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Geospace Dynamics Constellation (GDC) Project

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Proposal Information Package

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Goddard Space Flight Center
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Preface

This document is a Geospace Dynamics Constellation (GDC) Project configuration control board (CCB) controlled document. Changes to this document require prior approval of the GDC CCB Chairperson or designee. Proposed changes shall be submitted in the GDC Technical Data Management System (TDMS) via a configuration change request (CCR) along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

All of the requirements in this document assume the use of the word "shall" unless otherwise stated.

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This document is a project-specific document. Questions or comments pertaining to the document content or its relationship to the project are to be directed to the identified NASA point of contact for that project.

Change History Log

Revision	Effective Date	Description of Changes
Revision -	05/04/2021	Released per GDC-CCR-0013
Revision A	06/02/2021	Released per GDC-CCR-0014
Revision B	07/09/2021	Released per GDC-CCR-0018
Revision C	07/26/2021	Released per GDC-CCR-0020

Table of TBDs/TBRs/TBSs

Action Item No.	Location	Summary	Individual/ Organization Actionee

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1. INTRODUCTION

This Proposal Information Package (PIP) is being supplied with the National Aeronautics and Space Administration (NASA) Standalone Mission of Opportunity Notice-3 (SALMON-3) Program Element Appendix (PEA) P for science investigations for the Geospace Dynamics Constellation (GDC) mission.

1.1 Purpose

The purpose of this document is to describe the GDC mission concept, mission operations systems, mission assurance and project policies in sufficient detail to enable the proposal of viable investigations for the GDC mission.

1.2 Scope

The instrument accommodations described in this document are based on assumptions from the GDC Pre-Phase A implementation study, and conform to the constraints specified in the PEA. Should there be an inadvertent conflict between the PIP and the PEA, the PEA will take precedence.

Throughout this document, requirements are labeled as GDC-PIP-<#> (where <#> is a sequential number for the requirements in that category for ease of reference):

These items are requirements for proposed investigations (see Requirement P-1 of the GDC PEA). Specific requirements identified in this PIP do not imply the negation of more general requirements in the SALMON-3 AO or the GDC PEA.

If there is text in this PIP outside of those requirements that uses the word "should" it is to be taken as an advisory / best-practice, and is not a requirement.

The page number for each of these requirements is listed in a summary table in Appendix B of this document.

1.3 Reference Documentation

- Standalone Mission of Opportunity Notice-3 (SALMON-3) Program Element Appendix (PEA) P
- NPR 8715.6B, NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments
- NASA STD-8719.14A, Process for Limiting Orbital Debris
- GOLD Rules, GSFC-STD-1000G, Rules for the Design, Development, Verification, and Operation of Flight Systems
- GEVS, GSFC-STD-7000A, General Environmental Verification Standard
- GSFC-STD-1001A, Criteria for Flight and Flight Support Systems Lifecycle Reviews
- NPR 8705.4, Risk Classification for NASA Payloads

- NPR7123.1C, NASA Systems Engineering Processes and Requirements
- GDC Science and Technology Definition Team report (STDT)
- GPR 7120.4D, Risk Management
- IEST-STD-CC1246E, Product Cleanliness Levels – Applications, Requirements, and Determination
- GDC-SMA-PLAN-0002, Instrument Mission Assurance Requirements (IMAR)
- GDC-AO-DRMPED, Design Reference Mission Predicted Ephemeris Description
- GDC-AO-SYNATMUG, Synthetic Atmospheres: A User's Guide
- GDC-PYLD-REQ-0004, Representative Launch Environment
- GDC-PYLD-CDRL-0002, Representative Instrument Contract Data Requirements List (CDRL)
- NPR 7150.2C, NASA Software Engineering Requirements

2. GDC MISSION SCIENCE

2.1 Scientific Goals and Objectives

The GDC mission will dramatically change our understanding of how the upper atmosphere reacts to energy input from above, below, and within by addressing two overarching science goals with specifically actionable objectives. For background on the scientific goals, motivations, and objectives of GDC, see the Science and Technology Definition Team (STDT) report. The STDT report defined two Goals and ten Objectives (four for Goal 1, six for Goal 2).

NASA conducted a pre-Phase A implementation study to refine the science requirements in that report and to develop a mission implementation concept to maximize the GDC science return. That concept focused on a subset of the GDC Science Objectives that were considered to contain the most impactful science return that would be achievable within the scope of a cost-effective mission implementation (Objectives 1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 2.6).

Below are the GDC Science Objectives focused on by the implementation study, and each of those Objectives have been split into subobjectives in order to better enable the development of specific science requirements.

Goal 1: Understand how the high-latitude ionosphere-thermosphere system responds to variable solar wind/magnetosphere forcing.

- **Objective 1.1** *Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds.*

    1. **Subobjective 1.1-1** Determine the relative contributions to the high-latitude neutral pressure gradient from particle precipitation and from Joule heating in Earth's upper atmosphere.
    2. **Subobjective 1.1-2** Determine the relative contributions to modifications of the ion drag force from particle precipitation and from Joule heating in Earth's upper atmosphere.
    3. **Subobjective 1.1-3** Determine the contributions of the ion drag, pressure gradient, Coriolis force, and viscous forces to driving horizontal and vertical neutral winds in Earth's upper atmosphere.

- **Objective 1.2** *Determine how localized, coherent plasma density features arise and evolve.*

    1. **Subobjective 1.2-1** Determine the relative contribution of ionization source mechanisms to changing the ionospheric plasma number density (electron number density).

    2. **Subobjective 1.2-2** Determine the relative contribution of ionization loss mechanisms to changing the ionospheric plasma density.

    3. **Subobjective 1.2-3** Determine the relative contribution of ionization transport mechanisms to changing the ionospheric plasma density.

    4. **Subobjective 1.2-4** Determine the relative contribution of thermal changes to changing the ionospheric plasma density.

    5. **Subobjective 1.2-5** Determine the extent to which small-scale plasma density structure forms as a result of Kelvin-Helmholtz, Rayleigh-Taylor, gradient-drift, and other instabilities.

- **Objective 1.3** *Determine how neutral winds, auroral precipitation, and collisional heating drive high-latitude neutral density structures.*

    1. **Subobjective 1.3-1** Determine the relative contributions of particulate and EUV radiation and Joule heating to neutral heating rates.

    2. **Subobjective 1.3-2** Determine the relative contribution of neutral temperature changes to changes in neutral density.

    3. **Subobjective 1.3-3** Determine the average contribution of horizontal and vertical transport of neutrals to changes in neutral density.

Goal 2: Understand how internal processes in the global ionosphere-thermosphere system redistribute mass, momentum, and energy.

- **Objective 2.1** *Determine the relative importance of penetration electric fields and disturbance winds in driving plasma density variations at mid- and low latitude during geomagnetically active conditions.*

  1. **Subobjective 2.1-1** Determine the characteristics of penetration (including over shielding and under shielding) electric fields.

  2. **Subobjective 2.1-2** Determine the characteristics of disturbance neutral winds and the electric field generated by the disturbance dynamo.

