APPENDIX

EX-02

TO THE

EXPLORERS PROGRAM PLAN

Program-Level Requirements

The Ionospheric Connection Explorer

ICON Project

VERSION 1.1

SEPTEMBER 2014

SCIENCE MISSION DIRECTORATE

NASA Headquarters

Change Log

Version	Effective Date	Notes
1.0		Original Approved Version.
1.1	**9/12/14**	Changed typo regarding time limit in MDR-2. Correcting section 5.1, removing shall not exceed $163.4M and replace with PI-managed LCC to be established at KDP-C given the HQ 7/18/14 replan direction.

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1.0 SCOPE

This appendix to the Explorer Program Plan identifies the mission, science and programmatic requirements imposed on the University of California, Berkeley (UCB) Space Sciences Laboratory (SSL) and the Goddard Space Flight Center (GSFC) for the development and operation of the Ionospheric Connection Explorer (ICON) Project of the Explorer's Program. Requirements begin in Section 4. Sections 1, 2 & 3 are intended to set the context for the requirements that follow. This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Heliophysics Science Division within SMD to the Explorer Program Manager within the Flight Projects Directorate at GSFC.

UCB under contract to the Explorer Program at GSFC is responsible for the scientific success of the ICON project, utilizing the set of approved co-investigators reflected in the proposal including any approved changes prior to the release of this appendix.

SSL is responsible for design, development, test, mission operations and data verification tasks and shall coordinate the work of all contractors and co-investigators.

Changes to information and requirements contained in this document require approval by the Science Mission Directorate, NASA Headquarters by the same signatories that approved the original.

2.0 SCIENCE DEFINITION

2.1 BASELINE SCIENCE OBJECTIVE

ICON will explore the boundary between Earth and space to understand the physical connection between our world and our space environment. Recent NASA missions have shown how dramatically variable the region of space near Earth is, where ionized plasma and neutral gas collide and react. This region, the ionosphere, has long been known to respond to space weather drivers from the sun, but in this century the energy and momentum of our own atmosphere have newly emerged as regularly having effects of equal or greater magnitude. ICON will weigh the impacts of these two drivers as they exert change on our space environment.

Though the solar inputs are increasingly better quantified, the drivers of ionospheric variability originating from lower atmospheric regions are not. ICON is a single spacecraft mission that measures and analyzes these drivers. ICON presents a revolutionary concept of combining remote optical imaging and *in situ* measurements of the plasma at points where these are tied together by Earth's magnetic field. With these measurements, ICON will simultaneously retrieve all of the properties of the system that both influence and result from the dynamical and chemical coupling of the atmosphere and ionosphere. With this approach, ICON will be unique in its capability to quantify each driver and pinpoint the real cause of the variability. ICON will give us the ability to explain how energy and momentum from the lower atmosphere propagate into the space environment, and how these drivers interact with solar and magnetospheric effects during the extreme conditions of solar-driven magnetic storms.

ICON's science objectives are to understand:

S1) the sources of strong ionospheric variability;
S2) the transfer of energy and momentum from our atmosphere into space; and
S3) how solar wind and magnetospheric effects modify the internally-driven atmosphere-space system.

Regarding Objective 1, ICON targets the low-latitude ionosphere because recent global-scale observations of this region show remarkable spatial and temporal variability that contravene the conventional view of ion-neutral coupling in space and evince strong forcing by lower atmospheric drivers. Through a careful selection and arrangement of key observations, ICON is designed to finally determine the seemingly unpredictable source of ionospheric variability in equatorial geospace by measuring the properties of the atmosphere that regulate the daytime ionospheric dynamo.

Regarding Objective 2, ICON seeks to understand how both the background atmosphere and the large-scale waves propagating through it affect the ionosphere. These waves have spatial scales that are large horizontally (thousands of kilometers), but much shorter vertically (tens of kilometers). They have temporal periods of 8, 12, and 24 hours and can persist for months. ICON employs a limb-viewing approach that is ideal for resolving these waves in both horizontal and vertical directions. ICON will capture all of the important thermospheric drivers and ionospheric response on the appropriate spatial and temporal scales.

Regarding Objective 3, ICON will capture the competing effects of storm-time solar wind and magnetospheric drivers as they produce dramatic modifications in the dense equatorial plasma, while also determining influences originating in the atmospheric storm-time winds and neutral composition disturbance. ICON is designed to capture extreme changes in conditions in space.

