such as the Solar Dynamics Observatory (SDO) mission
 - Commercial antenna's "rented" by a spacecraft mission
- Determination made on the communications rate for both the uplink and downlink prior to any system reviews
 - Higher the rate the more costly it is
 - This is in the budget sent to headquarters

Documentation Process

- Documentation is extremely important in **ALL** phases of the mission
- The smaller missions have somewhat less whereas the observatory missions have a towering amount of documentation. But whatever the mission, they all have the same basic types.
 - Interface Control Documents (ICDs) define what and how the interface will work between any two facilities
 - Operations Concept Document (OCD) defines how the entire mission will function to satisfy the observatory objectives
 - Systems Requirements Documents (SRD) for every facility and observatory instrument from the high level Operational Requirements down to the specific Functional Requirements and finally to the Detailed Requirements that will support all phases of the mission – these are maintained and updated
 - Preliminary Design Document (PRD) provides the preliminary design of the software/hardware based on requirements
 - Detailed Design Document (DDD) is the basis for the development of the coding for the system or the building of the hardware

Documentation Process (continued)

- Mission Operations Plan (MOP) developed by all of the parties involved in the mission including the scientists and all of the facilities; it is a detailed plan which describes the actual operations of the mission
- Commissioning Plan developed by the science team on how their instruments will be tested on orbit and how long this will take
- Hardware Documents which define and specify all of the hardware equipment in all facilities including the spacecraft and observatory with diagrams
- Test Plans for every facility and observatory instrument based on the Functional Requirements and the Hardware specifications – these are maintained and updated with the results of the testing
- End of Life (EOL) document – what will be done with the spacecraft after the mission – a disposal orbit, entering an atmosphere or crash onto a planet or moon or asteroid; this also includes getting rid of any expendables such as fuel and draining batteries



Requirements Process

- Requirement Design
 - System Requirements are put together based on the high level Operational Requirements that were designed by the scientists and high level managers to support the mission
 - Each facility develops more detailed requirements which are derived from the Operational Requirements
 - The requirements document is done by the contractor team in coordination with the government team
 - Additional requirements are created from ICDs from other facilities including communication requirements
- System Requirement Review (SRR)
 - These detailed requirements are presented to a Configuration Control Board (CCB) and an audience represented from other facilities on the mission
 - This Requirements Review will also include a form Request for Action (RFA) to be filled out by any person attending the review



Design Process

- Preliminary Design
 - The design of the software or hardware is developed by the contractor team
 - This part of the design involves documentation and usually some prototyping
 - The documentation involves taking the requirements down one layer to determine how the basic design can implement each requirement
- Preliminary Design Review (PDR)
 - The Preliminary Design Review is presented to the CCB and other facilities involved in the mission
 - The prototyping, either in software or hardware, can demonstrate to the attendees during the PDR that your basic design can fulfill the requirements
 - The questions that the attendees ask about the design will be written on a RFA to be answered by the design team and presented to the Configuration Control Board (CCB)



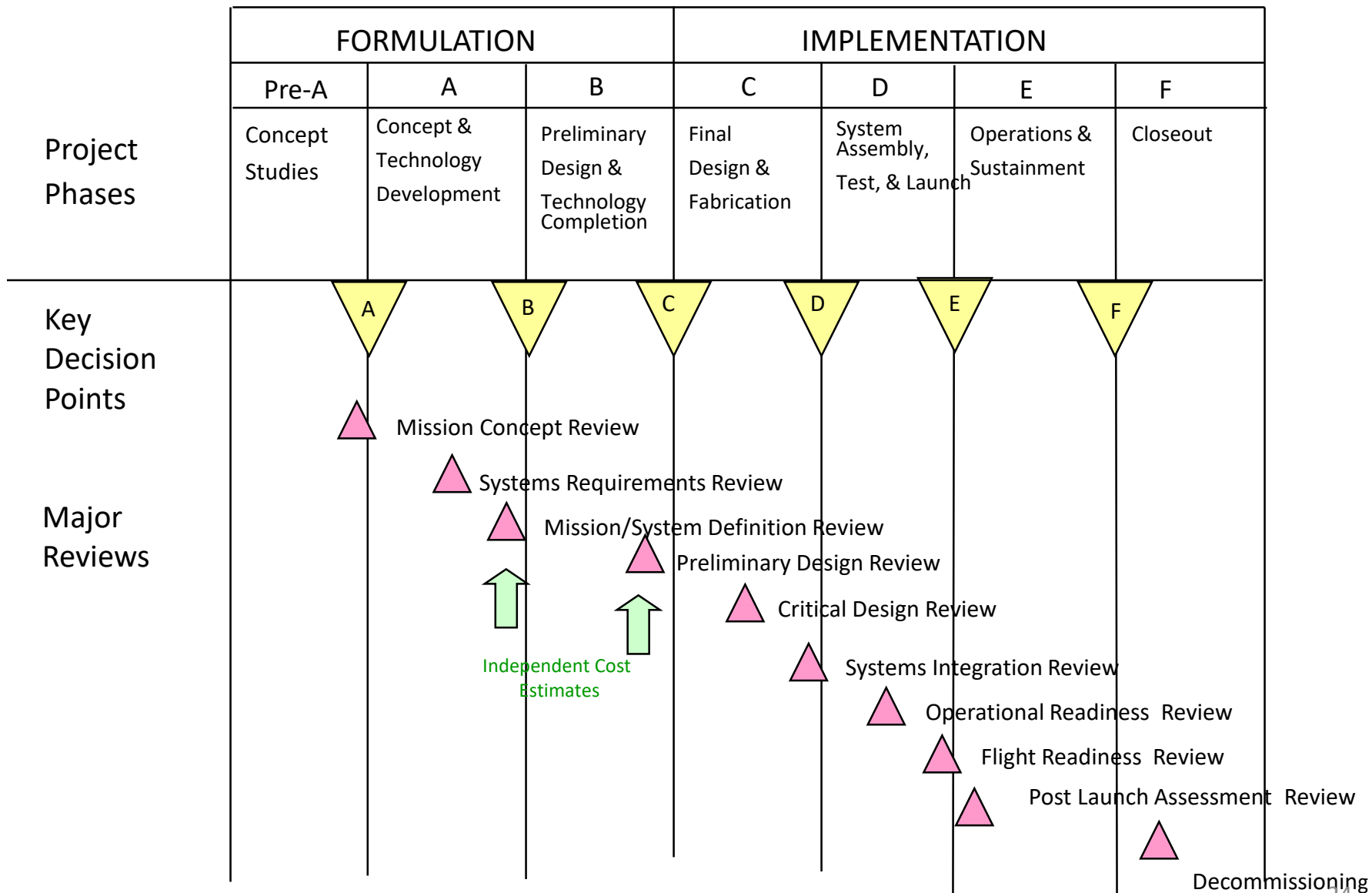
Design Process (continued)