  3. **Subobjective 2.1-3** Determine the contributions to low- and mid-latitude plasma motions driven by the penetration and disturbance dynamo electric fields.

  4. **Subobjective 2.1-4** Determine how plasma and neutral motions driven by penetration or disturbance dynamo effects at low- and mid-latitude give rise to instabilities and small-scale structure.

  5. **Subobjective 2.1-5** Determine how plasma motions due to disturbance winds or penetration effects at low- and mid-latitude give rise to modifications in ionization or recombination rates.

- **Objective 2.2** *Identify the processes that create and dissipate propagating structures within the ionosphere and thermosphere during geomagnetically quiet and active conditions.*

  1. **Subobjective 2.2-1** Determine the characteristics of traveling ionospheric disturbances (TIDs) and traveling atmospheric disturbances (TADs) and use these characteristics to reveal their generation mechanisms.

  2. **Subobjective 2.2-2** Determine the extent to which TID/TAD propagation is modified by the background state of the ionosphere/thermosphere.

  3. **Subobjective 2.2-3** Determine the mechanisms by which TIDs and TADs are dissipated.

  4. **Subobjective 2.2-4** Determine the relationship between TIDs and TADs.

  5. **Subobjective 2.2-5** Determine the extent to which magnetic conjugacy modifies TID generation and propagation in conjugate hemispheres.

- **Objective 2.3** *Determine the connections between winds and neutral density / composition variations at mid- and low latitudes during geomagnetically quiet and active conditions.*

    1. **Subobjective 2.3-1** Determine the extent to which high-latitude compositional changes are driven by vertical winds/upwelling at high latitudes.

    2. **Subobjective 2.3-2** Determine the extent to which mid- and low-latitude compositional changes are driven by high-latitude compositional changes that are then transported equatorward.

    3. **Subobjective 2.3-3** Determine the extent to which compositional changes at low- and mid-latitudes modify chemistry and ion-neutral coupling.

- **Objective 2.6** *Determine how hemispheric asymmetries in the Earth's magnetic field, seasonal variations, and magnetospheric input affect the ionosphere-thermosphere system.*

    1. **Subobjective 2.6-1** Determine the extent to which seasonal differences in solar illumination drive interhemispheric differences in neutral and ionospheric densities, temperatures, and composition.

    2. **Subobjective 2.6-2** Determine the nature of the global circulation that drives interhemispheric transport of plasma and neutral gas.

    3. **Subobjective 2.6-3** Determine the extent to which seasonal differences in hemispheric conductivity modify plasma drifts, neutral convection, and Joule heating in magnetically conjugate regions.

    4. **Subobjective 2.6-4** Determine the extent to which high-latitude magnetic asymmetries modify plasma drifts, neutral convection, and Joule heating rates in magnetically conjugate regions.

To assist in planning for and development of potential GDC investigations, the implementation study produced a Design Reference Mission (DRM) and a small set of numerical simulations of Earth's upper atmosphere during a small number of times of interest.

The DRM is documented in a set of modeled ephemeris files for six GDC observatories over the three-year mission. These notional DRM ephemerides describe a particular constellation configuration that is suitable for meeting the GDC Science Objectives. The final constellation configuration and ephemerides will be developed following the selection of investigations and a spacecraft solution, in order to optimize the science return of the selected investigations. These ephemeris files are described in document GDC-AO-DRMPED ("GDC Design Reference Mission Predicted Ephemeris Description").

In order to assist in the development of potential investigations, the GDC Acquisition Homepage Program Library includes several numerical simulations of the atmosphere developed with the

Global Ionosphere Thermosphere Model (GITM). These simulations are described in document GDC-AO-SYNATMUG ("Synthetic Atmospheres: A User's Guide").

The files and accompanying documents for the DRM predicted ephemeris and the GITM model simulations can be found in the GDC Program Library.

2.2 GDC Measurement Requirements

The GDC STDT report included a table of Physical Parameters that was assembled by determining what measurements were necessary for each Objective. Those Physical Parameters were refined as part of the GDC pre-Phase A implementation study.

In order to provide clarity for the GDC mission, the measurements were 1) prioritized, and 2) split into sub-parameters, where appropriate. A single instrument may measure some or all of the sub-parameters of a Physical Parameter.

The refined list of measurements is given in Table 2-1. For each Physical Parameter (or sub-parameter), key measurement characteristics are given. The sampling rate is based on the lowest scale sizes at the spacecraft altitude. All measurements are expected to be acquired globally, although it is understood that some Physical Parameters will only be significant at high latitudes.

Table 2-1. GDC Physical Parameters

Table 2-1. GDC Physical Parameters

Priority	Reference Number		Physical Parameter	Dynamic Range	Accuracy	Precision	Sample Rate
Primary	1	a	Thermal ion velocity, perpendicular to B (vector); *or* Electric field, perpendicular to B (vector)	± 5000 m/s *or* ± 250 mV/m	20 m/s *or* 0.5 mV/m	20 m/s *or* 0.5 mV/m	1 / sec
Primary	1	b	Thermal ion velocity, parallel to B	± 2000 m/s	20 m/s	20 m/s	1 / sec
Primary	2		Thermal plasma density	10^2 - 10^7 cm^{-3}	Larger of 100 cm^{-3} or 10%	Larger of 100 cm^{-3} or 1%	1 / sec
Primary	3		Thermal ion temperature	500 - 4000 K	Larger of 100 K or 10%	Larger of 50 K or 5%	1 / sec
Primary	4		Thermal ion composition (relative), by species	1 - 32 AMU	Larger of 100 cm^{-3} or 1%	Larger of 100 cm^{-3} or 1%	1 / 3 sec
Primary	5	a	Neutral wind, horizontal (in-track)	± 1500 m/s	20 m/s	10 m/s	1 / 3 sec
Primary	5	b	Neutral wind, horizontal (cross-track)	± 1500 m/s	20 m/s	10 m/s	1 / 3 sec
Primary	5	c	Neutral wind, vertical (cross-track)	± 150 m/s	20 m/s	10 m/s	1 / 3 sec
Primary	6		Neutral gas number density	10^7 - 10^{10} cm^{-3}	10%	2%	1 / 3 sec
Primary	7		Neutral gas temperature	400 - 2000 K	Larger of 50 K or 10%	Larger of 25 K or 2%	1 / 3 sec
Primary	8		Neutral gas composition, by species	1 - 40 AMU	Larger of 10^4 cm^{-3} or 5%, per species	Larger of 10^4 cm^{-3} or 5%, per species	1 / 3 sec
Primary	9	a	Auroral electrons energy / pitch angle distribution (downgoing)	Energy range 0.05 - 20 keV, dE/E<20%, Pitch Angle resolution 10°, Energy flux range 0.1 - 100 mW/m^2			1 / sec
Secondary	9	b	Auroral electrons energy / pitch angle distribution (upgoing)	Energy range 0.05 - 20 keV, dE/E<20%, Pitch Angle resolution 10°, Energy flux range 0.1 - 100 mW/m^2			1 / sec
Secondary	10	a	Auroral ions energy / pitch angle distribution (downgoing)	No species discrimination required, Energy range; 0.05 - 20 keV, dE/E<20% Pitch Angle resolution 10°, Energy flux range 0.1 - 50 mW/m^2			1 / sec
Secondary	10	b	Auroral ions energy / pitch angle distribution (upgoing)				1 / sec
Secondary	11	a	Spatial structures, electric field (0.1-25 km)	500 mV/m	10.0%	1%	1 / 3 sec (see Note 3)
Secondary	11	b	Spatial structures, thermal plasma density (0.1-25 km)	10^2 - 10^7 cm^{-3}	Larger of 100 cm^{-3} or 10%	Larger of 100 cm^{-3} or 10%	1 / 3 sec (see Note 3)
Secondary	12		Thermal electron temperature	500 - 10000 K	Larger of 100 K or 10%	Larger of 50 K or 5%	1 / sec
Secondary	13		Magnetic field perturbation (DC field, vector)	+/- 4000 nT	4 nT	1 nT	1 / sec
Secondary	14	a	Altitude of maximum thermal plasma density below 350 km	150 - 350 km	25 km	10 km	>100x / day
Secondary	14	b	Maximum thermal plasma density below 350 km	10^5 - $5x10^6$ cm^{-3}	10%	10%	>100x / day