As part of Objective 2, ICON must survey the waves affecting the equatorial ionosphere, and whether they are symmetric or anti-symmetric about the equator. A low-earth circular orbit with mid-latitude inclination provides the necessary range of latitudes while also focusing on the equatorial region. This orbit also gives ample opportunities for direct comparisons of ionospheric drivers and response (Objective 1), as well as the latitudinal coverage needed to quantify the extent of solar wind and magnetospheric influences on the dense equatorial plasma (Objective 3).

2.2 Science Instrument Summary Description

To produce the measurements needed to meet ICON's science objectives, the ICON science payload consists of four instruments that meet needs of the mission:

A. Dual Michelson Interferometers for Global High-resolution Thermospheric Imaging (MIGHTI) to measure neutral winds during the day and night; and temperatures at the boundary of space in day and night;

B. a Far Ultraviolet Imager (FUV) to measure daytime neutral composition and image the nighttime ionospheric F-layer;

C. an Extreme Ultraviolet (EUV) altitude profiler to measure the daytime ionospheric F-layer; and

D. an Ion Velocity Meter (IVM) to measure the *in situ* ion drifts during the day and night.

3.0 PROJECT DEFINITION

3.1 Project Organization & Management

The Principal Investigator (PI) at UCB is responsible for the overall success of the ICON Project and is accountable to the Associate Administrator of the Science Mission Directorate for the scientific success of ICON and to the GSFC/Explorers Program Manager for the programmatic success. The PI has delegated day-to-day management of the ICON project to the ICON Project Manager at UCB. The Technical Authority for ICON resides within NASA at the GSFC/Applied Engineering and Technology Directorate. The Principal Investigator is responsible for certifying ICON flight readiness to NASA's Associate Administrator of NASA SMD with the concurrence of the Explorer's Program Manager.

3.2 Project Acquisition Strategy

The development of the payload will be led by the SSL at UCB. Major payload components will be subcontracted out as follows:

- Neutral wind velocity and temperature interferometer to the Naval Research Laboratory;
- Ion velocity instrument to the University of Texas at Dallas; and
- Instrument Structures from ATK Space Components.

SSL will develop the two ultraviolet imaging instruments and the payload electronics. SSL will also be responsible for payload integration and test. The spacecraft bus and observatory level integration and test will be procured from Orbital Sciences Corporation. SSL will lead the development and implementation of the Mission and Science Operations and Data Analysis segments of the ICON mission.

4.0 PROGRAMMATIC REQUIREMENTS

4.1 SCIENCE REQUIREMENTS

4.1.1 Baseline Science Requirements

This section describes the baseline requirements for the Ionospheric Connection Explorer. Here the term baseline is defined as the verifiable requirements to which the mission must be designed. The mission shall make the detailed measurements described in SR-1 through SR-5. The ICON science objectives and associated observations for baseline mission are accomplished by flying ICON in the orbit and with the observational geometry and science data collection described in SR-6 through SR-8.

Throughout, the driving Science Objective(s) for each requirement is noted as S1, S2 and S3. Where more than one Science Objective place similar requirements on ICON, only the most stringent quantities are quoted.

SR-1 Horizontal Neutral Winds

ICON shall measure the horizontal component of the neutral wind velocity vector:

a) during the daytime over an altitude range of 95-280 km, **S1, S2, S3**;
b) during the nighttime over an altitude ranges of 95-105 km and 220--280 km, **S2, S3**;
c) with a vertical resolution of 5 km over the altitude range of 95-150 km, **S2;**
d) with a vertical resolution of 30 km over the altitude range of 150-280 km, **S2;**
e) with an in-track horizontal sampling of 500 km, **S1, S2;**
f) with a temporal sampling of 1 minute, **S1, S2;**
g) with a precision of 16.6 m/s, **S2;**
h) with a dynamic range of ±250 m/s, **S1, S3;** and
i) over 18 total hours of solar local time including all times between local sunrise and sunset, **S1, S2.**

SR-2 Vertical Ion Drifts

ICON shall measure the *in situ* motion of the ionospheric O^+ plasma perpendicular to the local magnetic field in the local magnetic meridional plane:

a) within ±10° of the geomagnetic equator, **S1, S2, S3;**
b) with an in-track horizontal sampling of 250 km, **S1;**
c) with a temporal sampling of 32 seconds, **S1;**

d) with a precision of 10 m/s, **S1;**
e) with a dynamic range of ±500 m/s, **S1, S3;** and,
f) over a range from local sunrise to local midnight, including all of daytime. **S1, S2, S3.**

SR-3 Ionospheric density profiles

ICON shall measure the altitude profile of the ionospheric O^+ plasma density:

a) over an altitude range of 200-400 km, **S2, S3;**
b) with a vertical resolution of 20 km, **S2, S3**;
c) with an in-track horizontal sampling of 500 km, **S2**;
d) with a temporal sampling of 1 minute, **S2**;
e) with a precision of 33% of the peak ionospheric density, **S2, S3;** and
f) over a range from local sunrise to local midnight, including all of daytime, **S2, S3**.

