UNIVERSITY OF CALIFORNIA, BERKELEY SPACE SCIENCES LABORATORY

Project Requirements Document
Document #: ICN-SYS-001
REVISION E

ICON Mission

CDRL: REQ-002
(L2 Mission Requirements Document)

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DOCUMENT REVISION RECORD

Rev.	Date	Description of Change
-	07/28/2013	Preliminary **DRAFT** Release
-	08/01/2013	Updated per Requirements TIM at Orbital
-	08/08/2013	Updated per Pointing WG, point both MIGHTI's at 90km
-	08/15/2013	Updated per PSET meeting discussion on Timing
-	08/20/2013	Updated per PSET meeting discussion on Alignment
-	08/21/2013	Added TBD/TBR List
-	9/10/2013	Updated target altitude, reflecting 575km trade
-	10/06/2013	Update reflecting flowdown to Payload Level 3
-	10/11/2013	Initial Release for SRR
A	10/14/2013	Revision A Review for SRR
B	11/04/2013	Revision B Changes per review and preSRR RFAs: - G-1, G-2: Changed downlink rate from 3.5Mbps to 3.4Mbps (rounding error, actual is 3.47Mbps) - G-3, G-4: Changed low rate downlink rate from 7kbps to 6.5kbps (rounding error, actual is 6.9kbps) - SC-3: Changed control from 3-axis to pitch and roll only per preSRR RFA #35 Revision provide to SRB for SRR
C	02/24/2014	Updated per Pointing WG, Revision of Section 3.2 and 3.3 Calibration and Pointing/Observing Requirements. Changed two G-7s to G-7a & G-7b; changed the two SBS-6s to SBS-6a & SBS 6b. Added page numbers and header information.
D	01/06/2015	1. Updated per SRB (B. Gibson) PDR comments 2. M-6 Launch Date changed from February 2017 to June 2017 3. M-13 Launch Mass Capability changed from 335kg to 343kg 4. O-2, O-4, O-6 Ferry, Launch Site & Facility changed from ETR to RTS 5. O-13 FUV Stellar roll changed from 50 degrees to 110 degrees 6. O-14 Observing Efficiency Removed (See L2-SCI-2a) 7. SC-1 Removed MIGHTI unit vector definition (now in payload alignment plan) 8. SC-7a MIGHTI knowledge changed from 3 m/s (3σ) to 3.3 m/s

		(3σ)
	01/09/2015 01/14/2015	9. SC-7b IVM knowledge changed from 3 m/s (3σ) to 4.5 m/s (3σ) 10. SC-14, G-1, G-7a TBR added to Data Volume per day and number of downlinks 11. SC-14 Require two days data storage instead of just 1 to allow for Ground Station downtime. 12. ICD-1 Removed reference to Payload to Instrument ICDs. This is derived at L3 Payload Requirements Document. 13. Removed SBS (Spacecraft Bus System) Requirements, contained in Orbital L3 Document 14. SC-14, G-1 Removed TBRs from Data Volume, pointed to Resource Allocation Document.G-7a Changed number of passes from 5 to between 5 and 7 downlink passes per day. Changed data requirements to replace "in xx% of all spacecraft attitudes" with "with xx% coverage" to be consistent with Mission Ops RFA response and L3 MOS requirements. No change to L3 S/C required.
E	03/17/2015	Revised SC-5a,SC-5b, SC-7a, SC-7b per CDR pointing budget updates Revised G-1 and G-2 from ">4.0 Mbps" to ">=4.0 Mbps"

TBD/TBR LIST

TBD	ORG	Plan to Close

Table of Contents

1.   Introduction

1.1 Purpose and Scope

This Level-2 Project Requirements Document (PRD) identifies the mission and programmatic Level-2 requirements for the development and operation of the ICON Mission. The Level-2 requirements are flowed down from the baseline Level-1 requirements, ICN-PM-007. The PRD specifies the requirement levied on the Project, and allocates those requirements to the systems that comprise the ICON mission as defined by the project architecture captured herein. These requirements include those that are externally negotiated as well as those that are derived or imposed internally by the Project. They specify the respective system's capabilities and constraints at the level of the Project's interaction with the main ICON systems, without specifying the implementation of the system internals, where possible. Once under configuration change control, these requirements represent the negotiated capabilities and constraints that are considered necessary to ensure a high probability of meeting the mission success criteria as captured in the Project Level 1 Requirements.

1.2 Change Control

Changes to the information and requirements contained in the Level-2 PRD are the responsibility of the ICON Project Systems Engineer (PSE) at the UCB. The PSE ensures that all the stated requirements will be fulfilled at the subsystem and system level. This document will be under version control at UCB and are subject to the approval authority of the Project Configuration Control Board (CCB). Any changes must be routed to the PSE who will obtain the necessary agreement from scientists and engineers before posting it as the official version.

1.3 Project Requirements Structure Overview

The ICON Requirement Document Tree is provided below assuming the following requirement levels:

- **Level 1 Requirements**: Fundamental and basic set of requirements levied by the Program or Headquarters on the Project. Level 1 requirements are sufficient to define the scope of scientific or technology validation objectives and describe the measurements required to achieve these objectives. Level 1 requirements also define success criteria for the baseline and threshold mission.
- **Level 2 Requirements**: PI Science and Project requirements levied on all mission segments (space, ground, and launch vehicle). PI and Project hold margin at this level to ensure Level 1 Requirements will be met without issue. Level 2 Requirements also include Mission Assurance Requirements, Environmental Test Requirements and technical resource allocations.
- **Level 3 Requirements**: Allocation of PI Science and Project requirements between mission elements (payload, spacecraft bus, ground data system, ground ops). For the payload, Level 3 cover required observables (altitude range, vertical resolution, precision, dynamic range, spatial sampling, etc). Level 3 Requirements for also include interface definitions (ICDs) between different elements.

- **Level 4 Requirements**: Subsystem and Instrument requirements. For Instruments, Level 4 Requirements include specific parameters (Exposure time, Pixel size, Etendue, QE, FOV, Transmission, etc).
- **Level 5 Requirements**: Component requirements. Level 4 Requirements cover all hardware and software components to be designed or procured, such as wheels, optics, gratings, and CCDs.