Note 1: Each Physical Parameter is categorized as Primary or Secondary (shaded) and is assigned a Reference Number; the numbers are organizational do not reflect prioritization within the Primary and Secondary categories. Some Physical Parameters are split into sub-parameters (e.g. 5a, 5b, 5c) for better organization and to recognize that some instrumentation may measure significant aspects but not all aspects of a Physical Parameter.

Note 2: Unless specified otherwise, all Physical Parameters are to be measured at the spacecraft.

Note 3: The sampling cadence assumes a power spectral density distribution to quantify spatial structures.

3. GDC MISSION DESCRIPTION

3.1 Overview

The GDC mission concept is a constellation in low earth orbit with at least six sets of the science payload. For planning purposes, NASA's Pre-Phase A study focused on a straightforward mission implementation of six identical observatories with homogeneous instrumentation. Although the actual implementation will be determined in Phase A/B, this document refers to the Pre-Phase A planning implementation.

The observatories will be launched on a single launch vehicle into a 375 km +/- 25 km circular orbit, with six planes having inclinations ranging from 81° to 82° using launch vehicle restarts and propulsive maneuvers by the observatories. The launch readiness date is September 2027. After orbit insertion, the different planes will drift with respect to each other and span the multiple spatial and temporal scales required by GDC over the course of the 3-year mission.

Currently, the GDC mission is divided in three science phases: local, regional, and global; with each phase having two sub-phases with different temporal configurations: fast and slow. The constellation will be operated by a ground system, consisting of a Mission Operations Center (MOC) responsible for command and control of the spacecraft; and a Science Operations Center (SOC) serving as the primary command, control, and telemetry interface for the instruments.

3.2 GDC Mission Timeline

3.2.1 Pre-launch development and implementation

Figure 3-1 illustrates the GDC key project milestones. Notional dates for instrument reviews are provided in Table 10-1.

Phase A starts following Key Decision Point A (KDP-A) and ends with a combined System Requirements Review (SRR) and Mission Definition Review (MDR). The Preliminary Design Review (PDR) occurs in Phase B and is followed by Critical Design Review (CDR) and System Integration Review (SIR) in Phase C. (A Pre-Environmental Review (PER) will precede the flight system environmental tests.) The Mission Operations Review (MOR) and Operations Readiness Review (ORR) will be held prior to launch. The integrated flight system will be shipped to the launch site following the Pre-Ship Review (PSR). After launch, a Post-Launch Assessment Review (PLAR) will be conducted. The definition of the reviews can be found in GSFC-STD-1001A, Criteria for Flight and Flight Support Systems Lifecycle Reviews.

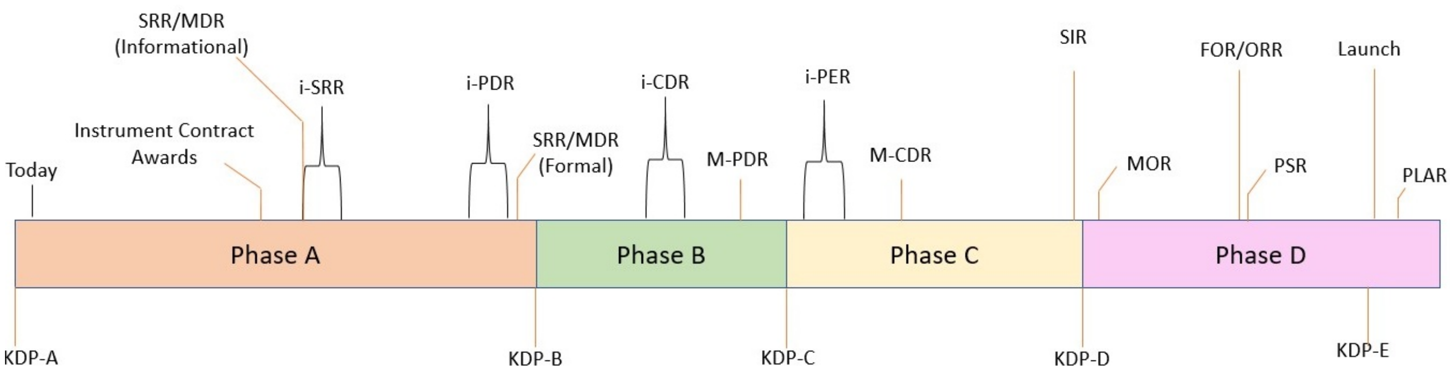

Figure 3-1. Mission Development and Implementation Timeline

3.2.2 Post-Launch Mission Phases

The GDC mission is planned to launch in September 2027 aboard a NASA selected launch vehicle. There is a commissioning phase of 90 days prior to starting prime science operations. As part of the commissioning process, the instruments are to be powered on in their science operational state. Each spacecraft will be in an operational mode to support science operations for more than 96% of the time, taking into account times for maneuvers, momentum unloading, calibrations, and other non-science operation activities.

The GDC spacecraft will perform regular maneuvers throughout the mission lifetime to maintain along-track separation (~every 2 weeks), control spacecraft momentum (~every 2 weeks), maintain required altitude under drag environment (~3.5 months), and initiate/stop differential plane drifts (two times in the mission timeframe).

Science data and system telemetry from GDC will be downlinked to Near Earth Network (NEN) ground stations. Two contacts per day for each spacecraft are planned. Each contact will be approximately 10 minutes. The Space Network (SN) will be used for launch, maneuvers, emergencies, and tracking, as required. The intended communication frequency band is S-band. Alternative approaches to data downlink will be considered in Phase A/B.