- Critical Design
 - This is the final design developed by each facility of their software or hardware and is developed from both the final requirements and preliminary design
 - The design is usually developed by the contractor team
 - It is then presented to the attendees at the Critical Design Review (CDR)
- Critical Design Review (CDR)
 - Again any questions that the attendees ask that cannot be satisfied in the design will be on the RFA form to be answered by the design team and presented to the CCB
 - At this point the development and design team start building the software or hardware to support the mission

Review Process

- System Requirements Review (SRR)
 - This presentation and documentation provides the requirements required to support the mission for each facility
- Preliminary Design Review (PDR)
 - The presentation and documentation that each facility presents to provide for the initial design from the requirements
- Critical Design Review (CDR)
 - The CDR is the final review and documentation given prior to the development of software and hardware to support the mission
- Operational Readiness Review (ORR)
 - The ORR is a combined review for all of the facilities supporting the mission which also includes the results of all of the testing
- Flight Readiness Review (FRR)
 - The final review given by each facility just a few weeks prior to the scheduled launch
- Integration Validation and Verification (IV&V)
 - Done in Fairmont, West Virginia
 - Top down approach from the requirements validation down to the critical design to verify that all requirements are fulfilled by the design
 - They receive all of the documentation from each facility to review

Major Project Reviews Precede Each Key Decision Point



Facility Testing

- Each facility tests the software or hardware over and over and over again
- The contractor team usually does the majority of testing the software/hardware and writes the discrepancy reports (DRs) on each software problem for the contractor development team
- The contractor usually provides the NASA representative for that facility a list of DRs and the fixes made to the software/hardware

Telemetry and Commanding Systems

- Telemetry
 - Received from the satellite – spacecraft/instrument portion via the communications downlink
 - Format is a packetized block of data containing the spacecraft and observatory data which is routed to the SOC and MOC
- Commanding
 - Real Time commanding to the satellite for the spacecraft or to the observatory instruments which is executed immediately
 - Near Real Time commanding that is stored in the spacecraft computer for execution at a specific time
 - A Command Load to the satellite for the execution by the instrument computer for that observatory instrument; each instrument has their own computer
 - The spacecraft on-board-computer (OBC) routes each load to the proper instrument computer or it stays on the OBC for execution by the spacecraft itself
 - Format is the packetized block of data sent to the spacecraft
- CCSDS Consultative Committee for Space Data Systems
 - This international committee developed the Packet Telemetry and Packet Telecommand system in use today

Telemetry System (continued)

- Telemetry Formats
 - Packetized Format is used to send data down to the communication facilities
 - CCSDS developed this packetization format

- Telemetry Data
 - Level 0 data – raw telemetry 0s and 1s formatted into frames
 - Level 1 data – basic processing performed, data is separated for each instrument and the spacecraft data to the MOC
 - Level 2 data – processed data by each instrument scientist in the SOC and provided to the science center so that the other instrument scientists can compare their data with each other
 - Level 3 data is final processing into pretty graphics and is provided to the public

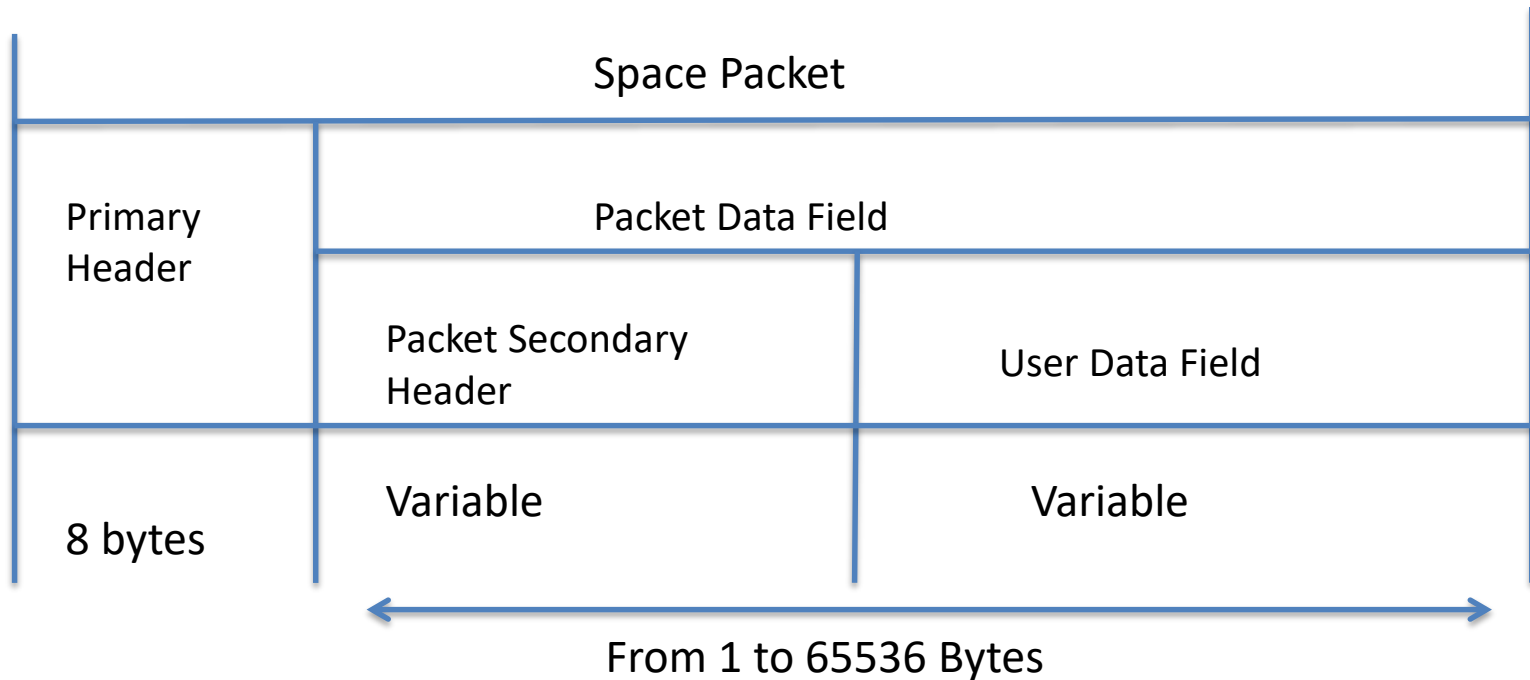


Packetized Telemetry Format

Block of data with length that can vary between successive packets, ranging from 7 to 65,542 bytes, including the packet header