Provides supporting information for Science Objective 1

SR-4 Neutral Temperatures

ICON shall measure the neutral temperatures:

a) over an altitude range of 95-105 km, **S2**;
b) with a vertical resolution of 5 km, **S2**;
c) with an in-track horizontal sampling of 500 km, **S2**;
d) with a temporal sampling of 1 minute, **S2**;
e) with a precision of 23.4 K, **S2**; and
f) over 18 total hours of solar local time including all times between local sunrise and sunset, **S2.**

SR-5 Thermospheric O/N_2 ratios

ICON shall measure the vertical column-integrated density ratio of O to N_2:

a) integrated over an altitude range of 135-300 km, **S2, S3**;
b) with an in-track horizontal sampling of 500 km, **S2**;
c) with a temporal sampling of 1 minute, **S2**;
d) with a precision of 16.6%, **S2**; and
e) over a range from local sunrise to local sunset, **S2, S3**.

SR-6 Orbit

ICON shall make all measurements from a near-circular low-earth orbit:

a) with an inclination between 24-30°, **S1, S2, S3**; and
b) from altitudes between 450 and 670 km, **S1, S2, S3**.

SR-7 Scientific Survey Observations

Given the required orbit, ICON shall make scientific measurements:

a) With an observing geometry such that at the magnetic dip equator, the magnetic field line that intersects the orbit track also intersects each one of the remotely measured volumes on the limb within 15 minutes of a magnetic dip equator crossing, **S1, S3**;
b) for at least 60 days out of each 91 day season, **S2**;
c) over a period of at least four 91 day seasons, **S2, S3**;
d) with an average observing efficiency of at least 80% per day **S2**; and
e) within a two year mission. **S3**.

SR-8 Scientific Conjugate Observations

Given the required orbit, ICON shall make targeted scientific measurements:

a) With observing campaigns to measure horizontal wind vectors both north and south of the orbit track within 10 minutes of a magnetic dip equator crossing in the daytime, **S1;**
b) with a frequency of up to once per day, **S1;**
c) over a period of at least 91 days, **S1;**
d) with a total number of conjugate observations of at least 40. **S1.**

4.1.2 Threshold Science Requirements

This section describes the threshold requirements for the Ionospheric Connection Explorer. Here the term threshold is defined as the minimum design requirements to which the mission could be reduced prior to launch and still be deemed worth flying. The mission shall make the detailed measurements described in TR-1 and TR-2. The ICON science objectives and associated observations for threshold mission are accomplished by flying ICON in the orbit and with the observational geometry and science data collection described in TR-3 through TR-5.

As the threshold science mission for ICON has only one science objective, the origin of each requirement is Science Objective 1.

TR-1 Horizontal Neutral Winds

ICON shall measure the horizontal component of the neutral wind velocity vector:

a) during the daytime over an altitude range of 120-150 km;
b) with a vertical resolution of 10 km;
c) with an in-track horizontal sampling of 500 km;
d) with a temporal sampling of 1 minute;
e) with a precision of 20 m/s;
f) with a dynamic range of ±150 m/s; and
g) over a solar local time range from 1 hour after local sunrise to 1 hour before local sunset.

TR-2 Vertical Ion Drifts

ICON shall measure the *in situ* motion of the ionospheric O^+ plasma perpendicular to the local magnetic field in the local magnetic meridional plane:

a) within ±10° of the geomagnetic equator;
b) with an in-track horizontal sampling of 500 km;

c) with a temporal sampling of 1 minute;
d) with a precision of 10 m/s;
e) with a dynamic range of ±250 m/s; and
f) over a solar local time range from 1 hour after local sunrise to 1 hour before local sunset.

TR-3 Orbit

ICON shall make these measurements from a near circular low-earth orbit:

a) with an inclination between 24-30°; and
b) from altitudes between 450 and 670 km.

TR-4 Science data collection

ICON shall be designed to make all scientific measurements:

a) wth an observing geometry such that at the magnetic dip equator, the magnetic field line that intersects the orbit track also intersects all remotely measured volumes on the limb within 15 minutes of a magnetic dip equator crossing by ICON:
a) over a period of at least 1600 orbits; and
b) with an average observing efficiency of at least 50% per day.