The spacecraft science attitude is expected to be 3-axis stabilized with fixed ram/nadir orientation. The GDC orbit altitude is 375 km+/- 25 km with inclinations between 81-82 degrees. During the mission lifetime, the various orbital planes will drift under Earth's oblateness and third body perturbations and consequently, the observatory is expected to experience the full range of sun beta angle/illumination.

The Design Reference Mission (DRM) Predicted Ephemeris Description (in the Program Library under Science Planning Resources) describes the notional mission phases and constellation sampling architecture. This DRM is provided for purposes of this AO – the final constellation configuration will be refined throughout mission formulation, in order to optimize the GDC science return.

Table 3-1 is a description of the planned phases of the GDC mission. Further refinement will occur following the instrument selection in Phase A.

Table 3-1. GDC Mission Phases

Launch & Acquisition		**Phase covering pre-launch configuration until observatory is power-positive and pointing at the sun** - Launch, separation, transponder power on, solar array deployment, Reaction Wheel (RW) power and sun acquisition
In-Orbit Checkout		**Phase used during first weeks to checkout and calibrate observatory** - Observatory ready to begin science ops at the end of this phase. Total In-Orbit Checkout and Calibration (IOC) lasts ~90 days
	S/C Checkout & Orbit Adjustment	**S/C checkout and S/C modes verified**; - Verify all spacecraft modes and systems are operational; Delta-V maneuver to adjust to final inclination
	Instrument Commissioning	**Turn on and transition instruments to science operational status**; Begins once GDC orbits have been established & S/C checkout completed. - Includes instrument turn on, checkout, calibration, & commissioning activities
Science Phase		**Phase that mission stays in majority of time once constellation is established. Dominated by routine continuous instrument operations with few other operational activities planned**
	Science Collection Phases	Continuous routine uninterrupted instrument operations; Constellation moves into local, regional, and global measurement configurations - Science data transferred to ground, then to SOC, through regular pre-planned ground contacts with all observatories
	Periodic Calibrations/ Housekeeping	**Interruptions in normal science phase needed for maintaining science quality** - Instrument calibration, decontamination operations
	Eclipse	**Observatory is to survive & minimize impact on science operations** - Power storage and thermal considerations may impact instrument operations
	Momentum Mgmt & Orbit Maintenance Maneuvers	**Required operations to unload RW angular momentum** (planned ~once per week), **orbit phasing operations** (~once/month) **and to compensate for atmospheric drag** (planned ~once/3.5 months) - Thruster firings will interrupt science activities for ~1 hour window (high voltage concerns)
	Safehold & Emergency Modes	**Several capabilities will exist on the GDC observatories for "safing" in the event of an anomaly** - Fault detection/correction, autonomous safehold, safing notification, power subsystem load shedding
Disposal		**At end of mission, NASA requires safe disposal of GDC** - Controlled re-entry into earth atmosphere

4. SPACECRAFT DESCRIPTION, ACCOMMODATION & CONSTRAINTS

GDC-PIP-4.1: Investigations shall design their instruments for accommodation on a spacecraft that possesses the characteristics and design elements described in Section 4 of this PIP.

4.1 Overview

The spacecraft will be configured to provide the necessary resources to accommodate the instruments, maintain the prescribed orbits, constellation configuration, spacecraft orientation and stability, specified Field-of-View (FOV), instrument commanding (per SOC upload), and telemetry and science data collection for transmission to the MOC/SOC over the mission lifetime. The S/C is responsible for the design and testing of deployables (or equivalent standoff structures) that are not integral and inherent to the instrument. Investigations are fully responsible for deployables integral to the function of the instrument. This includes, but is not limited to: the design, build, test and operation of all instrument-specific hardware mounted to the S/C. Table 4-1 provides a summary of spacecraft and instrument responsibilities at critical interfaces.

Table 4-1. Overview of Instrument and Spacecraft Responsibilities

Deployments/Retentions			
	Design and Implementation	Mass Allocation	Command of Deployments/Retentions (if applicable)
Instrument Covers (Ejectable or Detached)	Instrument	Instrument	S/C
Deployables Inherent to Instrument Function	Instrument	Instrument	S/C
Other Deployables	S/C	S/C	S/C
Structures and Electronics			
	Design and Implementation	Mass Allocation	
Detector/Sensor	Instrument	Instrument	
Instrument Electronics	Instrument	Instrument	
Mounting Brackets/Structure	Instrument	Instrument	
Intra-Instrument Cabling	Instrument	Instrument	
Survival heaters and Thermocouples	Instrument	Instrument	
S/C-Instrument Cabling	S/C	S/C	

Computation	
	Design and Implementation
Compression	Instrument
Data Buffering	Instrument (as needed)
Data Storage	S/C
Telemetry Formatting	S/C
Instrument Control	Instrument
Instrument Health and Safety Monitoring	Instrument

4.2 Spacecraft Description and Payload Resources

The GDC mission architecture and spacecraft are not yet defined. Therefore, a well-defined range of spacecraft capabilities and a complete list of accommodation requirements have not been determined. The following spacecraft description and payload resources are based on assumptions from the GDC Pre-Phase A implementation study.

Although the philosophy for spacecraft design has been to build conservative margins to accommodate a notional payload, the constraints indicated in Table 4-2 have bounded the design.

Table 4-2. Spacecraft Resource Summary

Bus Voltage	24-33 V
Survival Heater Voltage	24-33 V
Data Bus	TBD*
Data Bus Protocol	CCSDS
Timing Signal	1 Hz
Stored Command Capacity	Yes, limited capability
On-Board Data Storage	8.2 Gbits
Science Attitude Pointing frame	3-axis stabilized in a Local Vertical / Local Horizontal frame, with fixed ram/nadir orientation
Pointing Control	< 2 deg
Pointing Knowledge at the instrument sensor (post-processing)	<0.02 deg
Spacecraft Mag Field (DC) – Ram plate	1000 nT
Spacecraft Mag Field (DC) – Deployables (@1.2 m)	100 nT
Spacecraft Mag Field (AC/transients) – Deployables (@1.2 m)	2 nT/min
Variation of Spacecraft Surface Potential – across any two points on the Ram plate	0.1 V (relative to S/C ground)

* Protocol type is TBD and may include RS-422, SpaceWire, and 1553 among others. It is expected that the S/C will be able to accommodate a variety of data bus system configurations. Therefore, no data bus systems are precluded from potential S/C accommodations.

As reflected in Table 4-2, the conservative assumption for a spacecraft-provided deployable is a 1.2m boom. This boom, or these booms, would be the responsibility of the Project Office and would not be funded out of any investigation's budget.

However, it is recognized that certain investigations may require a longer boom in order to reduce spacecraft interference with instrument performance. After instrument selection, it is expected that that those investigations will negotiate with the GDC Project Office regarding a spacecraft requirement for a longer boom.

Proposals that request a longer boom must fully describe the acceptable level of spacecraft interference (e.g., maximum spacecraft-generated magnetic field), identify the required boom length (based on the anticipated spacecraft interference) and other boom technical specifications, and encumber reserves for the cost of a required boom (including meeting any cost-related requirement levied by the SALMON-3 AO and the GDC PEA). Those encumbered reserves (and the associated unencumbered reserves) will ensure that all costs are properly accounted for, but they will not be part of the investigation contract as the final boom provision will remain a Project Office responsibility.