Packet primary header – 8 bytes

Packet datafield variable from 1 to 65536 bytes



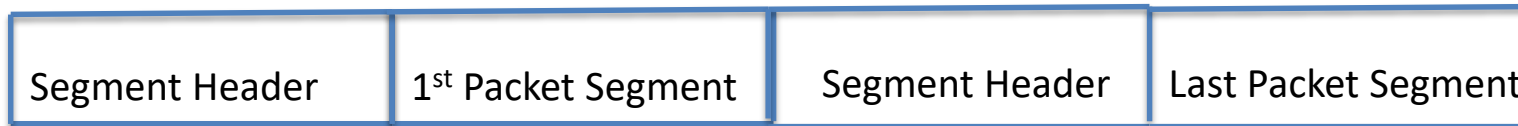
Command Format (continued)

- Command Formats
 - The packetized command format is sent from the Mission Control Center
- There are many layers – from the application layer (coding) up to the physical layer
- Command Link Transmission Unit (CLTU) – one or more code blocks of data to make up one transfer frame



Command Format (continued)

← 256 Bytes →



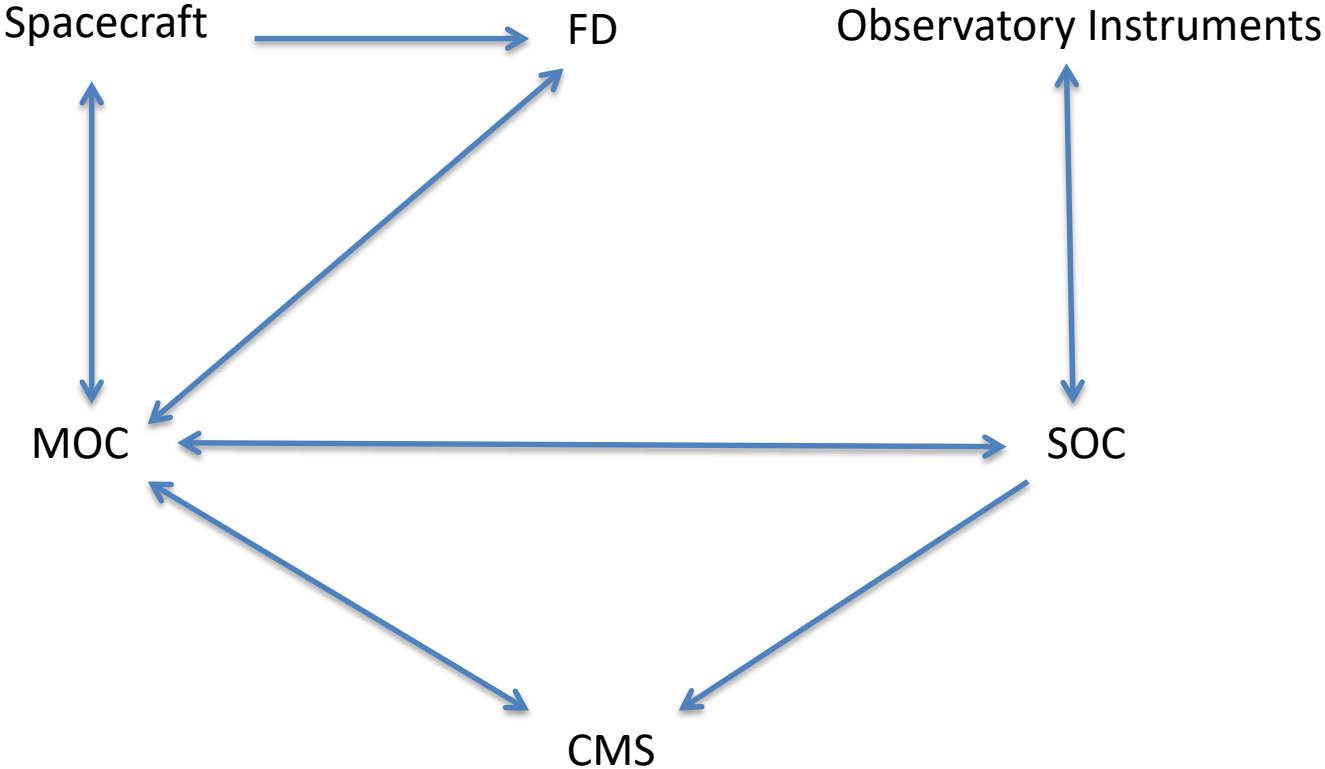


Coordination Process

- The Project Manager does all of the coordination for the mission
- Each of the facilities **MUST** work with each other closely and participate in the reviews that each holds
- The Project Manager holds very frequent meetings with all of the participants including the Project Scientist. The closer to launch, the more frequent the meetings to once weekly
- The Project Manger has a overall schedule for the entire project including all of the testing required by each facility, the instrument testing in the thermal vacuum chambers and the integration testing between all of the facilities



Facility Interface Testing



This requires that the communications personnel provide communications lines between all of the facilities prior to the interface testing. This testing is repeated many times.





QROC

Observatory Testing

- The testing process is for all the systems, both software and hardware which includes the communications link being used
- Various forms for the tests
 - Thermal Vacuum Chamber
 - Vibration Chamber
 - Acoustics Chamber
 - Space Environment Chamber
- Clean Room Tent
 - The observatory is put together
- ElectroMagnetic Interference (EMI) testing done on both the observatory equipment and the spacecraft and also done after the observatory is “mated” to the spacecraft
- **“Test as you would fly and fly as you tested”**

Integration Testing

- While the instrument(s) are in the thermal vacuum chamber testing is performed by the instrument team and then other tests with a communications link to both the SOC and to the MOC are very frequently performed
- Testing with all of the instruments after they are integrated into the observatory are continually performed over and over and then retested by the SOC and the MOC
- The testing between each of the facilities are retested many times
- Each of the facilities tests their communications link to the “station(s)” which will be used to support the mission, including the backup station(s) if requested by the mission