- **Reference Requirement Documents**: All ICON subsystems adhere to the mass, power and data budgets provided in the project-controlled resource allocation documents. All components adhere to interface requirements provided in their Interface Control Documents (ICDs) and environmental test and verification requirements provided in the ICON Environmental Requirements Document (ERD). Finally, to preserve the sensitivity of the optical instruments, it is critical that all elements of the ICON flight system comply with the ICON Contamination Control Plan (CCP).
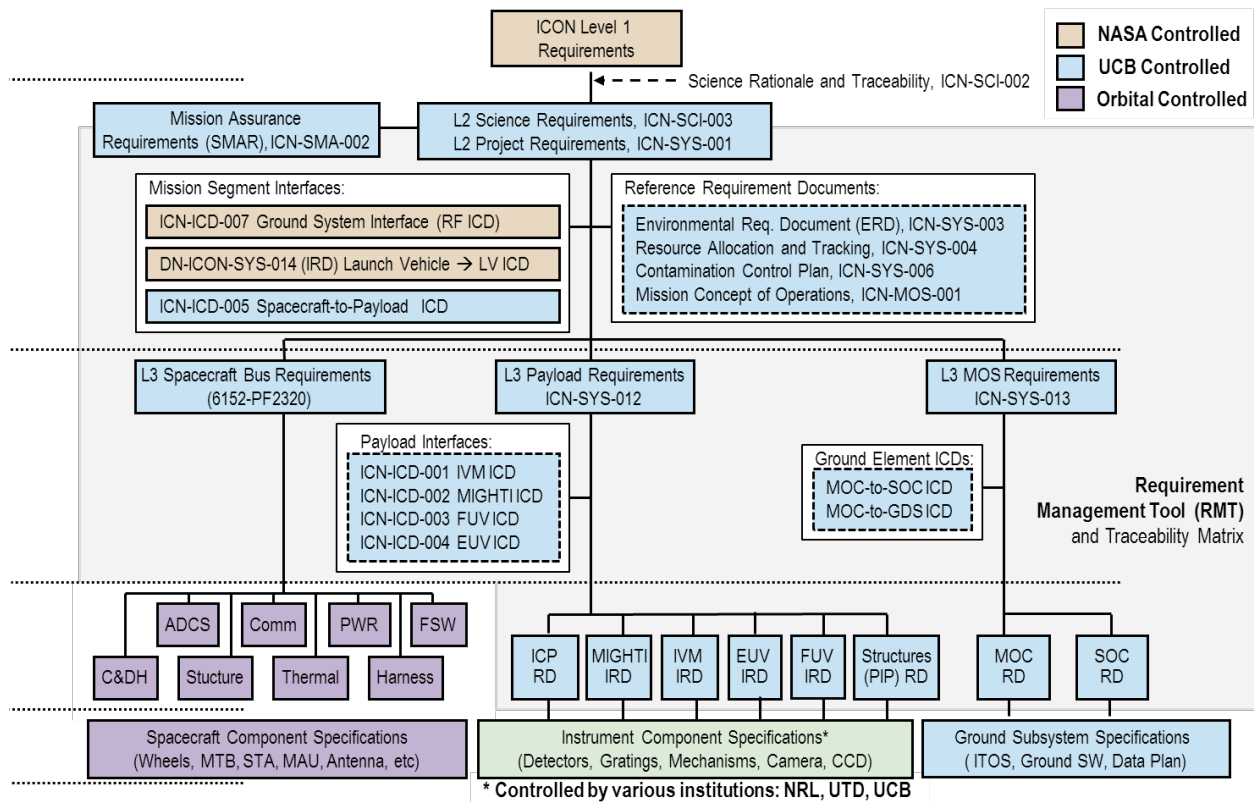

Table 1-1: Requirement Document Tree

1.4 Document Organization

Section 2 contains an overview of the project and defines the high level architecture of the spacecraft bus system.

Section 3 contains the project system requirements that are required to be met by the ICON Mission.

Section 4 covers interfaces.

Section 5 contains references to common requirements and external procedures, processes that must be followed by the project.

Section 6 was removed in Revision D. It originally provided the allocation of the L2 requirements to the Spacecraft Bus System. To avoid duplication, all requirements in this section were transferred over to the Orbital Spacecraft Requirements Document (6152-PF2320) with UCB approval on that document.

2. Project Architecture Overview

2.1 Science Objectives

The primary science objective for the ICON mission is to discover how winds and composition of the upper atmosphere drive the electric fields and chemical reactions that control Earth's ionosphere. The mission will resolve competing theories about the low-latitude ionospheric dynamo, and will explain how large-scale waves from the lower atmosphere can couple to the ionosphere and upper atmosphere. Understanding neutral-ion coupling in Earth's atmosphere has applications for solar and planetary atmospheres including Mars and Jupiter. ICON will be the first mission to simultaneously measure all the key parameters that both characterize and drive the ionosphere. It will remotely measure the neutral wind, temperature, composition, atmospheric and ionospheric density distributions as well as make in-situ measurements of the ion motion. ICON uses flight-tested science instruments in a low inclination orbit where the geometry magnetically links the in-situ and remote sensing measurements.

2.2 Summary Description of Project Architecture

The ICON Project is divided into 4 main systems: the Payload (P/L), the Spacecraft Bus System (S/C or SBS), the Ground System (GS) and the Launch System.

The ICON payload (P/L) will provide the function necessary, with support from the S/C, to meet the mission's science objectives outlined in the Project Level 1 requirements and further refined by the Science Requirements Document. The P/L consists of four scientific instruments, the Extreme Ultraviolet Imager (EUV), The Michelson Interferometer or Global High-resolution Thermospheric Imaging (MIGHTI) instrument, the Far Ultraviolet Imager (FUV), and two Ion Velocity Meters (IVMs) along with the Instrument Control Package (ICP), which controls the science instruments, commands and stores data from the instruments and is the payload interface to the spacecraft bus.

- EUV measures vertical airglow brightness profiles at 61.7 nm and 83.4 nm in an altitude range from 100-450 km at the Earth's limb.

- MIGHTI consists of two separate, identical channels, one forward-looking (fore) and one backward-looking (aft) channel that are mounted at 45° and 135° with respect to the velocity vector of the spacecraft. The MIGHTI measures neutral wind components utilizing the Doppler shift of 557.7 and 630.0 nm oxygen atomic emission lines at altitudes between 90-300 km at the Earth's limb. Combining the forward-looking observations with properly time shifted aft observations will allow reconstruction of the neutral wind vectors in the common viewing region.

- FUV measures the altitude distribution of 135.6 nm and 155 nm dayglow up to 450 km limb altitude and the 2-dimensional 135.6 nm nightglow distribution.

- IVM consists of two identical instruments, facing fore and aft, which measure the ion concentration and ion drift direction vector at the spacecraft location. These quantities can be mapped down along the local magnetic field line to be combined with the remote measurements made at the limb by all other science instruments.

The ICON spacecraft bus (S/C) is three-axis stabilized to provide ram facing and nadir pointing orientation for uninterrupted limb observations by the remote sensing instruments. The S/C is supplied by Orbital Science Corporation (Orbital) and provide the necessary functions for all mission phases including launch and on-orbit operations, including:

- providing structural support of the Instrument Payload and SC subsystem components for all loading environments including launch;

- autonomously maintaining the proper thermal operating environments for the spacecraft components on-orbit;

- providing electrical power and power control functions for all Observatory electronic equipment;

- providing the capability to communicate with the ground for both telemetry downlink and command uplink; and

- providing three-axis stabilized attitude control on-orbit, specific pointing performance capabilities, momentum dumping, and maneuvering for the Observatory.

The ICON Observatory is composed of the integrated S/C and P/L systems. The Observatory will be integrated to the launch system which is responsible for placing it into its operational orbit at 575 km altitude with 27° inclination, optimized for low latitude observations of the thermosphere/ionosphere system. The Observatory is operated by the GS.

The Ground System (GS) is composed of the Mission Operations Center (MOC), ground stations and other telemetry assets, the Science Operations Center (SOC), and science data analysis. The GS provides the functionality necessary to functionally communicate with the S/C, to plan the desired events and command the observatory, to receive and interpret data from the observatory, and to analyze and to submit the returned science and engineering data for archival. The MOC consists of the organizations and teams required to develop and conduct flight operations, the corresponding ground data system elements, and tracking networks & resources. The SOC includes the science team and instrument support personnel. The SOC provides the algorithms and instrument models required to validate the instrument design and interpret the science data from the instrument. The SOC is also responsible for observation planning and provides those plans to the MOC.