GDC-PIP-4.2: Proposals shall clearly identify any need for a spacecraft-mounted boom longer than 1.2m, detail required boom technical specifications, and encumber reserves for the boom's procurement. Proposals shall clearly identify the spacecraft interference's impact on instrument performance driving this need and the acceptable level of spacecraft interference in flight. Proposals shall assume the required boom specifications in the baseline investigation, and shall clearly identify and describe the scientific and technical risks if only the 1.2m boom is provided.

4.2.1 Sensor Unit and Electronics Box Mounting Distance

If necessary, all instrument electronics boxes will be accommodated to be within 0.6 m of the respective sensor units. A subset of the boxes can be accommodated to within 0.3 m of the respective sensor units. These mounting distances do not apply to boom/standoff mounted instruments.

4.2.2 Deployed Payload Stiffness

The S/C is expected to be able to accommodate deployment elements and payload subsystems with a deployed natural frequency greater than 1 Hz.

4.2.3 Navigation System

The spacecraft will use GPS to determine position and provide time via the tone and timing pulses to each instrument. UTC registration accuracy will be within 100 msec. Within a given spacecraft, time tag knowledge between instrument measurements will be within 10 msec. Definitive position and velocity knowledge relative to the inertial frame are 50m, 10 cm/s RSS 3-sigma, respectively.

4.2.4 Attitude Determination and Control

The GDC spacecraft is 3-axis stabilized and maintains pointing with one axis along the velocity vector and one axis pointing toward the earth (nadir direction). The S/C is designed to unload momentum infrequently with propulsion.

At the sensor, pointing accuracy is to be $< 2.0^{\circ}$ and the pointing knowledge $< 0.02^{\circ}$. In order to achieve the 0.02° sensor attitude knowledge, the instrument-generated uncertainty in pointing knowledge (due to physical misalignment within the sensor, thermal effects, etc.) is assumed to be less than 20 arc sec (3 sigma). Instruments that do not require 0.02 degree knowledge can have larger internal error budgets for these sources. The project will support on-orbit characterization of bias errors during commissioning to determine and apply bias corrections.

4.2.5 Electrical Interfaces

Each individual spacecraft electrical architecture is single string. The spacecraft will control the main bus power relays and each circuit will be fused in the spacecraft.

Power to the survival heater bus will be available continuously throughout the mission. Passive thermostats with fixed set points will be used to control the survival heaters, although alternative solutions can be proposed for instruments that may be perturbed by DC heater currents.

4.2.6 Power Interfaces

The spacecraft will power instruments using a direct-energy transfer, 28 V balanced power bus with a nominal range from 24 V to 33 V, but potential steady-state DC voltages between 0 V and 40 V. The spacecraft will not guarantee protection for instruments from failure propagation or instantaneous intentional or unintentional switch-off on the external power line. The spacecraft will require that instruments power on in a way that limits in-rush current (with the precise limit to be specified in project Phase A/B).

The GDC spacecraft will provide the command initiation and actuation pulse for release of deployable covers or mechanisms. Coordination is expected between the instrument and S/C. Strong consideration for non-explosive actuators (NEAs) is preferred.

The instruments will be responsible for isolating between primary and secondary power lines according to an interface specification document (to be developed in Phase A/B, expected to be ≥ 1 MΩ). The spacecraft will not provide any secondary voltage conversions responsible for instrument hardware. The spacecraft power system will require that any safety inhibits be independent, verifiable, and stable, and that they stay in a safe position even in the case of energy failure.

The spacecraft will use a single-point ground (SPG) approach. The instrument power conversion unit (PCU) provides the SPG for an instrument ground tree by referencing the secondary power return directly to the chassis.

Intra-instrument harnessing (including mass) is the responsibility of the instrument provider in coordination with the spacecraft team. The spacecraft team will provide all other harnessing.
Any interconnects internal to an instrument's deliverables is the responsibility of the investigations. Table 4-3 provides a summary of the spacecraft electrical interfaces available to the science payload.

Table 4-3. S/C Electrical Interfaces Summary

Services	QTY
28 V primary power service, 2A each	10
28 V deployable power service, 5A each (with required safety inhibits)	4
Communications services	10
Pulse Per Second (1 PPS)	10

4.2.7 Command & Data Handling

The spacecraft computer controls all spacecraft operations and distributes a timing signal. The S/C will have a minimal role in instrument commands and telemetry, providing a "bent pipe approach" for forwarding commands to the instruments, and receiving health and safety and science data from the instruments for storage and ultimate transmission to the ground. In general, communication services will consist of a "pass-through" of commands to and from the instrument interface with no data processing provided by the spacecraft. The spacecraft will have the ability to autonomously safe instruments based on pre-determined limit settings of S/C-provided telemetry and handshaking.

Data transfers are packetized using the Consultative Committee for Space Data Systems (CCSDS) or other mutually agreeable packetized data protocol. In normal operations, the spacecraft will support storage of command packets for distribution to the instrument at a later time. Memory is available, but limited, to all instruments for stored commands. Stored command packets may be individually time tagged at one second intervals, or may be part of a macro sequence.

Sharing data between instruments is not defined at this time.

The spacecraft will generate a 1 Hz timing pulse that will be distributed to each instrument. The spacecraft will distribute information that can be used to correlate the 1 Hz timing pulses among the spacecraft. The spacecraft will collect data from the instruments and store the data in the onboard data recorder. The S/C will not modify the science packets before downlink. Determination of the final format will be a phase A activity.

4.2.8 Thermal Interface

The instruments that are mounted to the S/C structure, including electronics, will be thermally coupled to the spacecraft. Coordination between the instrument provider and the S/C vendor is expected. The spacecraft surfaces within view of the instruments will be covered with multi-layer insulation (MLI) to minimize radiative coupling with the spacecraft. The spacecraft will provide the overall thermal design and integrated system thermal analysis to accommodate the instruments. The spacecraft will provide temperature sensors and heaters to monitor and maintain each instrument mounting interface within an operational temperature range of -10 to +40 degrees C, and a survival temperature range of -20 to +50 degrees C. It is expected that radiator surfaces have been allocated to the ram, zenith and nadir panels.

4.2.8.1 Thermal Interface for Deployed Instruments

The instrument sensor-to-spacecraft deployable interface will be maintained to an operational temperature range of -20 to +50 degrees C, and a survival temperature range of -30 to +60 degrees C. The deployed instruments will be thermally isolated from the deployed element and spacecraft, and coordination between the instrument provider and the S/C vendor is expected. Further refinement of operational and survival temperature requirements will be evaluated following instrument selection.

4.2.9 Spacecraft Propulsion

The spacecraft will have a propulsion system located on the aft panels, and thruster firings are anticipated. Instruments that desire accommodation on the aft face will be exposed to thruster plume contaminants and plume or thruster heating.