Thermal Vacuum Chambers

Left: WMAP loading into SES

Bottom: Swift Optical Bench Thermal Vacuum Test in Facility 238

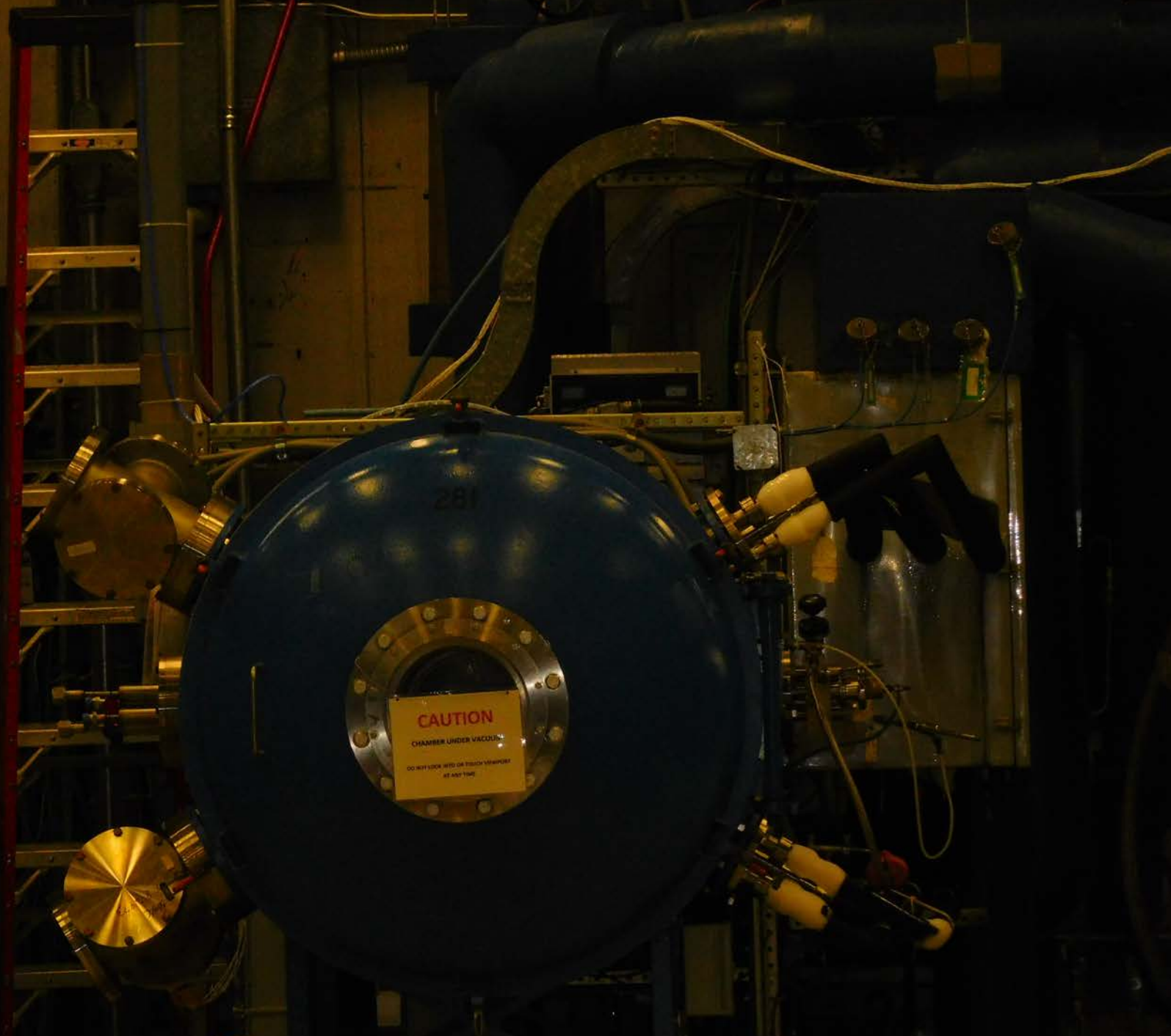
Right: HST Reaction Wheel Assembly in Facility 237



- Used to perform s and spacecraft
- Used to perform contaminants
- Temperature ra
- Ultimate Vacuu
- Currently bein