The launch system (LS) consists of the launch vehicle, ground and aircraft components of the service that delivers the Observatory to the desired operational orbit. The LS includes any mission specific hardware that does not remain attached to the Observatory.

2.3 Summary Description of Project Organization

The Principal Investigator, Dr. Thomas Immel, at UCB, leads a hardware development team consisting of UCB, the University of Texas at Dallas (UTD), Naval Research Laboratory (NRL) and Orbital Sciences Corporation (Orbital). Science support and data analysis will be provided by UCB, University of Illinois (UI), NRL, UTD, and the University of Colorado (CU).

UCB provides the project management and systems engineering, EUV and FUV imager development, ICP development payload and science operations, and the ground system MOC and SOC. NRL provides the MIGHTI instrument. UTD provides the IVM. SDL provides payload level integration and test facilities. Orbital provides the S/C, observatory integration and test, launch vehicle integration, and launch support.

3. Requirements on the Project System

This section contains the requirements that apply to the ICON mission. The majority of these requirements are derived from the following sources:
- Mission Level 1 Requirements
- Project Science Requirements Document

The remaining requirements are self-derived project architectural and design requirements imposed by the Project.

3.1 Project Architecture Requirements

3.1.1 Orbit Parameters

M-1 Low Earth Orbit
All ICON elements shall be designed for a near-circular orbit with a targeted altitude of 575 km at beginning of life (BOL).

Context: Altitude is defined with respect to the spherical Earth.

Rationale: The ICON low Earth orbit allows for observations in the low-latitude region with the capability of probing all local time and latitude combinations within less than 30 days (Science Level 2 Requirement). Orbit altitude was chosen so that the magnetic footprint will frequently (twice per orbit) fall in the vicinity of the remote sensing measurements to yield an extensive statistical database of observations while still allowing for sufficient in-situ measurements by IVM and dependent upon the local O+ number density. In addition, the orbit needs to be high enough to survive 2 years (Level 1 requirement and low enough to meet orbital debris requirements Error in targeted altitude is consistent with the capability of all Option B Launch Vehicles.

M-2 Orbit Inclination
All ICON elements shall be designed for an orbit with a targeted BOL inclination of 27 degrees.

Rationale: ICON makes observations of the properties of the low latitude thermosphere and ionosphere from an orbit of inclination between 24 and 28.5, with a sampling distance of 500 km great circle or less (Science Level 2 Requirement). Low inclination concentrates observations in equatorial ionosphere, observing all local times w/ each orbit. Also provides total coverage of all geographic and local time combinations with rapid precession of the orbit plane. Inclination is sufficient for science (<28.5 deg inclination) and consistent with the required mass capability all Option B Launch Vehicles.

M-3   EOL Orbit Altitude

The ICON Observatory shall be designed for an End of Life (EOL) orbit with a minimum altitude of 450 km.

Context: Accounts for 3 sigma launch dispersions with 2 sigma solar flux and a 550km launch.

Rationale: Set a reasonable EOL deck to avoid driving the spacecraft bus GNC design. Atmospheric drag starts to dominate the attitude disturbances below this altitude.

3.1.2   Launch Vehicle Parameters

M-4   Launch Vehicle

The ICON Observatory shall be designed to be compatible with the Explorer 2011 ELV Launch Service Class Option B until MPDR.

Rationale: Requirement of Explorers AO.

M-5   LV Insertion Errors

ICON shall be designed for orbit injection errors not to exceed: +/- 0.15 inclination error, +/-10 km insertion apse error, +/- 80 km non-insertion apse error (all errors are 3 sigma).

Context: Assumes Pegasus worst case insertion errors.

Rationale: The orbit dispersions are set to ensure that the optimal science observations are maintained in all nominal launch conditions with the emphasis on a circular orbit.

3.1.3   Launch Date and Mission Lifetime Requirements

M-6   Launch Date

ICON shall be designed, developed, integrated and tested by the planned launch date of June 2017 with a launch no later than December 31, 2018 with 1 month/year reserve.

Rationale: Explorer Program Requirement - Schedule Cost Cap and constraint specified in the Level 1 Requirements. Funding limitations for NET and AO req't on NLT dates. Baseline date is during declining phase of solar cycle as desired for Q3.

M-7   Design Lifetime

All elements of the ICON Observatory shall be designed for at least26 month mission (1 month checkout + 2 year science mission + 1 month decommissioning).

Rationale: Flight system must enable full science observations sufficient to achieve baseline science requirements with some margin.

M-8   Extended Mission Capability

The ICON Observatory shall not contain consumables other than component lifetime.

Rationale: Allows for an extended mission.

M-9   Orbital Debris Requirement

ICON shall comply with NASA Policy for Limiting Orbital Debris Generation NSS 1740.14 and NPR 8715.6 regarding limits on the generation of debris.

Rationale: Required for launch approval.

M-10   Lifetime Upper Limit

ICON shall be designed so that the observatory does not remain in orbit longer than 27 years.

Context: The mission orbit shall be designed so that the observatory has a minimum of an 80% probability of remaining above the End of Life altitude for the project's minimum design life assuming a 95% atmosphere.

Rationale: Driven by orbital debris requirements.

3.1.4   Resource Allocations

M-13   Observatory Mass

The ICON Observatory including any launch vehicle isolation system, shall not exceed the Launch Vehicle capability of the Explorer 2010 ELV Launch Service Class Option B (design assumption is 343 kg including margin).

Context: 10kg for Pegasus Soft-ride is booked within the 343kg, performance quote for a 575km orbit.

Rationale: Design assumption derived by the launch vehicle capability to the baseline orbit.

M-14   Observatory Power

The ICON Observatory shall provide all necessary power for the mission at EOL.

Rationale: Derived from the maximum SA area.

3.2 Operations Requirements by Mission Phase

3.2.1   Pre-launch Phase Requirements

The pre-launch phase begins at approximately 36 days before launch and extends through the actual release and ignition of the launch vehicle.

O-1   LV Integration Site

The ICON Mission shall be designed for observatory launch preparations and LV integration to occur at Western Test Range.

Context: Will need to comply with all applicable range safety requirements for WTR and RTS.

Rationale: This requirement is driven by the need to minimize the cost of launch vehicle integration operations.

O-2   LV Ferry Flight

The ICON Observatory shall be designed to support 3 ferry flights between the LV Western Test Range to the Reagan Test Site (RTS).

Context: Assumes Pegasus Launch. Once the Observatory is integrated to the Pegasus and mated with the Modified L-1011, it is transported to Kwajalein RTS for launch.

Rationale: Need to plan for ferry flight to the RTS and a return flight if any problems are found prior to launch. All work on the Observatory will happen at WTR.

O-3   Observatory monitoring during Ferry and Captive Carry flights

The ICON Mission shall provide telemetry from the Observatory throughout the ferry flight.

Rationale: For H&S the Observatory must be monitored during the ferry flight from WTR to RTS.

O-4   Launch Site

The ICON Observatory shall launch from the Reagan Test Site (RTS) Launch Site.

Context: Will need to comply with all applicable range safety requirements as defined by NASA-STD-8719.24.