The placement of the thrusters on the aft panels is not known at this time, nor the associated plume, thermal and contamination effects on adjacent surfaces. The spacecraft will provide a warning to all instruments via commands over the spacecraft bus prior to the firings. The operations concept involves sending instrument safing commands prior to any maneuver that involves thruster firings.

4.2.10 Magnetic Properties

The spacecraft will not generate a DC magnetic field of more than 100 nT at a distance of 1.2 m from the spacecraft in at least one location suitable for deployed sensors. The spacecraft will not generate a transient magnetic field of more than 2 nT/min at this same location.

The orbital variation of magnetic field as measured 1.2 meters from the spacecraft will be within 50 nT per orbit.

The AC variation of magnetic field as measured 1.2 meters from the spacecraft will be less than 2 nT RMS from 1-100 Hz.

4.2.11 Electrostatic Properties

The spacecraft will have a differential potential of less than 0.1 V for instruments on the ram face, and no exposed positive potentials on its exterior. It is expected that instruments will not be a significant driver of S/C potentials.

4.2.12 Fault management

The spacecraft fault detection and control software will detect and respond to events indicated by anomalous housekeeping telemetry. There will be a limitation on the number of critical sensors available to instruments. Autonomous safehold will place and maintain the observatory in a sun-pointing, power positive mode. The spacecraft will notify instruments via commands over the spacecraft bus of current or pending conditions such as safehold entry, pending load shed power off, thruster firing, etc. Instruments will be responsible for safing themselves following such notifications, although there will be certain safehold events where the spacecraft will power instruments off directly (without notice).

Investigations will be responsible for internal fault detection capabilities, expected spacecraft safing and sun viewing or other operational constraints to ensure that mission operations maintain the overall health and safety of the payload.

4.3 Spacecraft Accommodation

With the current understanding of potential spacecraft solutions, there are certain exceedances (listed below) that are likely to present instrument to spacecraft accommodation challenges.

Proposers should take these potential accommodation challenges into consideration:

1) Significant excursions from the PEA values for total payload power, volume, mass, data rate, etc.
2) A significant increase in frontal drag area -- observatories are expected to have difficulty accommodating more than 1 m^2 of deployed sensor area (projected in the ram direction).
3) A significant increase in total observatory Moment of Inertia (MOI), or a significantly detrimental change in the observatory CP/CG (Center of Pressure / Center of Gravity) offset.

4) Mounting on cross-track or nadir faces and requiring a Field of View (FOV) that is at an angle more than +/- 70 degrees from nadir in the cross-track direction.
5) Deploying on a cross-track face at an angle larger than +/- 70 degrees from nadir (i.e., closer to the cross-track axis).
6) Significantly tighter contamination, electrostatic, electromagnetic, or magnetostatic cleanliness requirements than those outlined in this document.
7) Protrusions more than 10 cm from the aft face or more than 5 cm from the ram plane.
8) In the stowed configuration, protrusions more than 15 cm from the nadir face or more than 15 cm from the zenith face.
9) Designs that would require a spacecraft length longer than 1.2m.

5. MISSION OPERATION SYSTEM AND GROUND DATA SYSTEM

The descriptions in Section 5 provide context for the SALMON-3 requirements in the PEA and should not be taken to supersede or nullify those requirements.

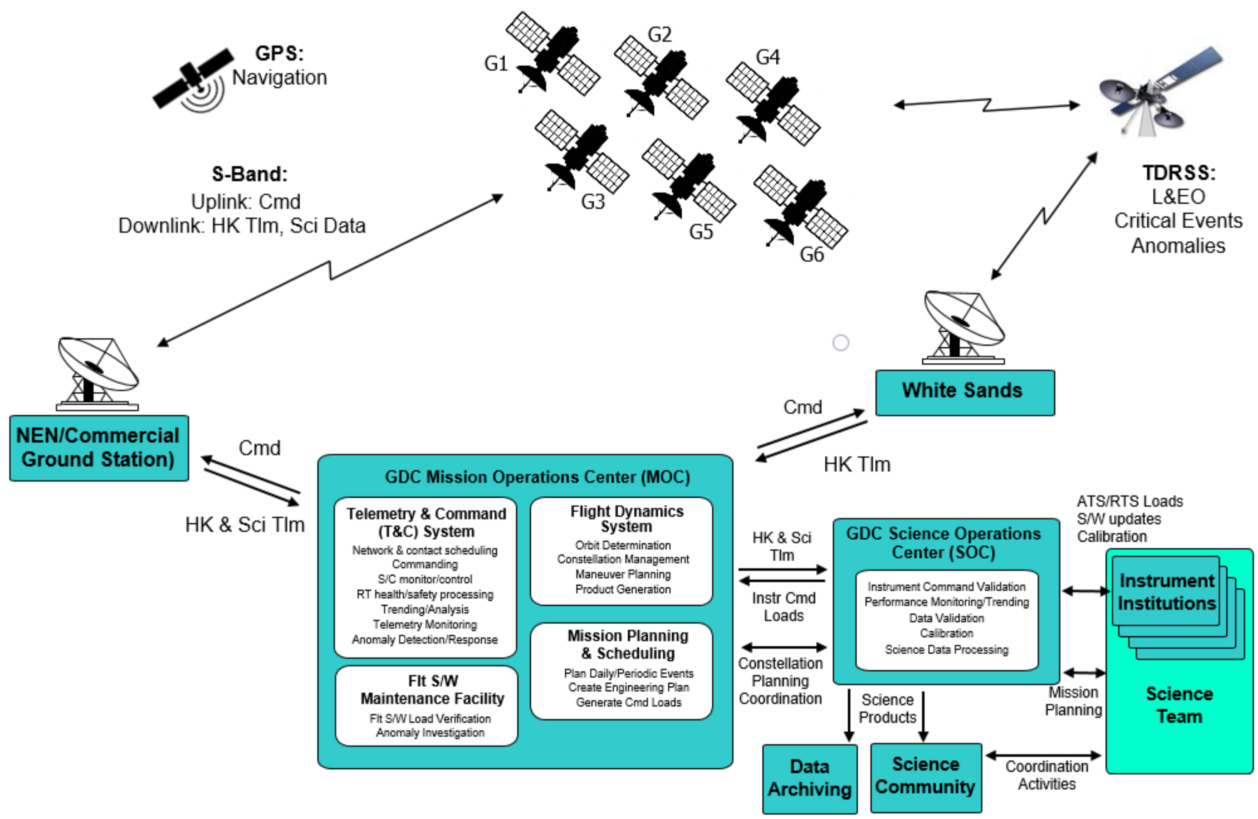

Figure 5-1. System Architecture Overview

5.1 Description

The GDC mission operations are designed to support the spacecraft integration and testing, launch preparation, early orbit checkout, and all nominal and off nominal orbital operations. The MOC is responsible for spacecraft operations, telemetry capture, and transmitting housekeeping and science data and other operational products to the SOC. The SOC is responsible for coordinating instrument operations and providing the MOC with instrument and payload-level commanding products. The MOC provides the necessary interfaces with the Ground System Network and the SOC, to facilitate the transfer of science data and commands with each spacecraft in the constellation. The MOC will develop operations products, procedures and software tools as required, as well as configure the necessary physical infrastructure, emergency power, HVAC, and security as required.