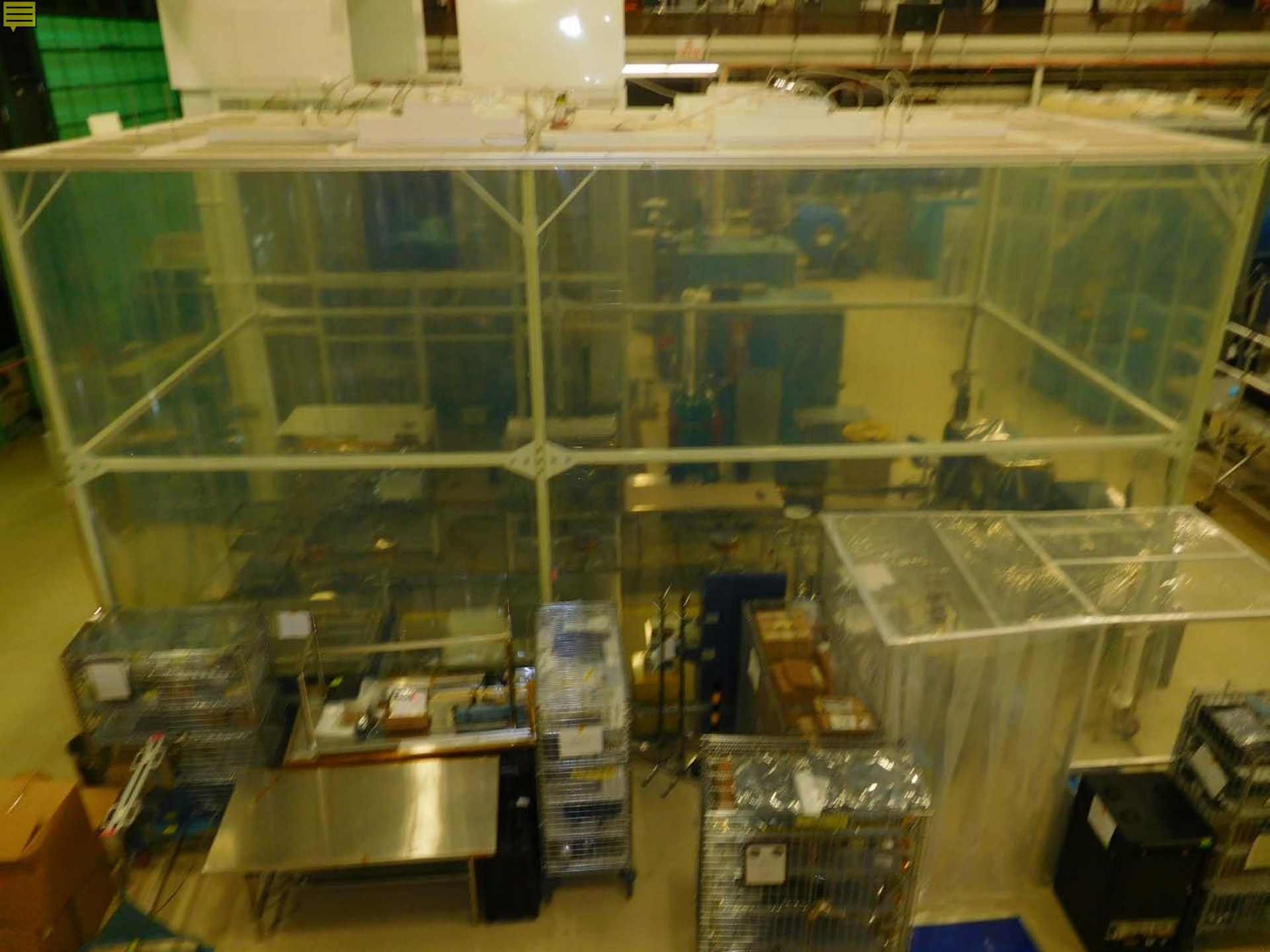


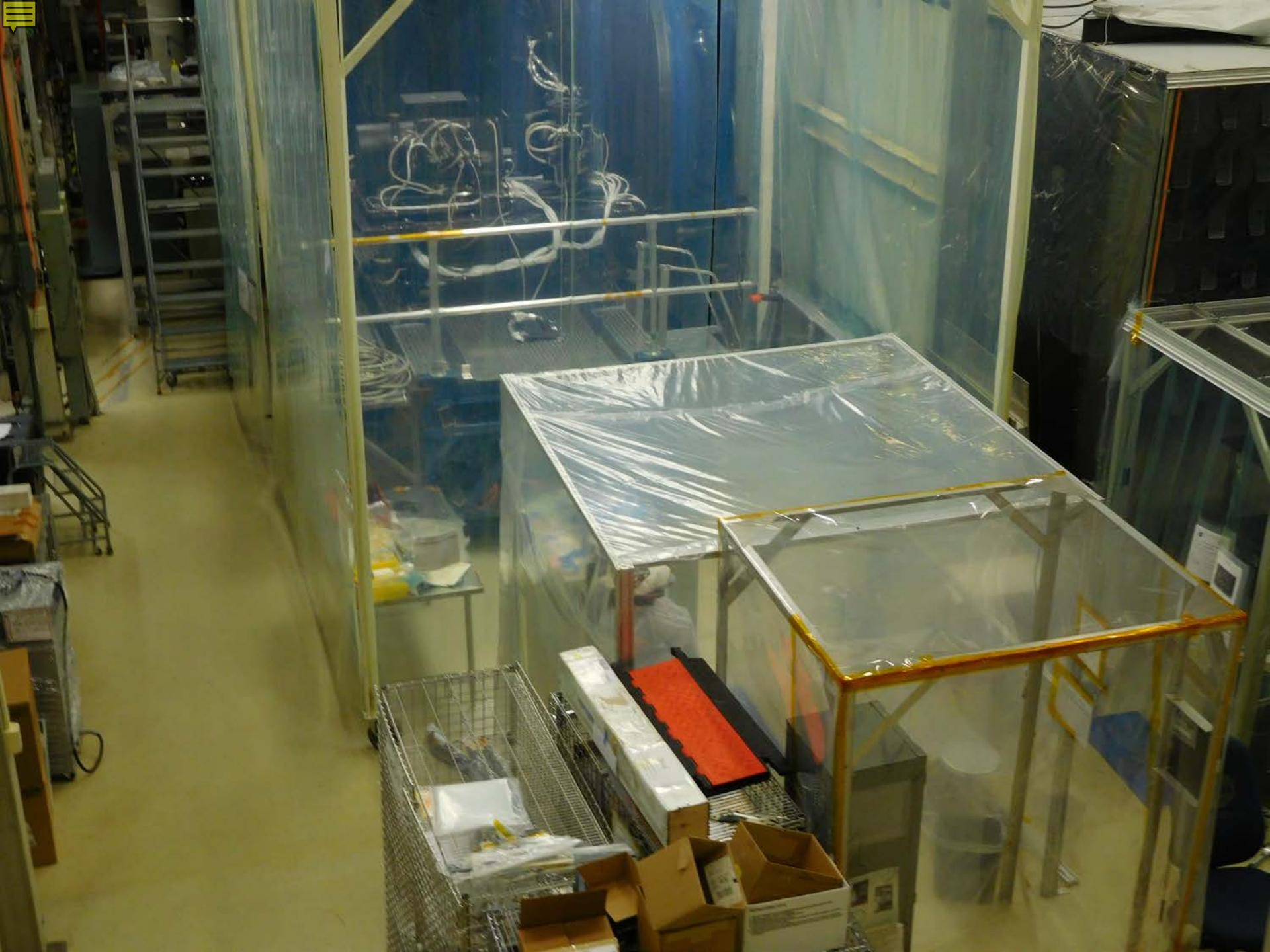
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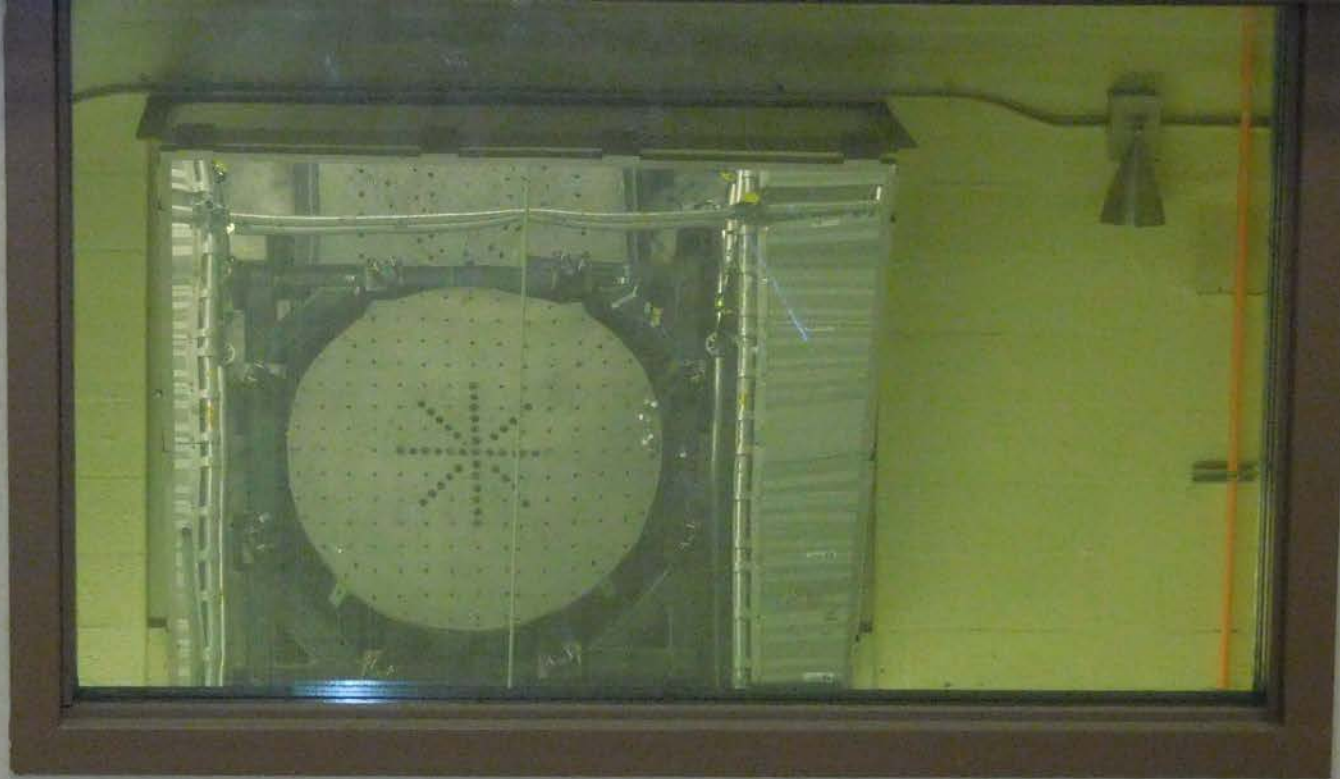