Rationale: No auxiliary propulsion is required to get into desired inclination from this launch site.

O-5   Instrument Checkout after Integration

The ICON Observatory shall be designed to allow an electronics level checkout of the payload system after integrated with the spacecraft bus system and the launch vehicle.

Context: Launch Vehicle includes L-1011

Rationale: Need to be able to verify that the instrument is still functioning following integration to the spacecraft bus and launch vehicle.

O-6   No Cleanroom at RTS

The ICON Observatory shall not require any clean room processing facilities upon arrival at the Reagan Test Site (RTS).

Context: There will be no clean room, or any other facility where we can take off the fairing and do any significant hands-on work with the spacecraft. If that is needed, then we have to fly back to the west coast.

3.2.2   Launch & Early Orbit Phase Requirements

The Launch and Early Orbit (L&EO) phase begins with the ignition of the launch vehicle.

O-7   Launch Vehicle Telemetry

The launch vehicle shall provide telemetry from the Observatory to the MOC during the launch sequence until the Observatory is separated from the launch vehicle.

Rationale: Assuming Pegasus launch sequence includes 1-hour captive carry and launch from L-1011. The one-hour captive carry portion of the launch operations provides the team with the final check-out prior to launch. Allows the ground to monitor the health of the observatory during launch.

O-8   Communications at Separation

ICON shall support communications with the Observatory within 60 seconds of separation from the launch vehicle and maintain communications until the observatory has obtained a power positive and thermally safe attitude.

Rationale: Ensure communications, to the extent possible, during the initial acquisition critical event. Observatory cannot turn on the transmitter any sooner to avoid interfering with the launch vehicle during its avoidance and deorbit maneuvers. Would like to turn on transmitter as soon as possible after launch to monitor health and status of spacecraft.

O-9   Autonomous Safe Acquisition State

The ICON Observatory shall obtain a power positive and thermally safe state without interaction with the mission operation system.

Rationale: In the event of a communications outage the spacecraft should reach a survivable state and be able to maintain it until the ground can establish initial contact.

3.2.3   Checkout Phase Requirements

The P/L checkout and calibration phase of the mission begins with the spacecraft team declaring that the spacecraft bus is in a state that will support the instrument covers open and power on. This phase will be concluded once the science and spacecraft teams have determined that the observatory is capable of supporting science operations.

O-10   Observatory Checkout
The ICON mission shall support commencement of the science operations within 30 days from launch.

Rationale: Driven by 2 year science mission and lifetime requirements.

O-11   S/C Bus Checkout
ICON shall be capable of performing checkout of the S/C bus functions in less than 10 days from LV separation.

Rationale: Driven by the mission plan and the need to be able to support commencement of science operations within 30 days of launch.

O-12   P/L Checkout
ICON shall be capable of performing checkout of the P/L in less than 20 days after S/C checkout.

Rationale: Driven by the mission plan and the need to be able to support commencement of science operations within 30 days of launch. This is sufficient time to allow for Instrument outgassing.

3.2.4   Payload Calibration Requirements

O-13   Payload Calibration
ICON shall support the calibration activities provided in the ICON Mission Operations Plan.

Context: The Mission Operations Plan provides the nominal timing and duration of the calibration activities planned for the ICON Mission.

O-13a MIGHTI On-Orbit Calibration
ICON shall be capable of pointing the MIGHTI boresight to within 1 degree (3-sigma) of a select star with a stability <21.6 arcsecs (3σ in all axes) for 60 seconds as described in ICN-OPS-001.

Context: This calibration requirement is driven by MIGHTI's pointing requirements, SC-7a, during nominal pointing modes. Additionally, drives the spacecraft to have a stable inertial pointing mode.

Rationale: To obtain the pointing knowledge requirement, MIGHTI requires an on-orbit calibration to zero static errors due to launch shift or other.

O-13b MIGHTI Zero-Wind Calibration
ICON shall be capable of pointing the bottom mid-point of one MIGHTI FOV at 90 +/-2.5km tangent point altitude for 60 seconds in the ram direction to within 1 degree, then maneuver 180° in <480 seconds (slew and settle) to point that same channel in the wake direction, as described in ICN-OPS-001.

Context: MIGHTI zero-wind calibration will occur about twice a month. This requirement does not drive SC capability beyond what is needed for the conjugate slew. The pointing knowledge during the zero-wind calibration holding periods is the same as for nominal pointing and conjugate operation.

Rationale: Required so the 'at zero' Doppler shift fringe position can be determined. The control in yaw angle determines how well the measurements overlap and if fairly loose since the tangent point locations are significantly different for different altitudes. The knowledge in yaw is driven by the subtraction of the S/C velocity, but (different from the conjugate slew) the relevant MIGHTI FOV is aligned with the S/C velocity, so that the S/C velocity component along with the MIGHTI FOV is not as sensitive to the yaw angle. However, for simplicity, it is chosen to be equivalent to the knowledge needed for conjugate slew. The two measurements should be made within 10 minutes of each other.

O-13c FUV Stellar Calibration
ICON shall be capable of rolling the observatory from LVLH up to 110 degrees with an accuracy of +/- 1 degrees so the FUV boresight "sweeps" across a select star field as described in ICN-OPS-001.

Context: FUV Stellar Calibration will happen approximately once a month during eclipse for ~ 10 minutes.

Rationale: Required so FUV's photometric response can be calibrated and the TDI algorithm can be verified.

O-13d EUV/FUV Nadir Calibration
ICON shall be capable of pointing the EUV and FUV boresights to within +/-1 degree (3-axis, 3 sigma) of nadir with a stability of 0.1 degrees over 12 seconds as described in ICN-OPS-001.

Context: EUV/FUV Nadir Calibration will occur once a month at the beginning of the mission for the first 6 months and then scheduled as needed.

Rationale: Required for flatfield calibration so the responsivity across the detector can be calibrated. The EUV and FUV boresights will be pointed at nadir separately since they have different elevation angles.

O-13e EUV Calibration
ICON shall be capable of repetitively viewing the moon (each lunar cycle) and sweep in yaw across the EUV FOV at 7 different pitch angles and rate as defined in the Concept of Operations, ICN-OPS-001.

Context: EUV Calibration drives on-board SC lunar mode, EUV instrument calibration mode, and on-the-ground mission operations planning to determine appropriate slew rate.

Rationale: Required so the EUV photometric response can be calibrated.

3.2.5 Science Operation Phase Requirements

The science operations mission phase begins 30-days after launch, once all spacecraft-bus and payload checkout and instrument calibration is complete. This phase will end at the start of the decommissioning phase.

O-15 Conjugate Slew Sequence

The ICON Observatory shall be capable of performing a sequence of four 90° yaw slew maneuvers each one within 150 seconds (slew and settle) followed by 60 seconds of observing time during which time the MIGHTI pointing and knowledge requirements are met (i.e. bottom mid-point of the MIGHTI FOV pointed at 90 +/- 2.5km and known to within 1.5km with a velocity subtraction error of less than 3 m/s).

Rationale: Driven by the need to meet the requirement to observe the horizontal neutral winds both north and south of the orbit track. The timing is set to complete the entire sequence of maneuvers and operations within 15 minutes of a magnetic dip equator crossing. (L2-SCI-9c).