4.1.3 Science Instrument Requirements

The ICON MISSION shall implement its science requirements with 4 instruments: ICON-FUV, ICON-IVM, ICON-EUV, and ICON-MIGHTI, which:

a) for determination of neutral composition and nighttime ionospheric densities, **ICON FUV** will provide measurements of the ultraviolet emissions of atomic oxygen and molecular nitrogen the upper atmosphere, including OI 135.6 and a portion of the Lyman Birge Hopfield bands of N_2, on the Earth's limb from 135-400 km in day and night;

b) For determination of ion velocities at the location of the observatory, **ICON-IVM** will provide measurements of the drift speed of the dominant ionospheric constituent, O^+, in the orbit-track direction and two perpendicular cross-track directions**;**

c) for determination of daytime ionospheric densities, **ICON EUV** will provide measurements of the ultraviolet emissions of ionospheric O^+ at 83.4 and 61.7 nm on Earths' limb in daytime in an altitude range from 100 to 500 km;

d) for determination of horizontal wind velocities in the upper atmosphere, **ICON MIGHTI** will provide measurements of the Doppler shift of prominent atomic emission lines at 630.0 and 557.7 nm present in the upper atmosphere on Earth's limb from 280 km down to 95 km; and

e) for determination of temperatures in the upper atmosphere, **ICON MIGHTI** will provide measurements of the emission profile of prominent O_2 molecular band emissions, centered at 762.0 nm, present in the upper atmosphere on Earth's limb from 105 km down to 95 km.

4.2 MISSION AND SPACECRAFT PERFORMANCE

ICON shall be managed as a Category 2 project per NPR7120.5E, and the mission class shall be Class C per NPR 8705.4

The mission shall be designed to operate for a baseline of 2 years after an on-orbit checkout period of one month beginning at launch.

4.3 LAUNCH REQUIREMENTS

This payload shall be launched on an expendable launch vehicle of Risk Category **(3, or 2)** per NPD 8610.7D depending on the launch services task order (LSTO) award.

The ICON satellite shall be launched into a circular low Earth orbit with altitudes between 450 and 670 km and an inclination between 24-30° by a launch vehicle.

The launch vehicle and launch services shall be provided by the Kennedy Space Center (KSC).

4.4 GROUND SYSTEM REQUIREMENTS

GSR-1 The ICON team shall provide the ICON Ground System to retrieve data and command the Observatory, the Mission Operations Center (MOC) to operate the spacecraft and the ICON Science Operations Center (SOC) for data analysis.

GSR-2 The ICON MOC shall collect > 95% of all data collected by the observatory and make this data available to the ICON SOC with at most a 7-day latency.

4.5 MISSION DATA REQUIREMENTS

4.5.1 SCIENCE DATA MANAGEMENT

The **ICON** project Principal Investigator shall be responsible for initial analysis of their data, its subsequent delivery to an appropriate data repository, the publication of scientific findings, and communication of results to the public.

In order to address the mission science objectives described in the ICON Science Definition Statement (Section 2) and to demonstrably satisfy the corresponding threshold and baseline mission science requirements specified in §4.1.2 and §4.1.1 respectively, the ICON mission shall meet the following data requirements:

MDR-1: The ICON MOC shall be responsible for collecting engineering and ancillary data necessary to validate and calibrate the scientific data prior to making the data publicly available. The ICON data products shall be produced by the ICON SOC and shall be calibrated in physical units or dimensions. The ICON observatory shall be designed to support the necessary instrument calibration maneuvers and modes. The time required to complete the validation and calibration of the ICON data shall be the minimum necessary to provide accurate, validated scientific data to the science community and the general public, but no greater than six months after the data are collected.

MDR-2: All data shall be archived in standard format for NASA missions (CDF or FITS where appropriate), along with the ICON software packages defined in the Project Data Management Plan at the Space Physics Data Facility (SPDF). The time required to deliver the ICON data and software to SPDF shall be the minimum necessary to provide accurate, validated scientific data and documented software, but the first delivery of these shall take place no more than six months after the Initial Orbit Checkout is completed, and shall occur at least every 3 months thereafter.

4.5.2 DATA MANAGEMENT PLAN

The ICON project shall develop a science data management plan to address the total activity associated with the flow of science data, from acquisition, through processing, data product generation and validation, to archiving and preservation. The data management plan shall be generated in preliminary form by the project Preliminary Design Review and formally approved as a Level 2 requirement no later than the Project's Critical Design Review. Science analysis software development, utilization, and ownership shall be covered in the Data Management Plan.