281

CAUTION
CHAMBER UNDER VACUUM
DO NOT LOCK INTO OR TOUCH MEMBERS
AT ANY TIME







VIBRATION EXCITER

35000 LBS FORCE
ARMATURE WEIGHT 35 LBS
FREQUENCY RANGE 5-2000 HZ

CAPABILITY

VERTICAL
HORIZONTAL







Integration Facility (SSDIF)

- ❖ This High Bay Cleanroom is a 1,161 m² (12,500 ft²), class 10,000 (ISO 7), horizontal laminar flow cleanroom.
- ❖ It is designed to support the integration and testing of two full-sized spacecraft simultaneously.
- ❖ Access to the cleanroom is through a 7.6 m x 12.2 m (25' x 40') overhead leaf door. Two 31,732 Kg (35 ton) cranes, with hook heights of 21.0 m (69') and 24.4 m (80'), provide lift and transport capabilities.
- ❖ A cable tray provides data cable access to the Automated Data Processing Room.
- ❖ A computer-based automatic control system monitors and controls environmental parameters on a 24-hour basis.
- ❖ Only approved personnel and materials are allowed



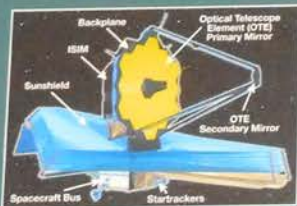




SPACE ENVIRONMENT SIMULATOR (SES) FACILITY 290

NASA GODDARD SPACE FLIGHT CENTER

DESCRIPTION



The SES is capable of achieving high vacuum while simulating a wide range of thermal conditions. Built in the early 1960s to perform thermal vacuum testing and outgassing of large test articles, the SES has had several major upgrades to keep it state-of-the-art. The latest upgrade was the addition of a 7.6 m (25 ft) diameter Helium Shroud to provide cryogenic (<20K) conditions to support projects such as the James Webb Space Telescope (JWST).

CHAMBER FEATURES

Nitrogen Shroud

- Gaseous Nitrogen (GN₂) capable: -100°C to +80°C (-148°F to +176°F)
- Liquid Nitrogen (LN₂) capable: -180°C (-292°F)

Contamination Monitors

- Four (4) TQCMs
- Four (4) CQCMs
- Residual gas analyzer (RGA)
- Cold finger (C/F)
- Scavenger plate (S/P)