O-16 Conjugate Operation

The ICON Observatory shall perform the Conjugate Operation <2 times/day, >2 weeks out of every month at locations between 0900 and 1500 Local Time (LT) when the orbit and magnetic field geometry are optimal.

Rationale: Driven by the need to meet the Level 2 requirement for conjugate slews, but need to restrict the number of times the operation occurs to constrain the SC worst-case power profile.

O-17 Constraint on Number of Slews

The ICON Observatory shall be capable of performing up to one maneuver (Conjugate, Zero-Wind, Calibration) per orbit and no more than two maneuvers per day.

Rationale: Restriction also required to constrain the worst case power profile.

3.2.6 Decommissioning Phase Requirements

This mission phase begins at EOM – 1 month to EOM (nominally L + 25 months).

O-18 Decommissioned State

The ICON Observatory shall be designed to be commanded to a decommissioned state following the end of its mission.

Context: The decommissioned state is defined as a state where the observatory the transmitter powered off and unable to be turned on without a ground command and the batteries have been fully discharged with and not able to significantly charge.

Rationale: Place the observatory in a state that will not interfere with future missions: transmitter turned off to free up the frequency and battery discharged to minimize to possibility of battery rupture/explosion that causes orbital debris.

O-19   Short Decommissioning Timeline
The ICON Observatory shall be placed in a decommissioned state within 30 days of the decision to terminate mission operations.

Rationale: Minimize the cost of the decommissioning effort.

3.3 Observatory Operability Requirements

The following requirements will outline the requirements on the observatory necessary to allow efficient operations of the system during all phases of the mission. All requirements are defined using the following coordinate system definitions, as provided in DN-ICON-SYS-016 ICON Coordinate System & Timing Definition.

Payload Coordinate System (PL-frame) Definition:
   Origin: Located in the plane of the PIP top facesheet directly above the geometric center of the launch vehicle attachment bolt circle.
   +X_{PL}: Parallel to the line connecting SMR1 and SMR2, with the positive sense in the direction of the IVM instrument.
   +Y_{PL}: Parallel to the line transiting through SMR3 that is orthogonal to the line connecting SMR1 and SMR2. Positive sense is in the direction of the solar array drive assembly.
   +Z_{PL}: Completes the right-handed orthogonal triad.

Observatory Coordinate System (Obs-frame) Definition:
   Origin: At the geometric center of the launch vehicle attachment bolt circle in the Observatory-to-launch vehicle interface plane
   +X_{OBS}: Completes the right-handed orthogonal triad.
   +Y_{OBS}: Parallel to the vector between the origin and the center of the launch vehicle attachment bolt hole on the spacecraft aft ring closest to the midline of the spacecraft panel containing the solar array drive assembly.
   +Z_{OBS}: Normal to the Observatory-to-launch vehicle interface plane, with positive sense from the interface plane towards the payload interface plate (PIP).

The PL-frame is *nominally* parallel with the Obs-frame. In reality, there will be small differences in alignment due to due to mechanical tolerances and on-orbit distortions.
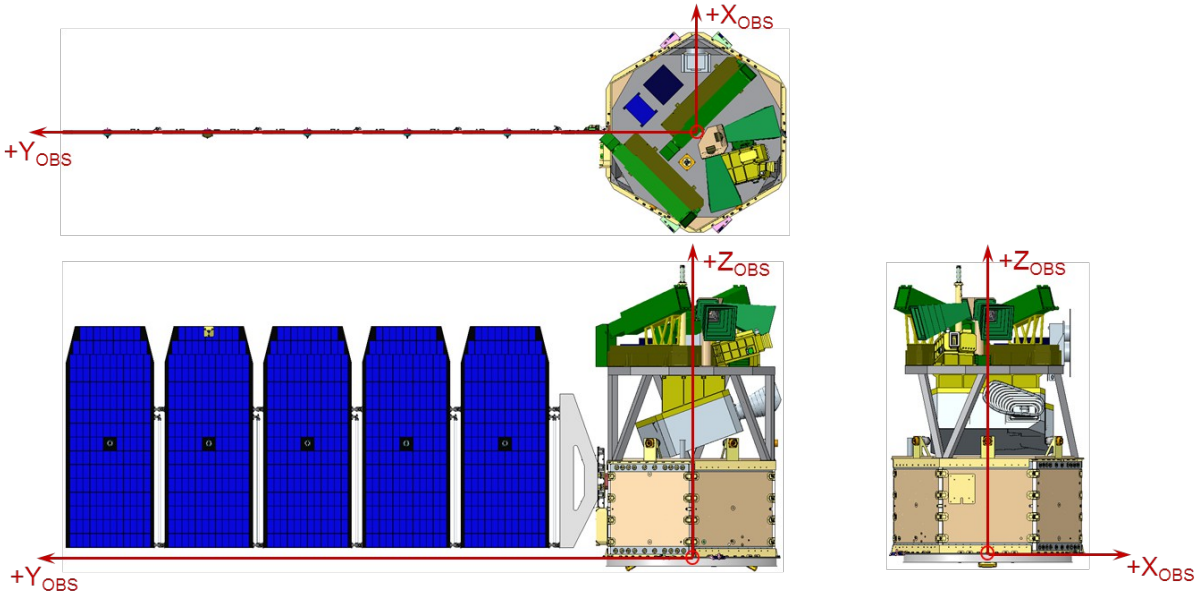
Body Coordinate System (B-frame) Definition:

    Origin: The center of mass of the Observatory, which will change depending on the configuration of the Observatory.

    $+X_B$: Defined by the Flight Software parameters for the ADCS sensors. By deliberate design of the software parameters, $X_B = X_{PL.}$

    $+Y_B$: Defined by the Flight Software parameters for the ADCS sensors. By deliberate design of the software parameters, $Y_B = Y_{PL.}$

    $+Z_B$: Defined by the Flight Software parameters for the ADCS sensors. By deliberate design of the software parameters, $Z_B = Z_{PL.}$

Local Vertical, Local Horizontal (LVLH) Coordinate System Definition:

    Origin: Observatory coordinate system origin

    $+Z_{LVLH}$: Points along the nadir vector

    $+Y_{LVLH}$: Points along negative orbit normal

    $+X_{LVLH}$: Completes the right-handed coordinate frame and points toward the direction of motion

$+X_{LVLH}$ will NOT remain pointed along the velocity vector in an elliptical orbit

ICON Observatory axes are aligned with LVLH axes in nominal pointing mode. Roll/Pitch adjustments used to point MIGHTI FOV bottom at 90 km grazing altitude.