The instrument teams will provide algorithms and/or code to the SOC to take Level 0 data and process it to Level 1/Level 2 products. The SOC produces Level 1/Level 2 (and possibly Level 3) products and sends it to the investigation lead institutions. The instrument teams then quality flag and validate the data, update calibration files, and update processing algorithms/code. The instrument teams then forward this material back to the SOC, along with any higher-level products that they develop. The SOC would also forward data directly to the science community and to a science data archive. The SOC is envisioned to coordinate with other key science institutions and mission partners to perform its duties. The instrument institutions are the “owners and operators” of the GDC flight instruments. They provide primary support in the care and operation of their GDC flight instruments and forward commanding sequences required for instrument operations. Investigations will provide necessary procedures for nominal instrument calibration and decontamination operations. The Science team will support GDC mission planning and operations in planning and coordinating calibration periods.

5.2 Teams

Management of mission operations will be the responsibility of the Mission Manager (MM), residing at the MOC. The MM will coordinate with each operational element to ensure effective planning and safe execution of each mission phase and to ensure that appropriate practices are applied throughout the mission.

A Flight Operations Team (FOT) will perform several critical functions: (1) real time commanding and control of the flight system, (2) mission level trending, performance and prediction, (3) mission planning, and (4) mission testing. Certified flight controllers in the MOC would perform uplink and downlink operations, monitor system health and safety and respond to limits and alarms using established operations procedures.

A Science Operations Team (SOT) will be responsible for operations at the SOC and would primarily plan and test integrated instrument command sequences, work closely with the FOT and the Science team.

The Science team will work closely with the SOT for coordinating the development of instrument sequences and coordination of science activities across the investigations.

5.3 Facilities

The mission operations and ground system will include hardware, software, data links and facilities used to conduct operations, generate uplink commands, receive, process and disseminate telemetry. Communications between the ground systems will occur over secured network connections and be protected by strong firewall protection and encryption standards.

6. OPERATIONAL SCENARIOS

6.1 Launch and Early Orbit

Launch and early orbit is defined as the time frame between pre-launch and the initiation of power positive observatories. The observatories will be launched from a single launch vehicle. The observatories will be powered on prior to launch, but in a low power configuration with the instruments powered off. The transmitters will be powered on 10-15 minutes prior to separation to allow for telemetry at separation. Separation, deployment, and sun acquisition will be monitored via TDRS. Both SSA services from a single TDRS will need to be utilized as observatories will be released in pairs with each pair being released approximately 45 minutes apart. The transponders for each pair will need to be on separate frequencies. The spacecraft will execute orbit adjustments as required to achieve their desired orbital configuration. The nominal orbital configuration for the DRM is given in the document GDC-AO-DRMPED, “Geospace Dynamics Constellation Design Reference Mission: Predicted Ephemeris Description”.

6.2 In orbit Checkout

The on-orbit checkout / commissioning phase will consist of the first 90 days. It will include checkout and calibration of the observatories, and will encompass both spacecraft checkout, instrument power on and commissioning. Spacecraft components will be brought online and capabilities verified. This will nominally include checkout and calibration of the Attitude and Control System (ACS), propulsion system, safehold conditions, and instrument power on, checkout and commissioning.

6.3 Nominal Mission and Nominal Science

The observatories and instruments are intended to operate in a steady state with little variation. The nominal mission phase will consist of routine and continuous instrument operations. Spacecraft operations will utilize the NEN via an S-band link for command and telemetry. The S-band downlink will require about 10-12 minutes of downlink per spacecraft per day. Command uplink will need to occur approximately once per week for nominal command loads. The spacecraft will have an onboard data recorder capable of holding science and housekeeping data.

Though eclipse durations are expected to be sufficiently short as to minimize their effects, the observatories will go through eclipse seasons where the main requirement will be to minimize the impact on science operations.

It is the plan for all GDC observatories, including all instruments to operate in science mode throughout the orbit, including regions of high penetrating radiation like the SAA.

GDC spacecraft will perform regular maneuvers throughout the mission lifetime to maintain temporal separation (~every 2 weeks), control spacecraft momentum (~every 2 weeks), maintain required altitude under drag environment (~3.5 months) and initiate/stop differential plane drifts (two times in the mission timeframe). Primary navigation will use GPS and S-band two way Doppler for back up.

6.4 Disposal

At the end of the mission, the baseline approach is to dispose of each spacecraft via controlled re-entry and be fully compliant with NASA disposal requirements.

7. ENVIRONMENTAL FACTORS

Instruments shall be able to withstand the orbital and launch environments of the GDC mission. The following sections describe particular areas of concern the instruments must account for in their design and testing program.

7.1 Atomic Oxygen (AO)

The altitude range that the GDC observatory will be orbiting is an atomic oxygen-rich environment. Atomic oxygen reacts with and erodes many organic materials (kapton polyurethanes, epoxies, etc.) and exposes satellites and spacecraft to damaging corrosion. Atomic oxygen degradation will need to be considered when selecting materials that will be in the ram direction at any time during the mission. Mitigation strategies will need to be taken for materials that are especially susceptible.

GDC-PIP-7.1: Instruments shall only have exterior exposed surfaces that can survive an atomic oxygen fluence of 3×10^{22} AO per cm^2 over the duration of the mission life.

7.2 Radiation

GDC-PIP-7.2: Instruments shall be able to survive a 3 krad-Si per year of mission life for 100 mils Al equivalent shielding (with a total mission life of 9 krad-Si at 100 mils Al) which includes a confidence level of 95%.

GDC-PIP-7.3: Instruments shall be designed to avoid or tolerate errors to single event effects.

- Instrument components shall be designed to avoid or tolerate errors due to non-destructive Single Event Effects (SEEs) and have Linear Energy Transfer (LET) thresholds for SEEs greater than 20 MeV-cm^2/mg. If parts have a threshold less than 20 MeV-cm^2/mg then single event rate calculation and mitigating design factors will be required.
- All devices shall have thresholds for Single Event Latchup (SEL) greater than 37 MeV-cm^2/mg.
- All power transistors shall have a Single Event Gate Rupture (SEGR) and Single Event Burnout (SEB) threshold LET > 37 MeV-cm^2/mg when biased at 133% of the application Vds or Vce. (Vds is the drain-source voltage, and Vce is the collector-emitter voltage.)

7.3 Magnetic Cleanliness

The GDC instrument magnetic requirements will be dependent on the limitations of selected instruments within the science payload; therefore, GDC magnetic requirements will be determined after instrument selection. The investigations will work with the project to communicate their instrument magnetic cleanliness requirements, signature, and the associated precautions needed.

The current assumption is that the GDC science payload will be highly susceptible to magnetic field effects. Magnetic cleanliness is difficult to achieve if it is not addressed and designed for through all instrument design phases. Investigations will refine and implement standard magnetic cleanliness design mitigations and best practices early in the design phase. (See Sections 2.6 and 7.2.1 of the PEA for related discussions.)