4.6 MISSION SUCCESS CRITERIA

ICON will be the first investigation of the drivers of variability in the dense plasma of the equatorial ionosphere. The combined measurements of the drivers (neutral winds) and responses (plasma density changes) have never been achieved in any manner that resolves the cause of the large day-to-day variation in ionospheric densities. To achieve this, ICON shall:

- Measure the line-of-sight neutral winds from 120 to 150 km tangent altitude on the limb.
- Measure the component of the ion drifts perpendicular to the local geomagnetic field *in situ* at the observatory.
- Concurrently measure both the neutral wind and *in situ* ion drifts as described above when ICON is within 5° of the geomagnetic equator, such that the two measurements are connected via the Earth's magnetic field.
- Perform these measurements over a period that spans one full orbital precession cycle, providing a complete measurement of atmosphere-ionosphere coupling in Earth's equatorial region for all magnetic declinations. A full orbital precession cycle is approximately 55 days, pending final orbit determination.

5.0 NASA MISSION COST REQUIREMENT

5.1 LIFE CYCLE COST

ICON PI-managed life cycle cost (LCC) for the design, development, mission operations, and data analysis and archiving is to be established at the SMD KDP-C gate review. The PI-managed LCC will not include the Headquarters held reserves (i.e., Unallocated Future Expenses (UFE)), Launch and associated launch vehicle integration costs and Program Office costs. The ICON

Management and Agency LCC estimates and phasing of those funds as well as the launch readiness date will be baselined at KDP-C and documented in the decision memo.

5.2 COST MANAGEMENT AND SCOPE REDUCTION

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the ICON project shall pursue scope reduction and risk management as a means to control cost. The ICON Project Plan shall include potential scope reductions and time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the ICON Project Plan may be exercised; however, any reduction in scientific capability, including those reductions specifically identified in the ICON Project Plan, shall be implemented only after consultation with and approval by the Program Scientist. Any potential scope reductions affecting these Program Requirements shall be agreed to by the signers of this document.

6.0 MULTI-MISSION NASA FACILITIES

The ICON project shall use the following NASA facilities:

- Kennedy Space Center Eastern Test Range launch facilities (as required)
- GSFC Spectrum Management for NTIA licensing using government frequencies
- TDRSS facilities for commanding and data retrieval
- NASA ground stations at Wallops and Santiago

7.0 EXTERNAL AGREEMENTS

The following agreements with non-US entities will be required to carry out the ICON mission:

- UCB and the Centre Spatial de Liège for ultraviolet instrument calibration.

8.0 PUBLIC OUTREACH AND EDUCATION

The ICON project shall develop and execute an Education and Public Outreach Plan consistent with SMD requirements for the class of project. Science images shall be made available for outreach purposes within one month of the end of in-orbit checkout.

9.0 SPECIAL INDEPENDENT EVALUATION

ICON has no requirement for special independent evaluations.

10.0 WAIVERS

The 7120 Compliance Matrix for the **ICON** project indicates no necessity for NPR 7120.5E waivers.

11.0 REQUIRED APPROVALS AND CONCURRENCES

APPROVALS:

Approved b[redacted]________ Date: [redacted]

Nicholas Chrissotimos, Explorer Program Manager, GSFC

Approved by: [redacted]______________ Date: [redacted]

Christopher J. Scolese, Director, GSFC

Approved by: [redacted]______________ Date: [redacted]

Dr. John Gruns[redacted]l, Associate Administrator, NASA HQ SMD

SMD FRONT OFFICE CONCURRENCES

Concurred by: [redacted] Date: [redacted]

Dr. Tupper Hyde, Chief Engineer for SMD, Office of the Chief Engineer

Concurred by: [redacted] Date: [redacted]

Geoff Yoder, SMD Deputy Ass[redacted]ciate Administrator for Programs

Concurred by: [redacted] Date: [redacted]

Charles Gay, SMD Deputy Associate Administrator

ICON PROJECT CONCURRENCES

Concurred by: [redacted] Date: [redacted]

Dr. William Craig, ICON Project Manager, SSL, University of California, Berkeley

Concurred by: [redacted] Date: [redacted]

Dr. Thomas Immel, Principal Investigator, SSL, University of California, Berkeley

SMD HELIOPHYSICS CONCURRENCES

Concurred by: [redacted]__________ Date: [redacted]

Dr. Elsayed Talaat, ICON Program Scientist, SMD Heliophysics

Concurred by: [redacted]__________ Date: [redacted]

Dr. Jeffrey Newmark, SMD Heliophysics Program Scientist

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Willis Jenkin [redacted] SMD Heliophysics Program Executive

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Victoria Elsbernd, SMD Heliophysics Deputy Division Director

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NASA CONCURRENCES-GODDARD SPACE FLIGHT CENTER

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Dr. Douglas Rowland, ICON, Mission Scientist, GSFC

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Gregory F[redacted]zier, Deputy Program Manager – Explorer Program