- **Roll** is defined to be a rotation around the $+X_B$ axis, with positive sense per the right-hand rule.
- **Pitch** is defined to be a rotation around the $+Y_B$ axis, with positive sense per the right-hand rule.
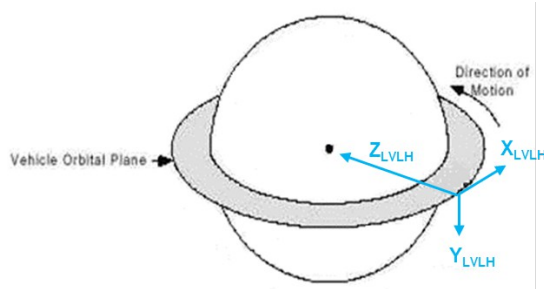
LVLH Coordinate System
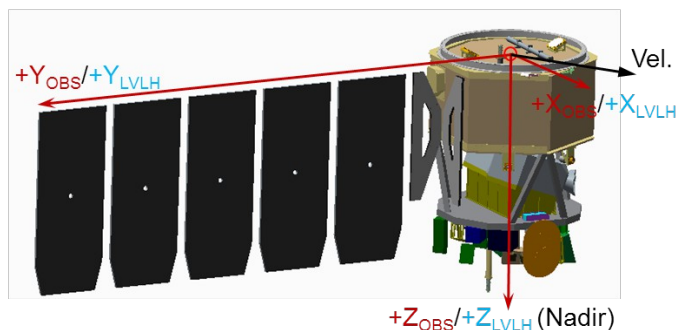
Relationship Between Obs. & LVLH coordinate systems for an elliptical orbit (excluding MIGHTI pointing roll/pitch adjustments)

J2000 Earth-Centered Inertial Coordinate System Definition:
Origin: Earth center of mass
Earth-centered inertial frame defined with Earth's mean equator and equinox at 12:00
Terrestrial time on 1 January 2000.

- $+X_{J2}$: Aligned with mean vernal equinox of epoch

- $+Z_{J2}$: Aligned with Earth's spin axis

- $+Y_{J2}$: Completes right-handed coordinate frame by rotating 90 deg East from the $+X_{J2}$ axis about the celestial equator

Observatory attitude is reported as an Observatory J2000 ECI to body axes quaternion. MIGHTI alignment calibration will use a MIGHTI to J2000 ECI axes quaternion compared with the Observatory attitude quaternion to determine alignment to Observatory body axes.
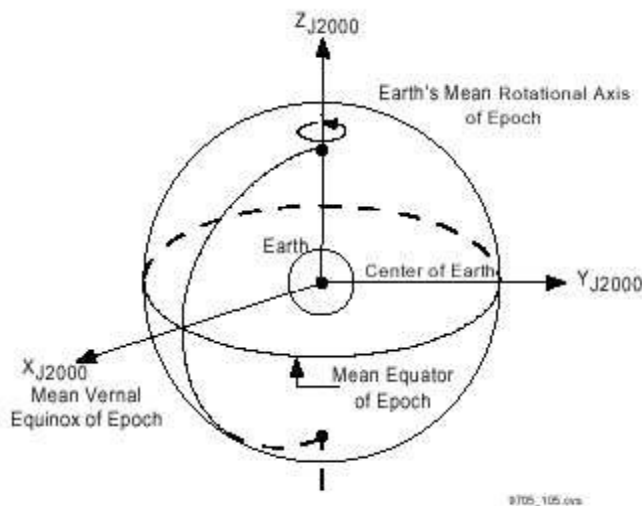
3.3.1 Pointing/Observing Requirements

SC-1 Point MIGHTI FOV
During nominal operations, the S/C shall point the MIGHTI Fields of View at a tangent height of 90km ± 2.5 km (3σ) above the Earth's reference ellipsoid (WGS84), symmetric about the LVLH-Y-axis (toward the northern hemisphere).

Context: The MIGHTI FOVs are defined by unit vectors in the payload alignment plan (ICN-SYS-021) and correspond to the center point on the bottom of MIGHTI's FOV. In a highly elliptical orbit (3-sigma LV errors), the left and right edges of the MIGHTI FOV can vary as much as 5.5km in altitude. In this case, MIGHTI will recover the altitudes in the horizontal direction in post processing given imaging information in this direction.

Context: Note that by meeting this pointing requirement, the S/C meets the pointing stability requirement over the longest integration time, 60 seconds.

Rationale: The science requirement driving the pointing requirement for the MIGHTI instrument during normal science mode (day and night) demands that both MIGHTI fields of view observe the range of tangent points on the limb ranging from 90 km to 105 km in height, with 5 km altitude resolution. A deviation of half that altitude variation between the MIGHTI A and MIGHTI B fields of view is acceptable.

SC-2   IVM Pointing

The ICON Observatory shall fly such that the Ram axis lies within +/-2.5 degrees of the velocity vector at all times.

Context: Observatory pointing during nominal operations is constrained by MIGHTI Fore and Aft Pointing and the requirement to point IVM in the Ram direction.

Rationale: Required by IVM to ensure Ram is in sensor angle of acceptance at all times and the offset between the sensor look direction and the satellite velocity are constrained..

SC-3   EUV Pointing Control

During nominal operations, the ICON Observatory shall be capable of pointing the horizontal extremes of the EUV FOV bottom within a tangent height of 10 km (3σ) of each other.

Context: Observatory pointing accuracy is driven by MIGHTI and pitch restriction is driven by FUV. See pointing budget for other instrument requirements, which are looser.

Rationale: The science requirement driving the pointing requirement for the EUV instrument demands a 100-450 km tangent height FOV with a 20 km vertical resolution. This drives the pointing control to half the vertical resolution between the horizontal extremes of the EUV FOV bottom.

SC-4   FUV Pointing Control

During nominal operations, the ICON Observatory shall point the horizontal extremes of the FUV FOV midpoint within a tangent height of 2 km (3σ) of each other.

 Context: Observatory pointing accuracy is driven by MIGHTI and pitch restriction is driven by FUV. See pointing budget for other instrument requirements, which are looser.

Rationale: The science requirement driving the pointing requirement for the FUV instrument demands a 0-450 km tangent height FOV with an approximate 4 km science pixel resolution. This drives the pointing control to half the vertical resolution between the horizontal extremes of the FUV FOV midpoint.

SC-5a MIGHTI Pointing Knowledge

The ICON Observatory pointing knowledge of the MIGHTI instrument bottom vector boresight, relative to LVLH frame of reference, shall be known within a tangent height of 1.85 km (3σ).

Context: The MIGHTI pointing knowledge is driven by the subtraction of S/C velocity from the measured line of sight velocities, not the altitude resolution.

Rationale: From the MIGHTI error budget, the requirement to measure the wind vector <8.7m/s demands the error due to pointing uncertainties be <616m (1-sigma) or <1.85km (3-sigma) in tangent point altitude and <1.5m/s (1-sigma) or <4.5m/s (3-sigma) of S/C velocity contribution to retrieve wind velocity.

SC-5b FUV Pointing Knowledge

The ICON Observatory pointing knowledge of the FUV instrument boresight, relative to the LVLH frame of reference, shall be known within a tangent height of 9.15 km (3σ).

Rationale: The pointing knowledge is driven by the FUV resolution element size

SC-5c EUV Pointing Knowledge

The ICON Observatory pointing knowledge of the EUV instrument boresight, relative to the LVLH frame of reference, shall be known within a tangent height of 10 km (3σ).

Rationale: The pointing knowledge is driven by the EUV resolution element size

SC-6a FUV Pointing Stability

The ICON Observatory pointing stability of the FUV instrument boresight, relative to LVLH frame of reference, shall be stable within a tangent height of 2 km (3σ) over at least 12 seconds.

Rationale: The observatory pointing stability limits the altitude change to <2km of the FUV when the steering mirror is at 30 degrees. It also limits the difference from the left to right edge of the FUV field of view to better than half the required 4km vertical resolution.   of the FUV pointing during one exposure of 12 seconds.

SC-6b EUV Pointing Stability

The ICON Observatory pointing stability of the EUV instrument boresight, relative to LVLH frame of reference, shall be stable within a tangent height of 10 km (3σ) over at least 12 seconds.