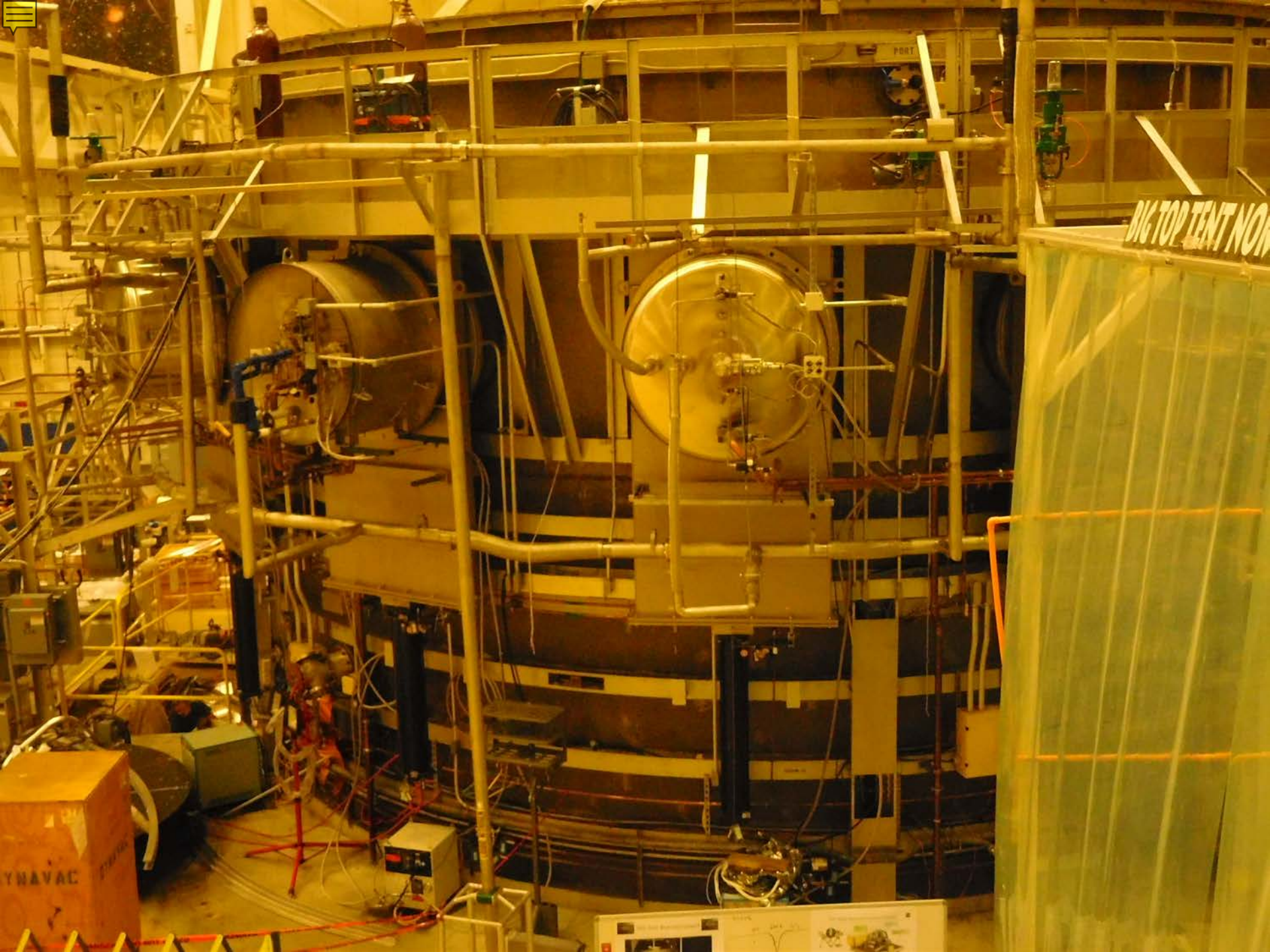
JWST Cryo-Vac Test Helium Volume Set-Up

- Integrated Science Instrument Module (ISIM)
- Includes the SES Integration Frame (SIF) for mounting the Surrogate Thermal Management System (STMS) and other He panels
- Four Science Instruments (SIs) within ISIM: Mid-Infrared Instrument (MIRI), Fine Guidance Sensor (FGS), Near Infrared Spectrograph (NIRSpec), Multi-Infrared Camera (MIRCam)

Helium Shroud

- Constructed to allow cryogenic vacuum test of JWST ISIM and Primary Mirror Backplane hardware that will operate at 35K and below
- Reconfigurable to provide two test volumes: 7.6 m (25 ft) dia x 4.6 m (15 ft) high and 7.6 m (25 ft) dia x 8.5 m (28 ft) high
- Helium refrigerator provides 1000W of cooling at 20K (-424°F)
- Helium refrigerator upgraded to be remotely operated and equipped with an uninterruptible power supply (UPS)



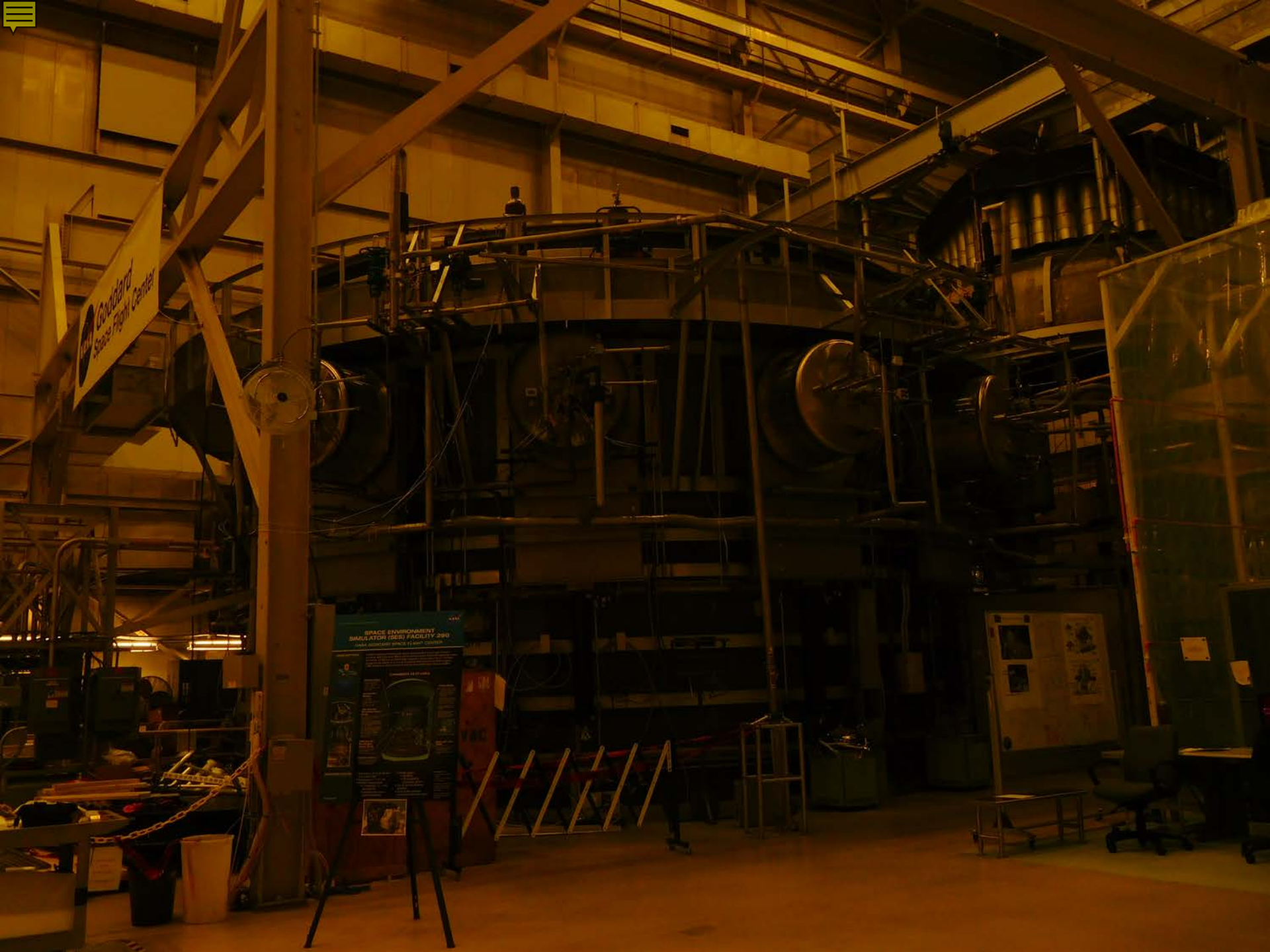


DIG TOP TENT NO

YNAVAC

Control panel with various dials and switches, including a prominent red emergency stop button.