Context: S/C pointing stability is driven by EUV. See pointing budget for other instrument requirements, which are looser.

SC-7a MIGHTI Velocity Subtraction Error

The ICON Observatory shall provide knowledge of the velocity vector component in the MIGHTI boresight direction to within 4 m/s (3σ). This is allocated as 0.1 m/s velocity magnitude knowledge and 4 m/s knowledge error due to pointing knowledge error.

Rationale: The Observatory velocity knowledge is driven by MIGHTI and shall be within 0.1 m/s (3σ). Both MIGHTI and IVM require subtraction of S/C velocity from the measured line of sight velocities. The velocity subtraction error pointing knowledge is driven by MIGHTI. The S/C velocity subtraction shall contribute no more than a 4 m/s uncertainty (3 sigma) to the line of sight wind velocity due to MIGHTI pointing knowledge error.

SC-7b IVM Velocity Subtraction Error

The ICON Observatory velocity shall provide knowledge of the velocity vector component in the IVM boresight direction by providing velocity magnitude knowledge to within 3 m/s (3σ) and relative pointing knowledge of the velocity vector and IVM boresight to within 9.5 m/s (3σ).

Context: The S/C velocity knowledge is driven by MIGHTI. See pointing budget for other instrument requirements, which are looser.

Rationale: Both MIGHTI and IVM require subtraction of the S/C velocity from the measured line of sight velocities. The velocity subtraction error velocity knowledge is driven by the science requirement to measure cross-orbit-track ion velocity components of the local plasma within 9.5 m/s when subtracting the S/C velocity. Pointing knowledge, S/C velocity error, pointing offset, and mounting offset all equate to approximately 1.5 m/s additional error. The S/C velocity subtraction shall contribute no more than a 3 m/s uncertainty (3σ) to the IVM ion velocity measurement pointing knowledge error.

SC-8 Position Knowledge

The ICON Observatory position shall be known to an accuracy of <2 km in all directions.

SC-9 Pointing and Position Information

The ICON Observatory shall be capable of reporting attitude, position and velocity information at a rate greater than or equal to 1 Hz (3-axis, 3 sigma), both on-board and on-the-ground.

Rationale: On-board provides information the ICP needs to do FUV TDI processing. On the ground, allows for reconstruction of the observatory attitude by the Science Team.

SC-10a   Restrict location where MTBs are used for IVM
The ICON Mission shall not use the MTBs within +/-15 degrees absolute latitude about geo magnetic equator.

Context: This is budgeted down to ground requirement and SC, which is why it is shown here at L2. SC needs approximate model to verify.

Rationale: Avoid contamination of IVM measurements in regions of high science interest.

SC-10b   Restrict duty cycle of MTBs for IVM
When MTBs are enabled, the ICON Observatory shall use duty cycle scheme of > 12 seconds on 20 seconds off.

Context: This is budgeted down to ground requirement and SC, which is why it is shown here at L2.

Rationale: Provides hi-res drift and density over an outer scale of 160 km. Allows 40-point average every 32 seconds (250 km along track)

3.3.2   Observatory Autonomy and Fault Protection Requirements

SC-11 Safe State Duration
The ICON Observatory shall maintain a safe state for 14 days without ground intervention.

Context and Rationale: A safe state requires the following conditions: stable attitude; positive power; sufficient thermal control to maintain all the hardware within survival temperatures; command and state-of-health telemetry capability. The system needs to be able to maintain itself in a safe state autonomously in an anomalous situation to allow time for the ground to react to and resolve the problem. It needs to be able to do this autonomously as the ground is not in constant contact with the spacecraft. 14 days is the limit of the predictive ephemeris to know absolute position of the Observatory. This duration also limits the verification activity for this requirement to a reasonable time period.

SC-12 Autonomous Safehold Mode
The ICON Observatory shall initiate a safehold mode upon detection of a predefined anomalous condition.

Rationale: The system needs to be able to maintain itself in a safe state autonomously in an anomalous situation to allow time for the ground to react to and resolve the problem.

It needs to be able to do this autonomously as the ground is not in constant contact with the spacecraft.

SC-13a Ground Override of Fault Detection

ICON shall provide a method of terminating or overriding, via ground commands, all autonomous fault detection and fault protection logic executed on the observatory.

Rationale: The ground needs to be able to interact with the spacecraft in the safe state to be able to resolve the issue. The ground needs to be able to return the observatory to nominal operations once the issue has been resolved.

SC-13b Communications Availability

ICON shall be designed to allow communications, including anomalous conditions, to the Observatory assuming the links can be closed.

Context and Rationale:
Requires that the observatory's receiver be powered on and that there are no restrictions on the MOC.

3.3.3 Command and Data Handling Requirements

SC-14 Data Storage

The ICON Observatory shall have sufficient data storage for up to 2 days of Observatory data.

Context: Observatory data includes both science data as well as observatory Health and Status telemetry. Assumes an orbit average instrument data rate.

Rationale: Need to have sufficient onboard storage in the event of a ground station outage. Allows for 1 day downtime.

SC-15 Data Retransmit

The ICON Observatory shall provide the capability to replay/retransmit stored science and engineering data that has previously been sent.

Context: This doesn't apply to the condition of a reboot. Some limited information may be available.

Rationale: Data will occasionally be sent but not received on the ground for various reasons, the system needs to be able to replay that data.

SC-16 Command Storage

The ICON Mission shall have the ability to store and execute up to 10 days of commands & sequences autonomously.

Rationale: Applies to nominal operations post the initial checkout and period. Need to have sufficient sequence storage capability to avoid frequent uplinks to the spacecraft. Reduces contact and product generation costs.

SC-17 Health and Safety Data – Autonomous Action

The ICON Observatory shall provide the GS with sufficient telemetry to allow the reconstruction of autonomous actions taken by the spacecraft.

Rationale: The MOC needs to know what happened to be able to figure out what steps to take next.

SC-18 Health and Safety Data – Observatory State

The ICON Observatory shall provide the GS with sufficient telemetry to allow the determination of the observatory state.

Rationale: The MOC needs to know what the state of the spacecraft is to determine the health of the observatory and whether it is ok to change the observatory state.

3.4 Ground Systems and Communications Requirements

3.4.1 Data Rates and Volume

G-1 Data Volume

ICON shall be capable of downlinking the total data volume provided in ICN-SYS-004 per day at an symbol rate >=4.0 Mbps during nominal mission operations.

Rationale: Provides sufficient data volume and rate to downlink required Science data in a timely manner.

G-2 Nominal Downlink Data Rate

The ICON Observatory shall support >=4.0 Mbps symbol rate to the Berkeley Ground Station and the NASA NEN ground stations with 95% coverage.

Rationale: Support downlink of science and engineering data within five 10 minute passes per day.

G-3 Low Rate Downlink Data Rate

The ICON Observatory shall support >6.5 kbps information rate to the Berkeley Ground Station and the NASA NEN ground stations with 99% coverage.

Rationale: Support downlink of engineering data for contingency support.

G-4 TDRSS Return Data Rate

The ICON Observatory shall support >6.5 kbps return information rate to the TDRSS with 80% coverage.

Rationale: Support engineering telemetry during launch vehicle separation and commissioning operations.