Goddard
Space Flight Center

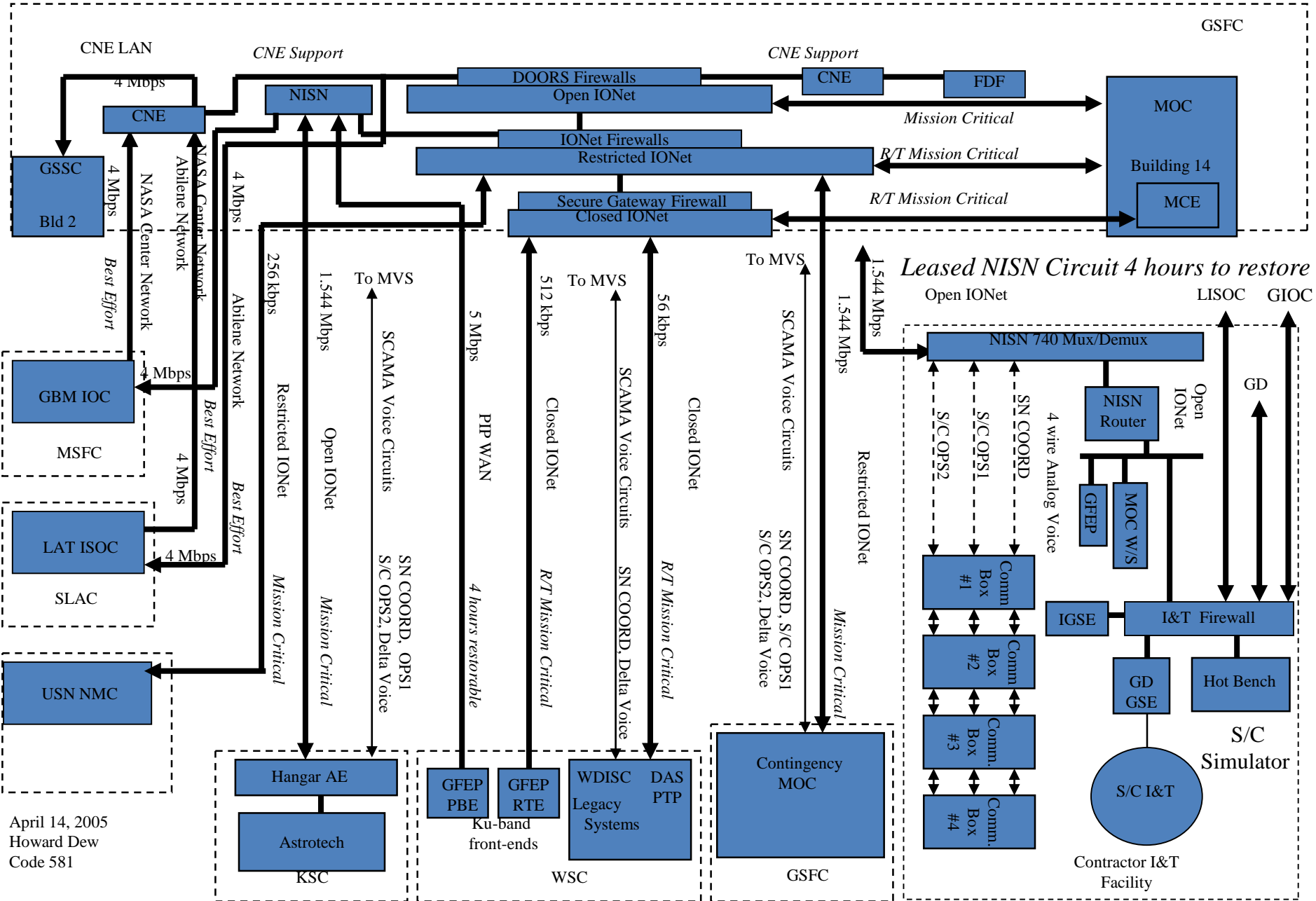
SPACE ENVIRONMENT
SIMULATOR (SES) FACILITY 200
NASA GODDARD SPACE FLIGHT CENTER



Whiteboard with diagrams and text, partially obscured by shadows.



Launch Site Testing



April 14, 2005
Howard Dew
Code 581

Spacecraft and Observatory Instrument Testing After Launch

- The Commissioning Plan developed by the scientists prior to development is used to test and validate each instrument
- This testing of the spacecraft subsystems takes place immediately after launch
- The first system to be deployed is the solar array and is of extreme importance because the spacecraft is being powered by one or more batteries which only lasts a finite number of hours
- All of the spacecraft subsystems are monitored by the MOC
- The observatory instrument voltages both high and low are brought up prior to the instrument(s) checking and calibration testing
- After the instruments are calibrated properly then the science operations begin
- This may take anywhere from one month to six months depending on the number of instruments and the size/complexity of the mission

Ongoing Support of the Satellite and Science Data Processing

- The MOC continues the support of the mission with the Flight Operations Team monitoring the spacecraft
- The SOC monitors each instrument and continues to receive the science data
- The SOC prepares the commands for each instrument which is sent to the CMS in concert with the MOC sending spacecraft commands to the CMS to develop a command load for the spacecraft
- The MOC then sends the command loads to the satellite for on-board processing
- Each scientist processes the data from their instrument and evaluates the results

Spacecraft Bus and Launch Vehicles

- **Spacecraft Bus**
 - This is built by a contractor company to the specifications to support the observatory
 - The delivery is made to the organization (NASA, ESA, etc) and is then goes through all of the testing prior to the mating of the observatory
 - After mating of the bus and observatory, testing goes into high gear – EMI, thermal vacuum, vibration and finally the SES
 - Delivery is then made to the launch site where testing is again done to ensure that no problems occurred during transport

- **Launch Vehicle**
 - There are many launch vehicles from small (Pegasus or Antares) to a medium size (delta) to the largest vehicles (Titan and the European Ariane 5 or 6)
 - They are supplied to the mission by the contractor company and are controlled by that company to launch
 - The spacecraft bus/observatory is then mated to the launch vehicle and many more tests are conducted to ensure that every subsystem is working properly

AND FINALLY LAUNCH DAY HAS ARRIVED
AFTER MANY YEARS OF SWEAT AND
DETERMINATION

EVERYONE'S FINGERS ARE CROSSED

THE LAUNCH IS CONTROLLED FROM THE
LAUNCH SITE WITH SUPPORT OF THE
LAUNCH VEHICLE CONTRACTOR

Launch Day – Falcon Heavy Rocket

<https://www.youtube.com/watch?v=IS9XcEEek48>

Conclusion and Issues

Conclusions

- The amount of testing and continual re-testing of all systems provides a good probability for mission success
- The cost of each mission depends on both on the size of the project but more importantly on the engineering requirements needed to support the science goals and to build the instrument suite

Issues

- The main issue is with the number of satellites already in orbit but the doubling of the new missions to an already overcrowded LEO and MEO
- There are over 1400 satellites in orbit presently
- The amount of orbital debris in orbit around the earth is expanding every year
- Estimation of 75 to 125 million pieces of debris from no bigger than a small chip to a non functional satellite still in orbit

Citations

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