G-5   Ground Station Uplink Data Rate
The ICON Observatory shall support a 2 kbps uplink data rate from the Berkeley Ground Station with 99% coverage.

G-6   TDRSS Forward Data Rate
The ICON Observatory shall support a 2 kbps forward rate via TDRSS with 80% coverage.

Rationale: This uplink data rate also allows closing of the TDRSS forward link that uses the same modulation scheme.

G-7a   Downlink Duration
During nominal operations, the ICON Mission shall be capable of downlinking the total data volume provided in ICN-SYS-004 within a minimum of 5 and a maximum of 7 contacts per day.

*Context: More than 7 passes a day may be taken during early orbit operations, commissioning and/or anomalies if the system as designed for the nominal case allows. Fewer than 5 passes a day may be taken if full data recovery and commanding can be done with less. *

Rationale: For planning purposes. Sufficient to downlink daily data volume. Number of downlinks a day is restricted here to dictate power (transmitter on time) requirement. Additional contacts expected during commissioning.

3.4.2   Space-to-Ground Compatibility

G-7b   Berkeley Ground Station Compatibility
The Berkeley Ground Station shall be compatible with ICON as defined in the RFICD.

Rationale: Ensures data downlink requirements during nominal science operations are met with dedicated ground station (BGS). Using this station as our primary station will reduce mission operations costs.

G-8   TDRSS Compatibility
ICON shall be compatible with TDRSS for two-way communications between the Observatory and the Ground System as defined in RFICD.

Rationale: Telemetry coverage is needed for all critical events, so TDRSS provides continuous coverage as needed during launch, early operations phase, attitude maneuvers and potential anomalous conditions.

G-9   NEN Ground Station Compatibility

The spacecraft bus system shall be compatible with the Near Earth Network (NEN) Tracking Network as defined in the RFICD.

Rationale: NEN stations are used for secondary telemetry recovery, backup and emergency communications at Wallops (secondary) and Santiago (back-up).

G-10   Frequency and Format

ICON shall be CCSDS-compatible, S-Band, downlink / return link with OQPSK modulation, uplink / forward link with PCM/PSK/PM.

Rationale: Ensure that the observatory is compatible with existing ground systems with minimal project specific adaptation support. Command and Telemetry formats used will be specified in the RFICD.

G-11   COP-1 Requirement

ICON shall implement the CCSDS COP-1 Protocol for commanding.

Rationale: See UCB ICN-TN-002 Commanding via COP-1 Protocol.

3.4.3   Link Budget Margins

G-12 Communications Pass Requirements – Command Link

ICON shall have > 6 dB command link margin when > 5º above the horizon as viewed from a ground station and a BER of 10^{-6}, with 99% coverage.

Rationale: Ensure there are robust margins during command uplinks. The limit in S/C attitude allows for appropriate nodes in the S/C antenna pattern.

Context: Assumes ICON baseline and back-up Ground Stations (BGS, WSGT, NEN).

G-13 Communications Pass Requirements – Telemetry Link

The spacecraft bus system shall have > 3 dB telemetry link margin when > 5º above the horizon as viewed from a ground station and a BER of 10^{-6} with 95% coverage.

Rationale: Ensure that the data quality is high during the S/C to Ground Station transmission to reduce the amount of Data Management and retransmission required. The limit in S/C attitude allows for appropriate nodes in the S/C antenna pattern.

Context: Assumes ICON baseline and back-up Ground Stations (BGS, WSGT, NEN).

G-14 Communications Pass Requirements – TDRSS Forward Link

The spacecraft bus system shall have > 0 dB forward link margin for communications via TDRSS and a BER of 10^{-5} with 80% coverage.

Rationale: Ensure there are robust margins during TDRSS command uplinks. The limit in S/C attitude allows for appropriate nodes in the S/C antenna pattern.

G-15 Communications Pass Requirements – TDRSS Return Link
The spacecraft bus system shall have > 0 dB return link margin for communications via TDRSS and a BER of 10^{-5} with 80% coverage.

Rationale: Ensure that the data quality is high for low-rate S/C to TDRSS transmission. The limit in S/C attitude allows for appropriate nodes in the S/C antenna pattern.

3.4.4 Timing Requirements

G-16 End-to-End Time Correlation
ICON shall correlate science measurements to Universal Coordinated Time (UTC) to better than 100 msec for data records and operations.

*Context: The choice to correlate all measurements to a common absolute time reference (UTC) allows **relative** measurements between each of the on-board instruments as well as the **absolute** time required to compare to any ground based measurements (~10x looser than relative requirement).*

Rationale: 100 msec is equivalent to less than 1km orbit travel. Imagers (EUV and FUV) do not require high accuracy time data tagging. Timing affects the spatial registration of the IVM science data, accuracy <1 km is sufficient for all science questions.

4. Project System Interfaces and Responsibilities

This section provides the interface agreements and lead responsibilities for the interfaces between major project system elements.

ICD-1 Payload to Spacecraft Bus System Electrical Interface
ICON shall comply with the payload system to spacecraft system Electrical Interface Control Document (EICD) which defines the electrical and data interfaces between these two systems.

Context: developed by UCB, with Orbital concurrence.

ICD-2 Payload to Spacecraft Bus System Mechanical Interface

ICON shall comply with the payload system to spacecraft system Mechanical Interface Control Document (MICD) which defines the mechanical and thermal interfaces between these two systems

Context: developed by UCB, with Orbital concurrence.

ICD-3 Space System to Ground System Interface
ICON shall comply with the Radio Frequency Interface Control Document (RFICD) developed by NASA Goddard Space Flight Center in collaboration with the MOC at UCB.

ICD-4 Launch System to Space System Interface
The Observatory to launch system Interface Requirements and Control Document shall define the mechanical and electrical interfaces between these two systems.

Context: developed by Orbital in conjunction with KSC, with UCB concurrence.

ICD-5 Launch System to Mission System Interface
The launch vehicle to mission system interface shall be documented in the ICON Launch Site Support Plan and Communications Annex developed by the Launch Services Group.

ICD-6 Observatory Mechanical Configuration Responsibility
The spacecraft bus system shall be responsible for the mechanical configuration of the integrated observatory.

Rationale: The spacecraft bus system provides the interfaces between the payload system and the LV System and needs to have control of the overall configuration to meet the requirements of both of these interfaces.

ICD-7 Observatory Dynamics Analysis Responsibility
The spacecraft bus system shall be responsible for the dynamics analysis of the integrated observatory.

Rationale: The spacecraft bus system is the only system with all of the necessary information to complete this analysis.

5.   Common Project Requirements and Documents

P-1   Mission Category
The ICON mission shall meet the requirements for Category 2 missions per NM 7120-81.

P-2   Risk Classification
The ICON mission shall meet the requirements for Class C missions per NPR 8705.4.

P-3   Adherence to Safety and Mission Assurance Requirements (SMARs)
All ICON institutions shall be compliant the ICON SMARs provided by UCB.

P-4   Adherence to ICON Environmental Requirements Document

All ICON systems shall comply with the ICON Environmental Requirements Document, ICN-SYS-003.

Rationale: Outlines the expected environment for all project flight systems.

P-5   Adherence to ICON Contamination Control Plan

All ICON systems shall comply with the ICON Contamination Control Plan, ICN-SYS-006.

Rationale: Outlines the expected contamination control procedures for ground processing of the observatory.