7.4 Electrostatic Cleanliness

The GDC instrument electrostatic requirements will be dependent on the limitations of selected instruments within the science payload; therefore, GDC electrostatic requirements will be determined after investigation selection. The investigations will work with the project to communicate their instrument electrostatic cleanliness requirements, signature, and the associated precautions needed.

The current assumption is that the GDC science payload will be highly susceptible to electrostatic field effects. Electrostatic cleanliness is difficult to achieve if it is not addressed and designed for through all instrument design phases. Investigations will plan to identify and implement design approaches to mitigate electrostatic field buildup early in the design phase. (See Sections 2.6 and 7.2.1 of the PEA for related discussions.)

7.5 Contamination

The current assumption is that some, if not all instruments in the GDC science payload will be sensitive to particle and molecular film contamination. Accordingly, after selection investigations will be asked to provide the anticipated allowable contamination levels (per IEST-STD-CC1246E) on contamination sensitive surfaces that could be cross-contaminated by adjacent spacecraft or instrument surfaces. Instruments will follow a good neighbor policy whereby mission contamination requirements for outgassing and surface-cleanliness will be set by the most contamination sensitive instruments. (See Sections 2.6 and 7.2.1 of the PEA for related discussions.)

GDC-PIP-7.4: Instruments and associated Ground Support Equipment (GSE) shall be compatible with being in a class 7 cleanroom environment per ISO-14644-1.

Adequate care must be taken during instrument design to assure that materials will not generate particles or molecular outgassing that could be deleterious to the instrument, other instruments or the spacecraft. Material selection must assure materials are appropriate for the instrument and the mission environments. The vacuum stability of all materials shall be per GDC-SMA-PLAN-0002, Instrument Mission Assurance Requirements (IMAR) outgassing requirements (1.0 TML & 0.1 CVCM). Exterior surfaces should not generate particles and should be cleanable with Isopropyl Alcohol and cleanroom compatible polyester wipes. If there are surfaces that cannot be cleaned, then the investigation should provide protective covers to protect them from contamination during ground processing and, if necessary, launch.

The GDC project will perform an analysis using state of the art 3D mass transport software (ISEM, MOLFLUX, and others). The analysis will assure that out gassing, ascent venting, and molecular venting rates are sufficient to meet the anticipated low outgassing and molecular deposition rates for this mission. Outgassing rates will be verified through TQCM monitored bake-outs. The observatory and launch site facilities will have a dry nitrogen purge available during I&T up until launch if required. It is expected that there may be brief interruptions to the nitrogen purge availability on the scale of several hours. Surface cleanliness levels will be monitored through witness sample particle fall-out plates, direct surface cleanliness testing, and UV and white light inspection. Cleaning operations will be performed as necessary. I&T operations will be conducted in class 7 cleanrooms per ISO-14644-1. When not in a class 7 cleanroom or better, the flight hardware will be bagged or otherwise protected.

If the instrument has a voltage exceeding 100V, the investigation will be expected to provide the vacuum level required to prevent corona discharge damage.

7.6 Orbital Debris

The observatory (of which the instruments are a part) will be compliant with orbital debris and spacecraft re-entry requirements per NPR 8715.6B and NASA STD-8719.14A, "Process for Limiting Orbital Debris". As the instrument materials will be included in the Observatory Master Equipment List, investigations should remain aware of the impact of certain materials on the project's compliance with these requirements. During development, investigations shall work in conjunction with the project and may be required to make design accommodations for that compliance.

7.7 Surface Charging

GDC-PIP-7.5: Instruments shall only have external surfaces where no more than an area of 6 cm^2 has a resistivity >1E9 Ohms/ cm^2.

7.8 Launch Environment

GDC-PIP-7.6: Investigations shall design and test in accordance with the GDC-PYLD-REQ-0004GDC "Representative Launch Environment" document located in the GDC Program Library.

The launch vehicle for the GDC project has not yet been selected. The loads in this document are intended to envelope flight loads for all possible spacecraft and launch vehicle configurations. The launch environments will be updated when mission specific information becomes available.

8. DELIVERABLES, V&V AND I&T

8.1 Deliverables

The investigations are required to perform the necessary systems engineering (SE) required to ensure that the instrument meets all of the performance, interface, and implementation requirements of the mission; including the analyses, flow-down of technical requirements, allocation of system budgets, verifications for the instruments, definitions of interfaces, technical risk evaluations, system design tradeoff analyses, requirements for GSE, orbital performance analysis, flight software requirements analysis, and lower level requirements (e.g. subsystem, components, assemblies, parts). This includes documenting all information from the design, qualification testing, acceptance testing, and compatibility testing of the hardware and software, in conjunction with analysis and assessment of the data with respect to expected performance.

The following sections identify instrument delivery items for the GDC project. As described in the following sections, the investigations will:

- Provide or contribute to all data requirements.
- Provide models to support system level modeling and analysis.
- Provide hardware (and software) that meets project requirements.

8.1.1 Data Requirements

The manuals, reports, plans, and other written documentation listed in GDC-PYLD-CDRL-0002, the GDC Representative Instrument Contract Data Requirements List (CDRL) located in the Program Library are used to control the development of the instrument, its interface with the spacecraft, and the certification of the flight worthiness of the instrument and its software. The CDRL includes Mission Assurance Requirements documents located and defined in the GDC-SMA-PLAN 0002, the GDC IMAR. The exact composition of the CDRL may change after selection, but prior to confirmation. A comprehensive CDRL will be negotiated with each selected investigation and will be tailored appropriate to the contractual agreement. The final CDRL will require investigations to compose or provide input to controlling data at various stages in the instrument life cycle. Refer to the CDRL for further descriptions of documents and data referenced in the PIP, as well as corresponding due dates.

GDC-PIP-8.1: Investigations shall budget and schedule for the composition and provision of input to controlling data document. Investigations shall use the GDC Representative Instrument CDRL (GDC-PYLD-CDRL-0002) for planning purposes.

8.1.2 Models

The instrument teams shall be required to support spacecraft level modeling, design, and interface definition through delivery of structural, radiation, thermal, contamination and 3D Computer-Aided Design (CAD) instrument models at an appropriate level of fidelity based on negotiation with the project. For example, deployables may need higher fidelity structural models to be delivered than would be expected for an electronics chassis. Refer to the CDRL for additional specifics on modeling requirements.

8.1.3 Development Units

The development approach for the instrument subsystems should include the use of Engineering Models (EM), Engineering Test Units (ETU), and/or qualification units to reduce the development risk associated with each subsystem depending on the maturity of the design. The GDC project will use the specified units for software development, interface testing and fit-checks, and to create a ground test bed to enable functional testing without the need for the flight units.

GDC-PIP-8.2: Investigations shall test and deliver instrument units as described by Table 8-1. These instrument unit deliveries will include the specifications and additional items identified in Sections 8.1.3.1 through 8.1.3.5, and the support and accompanying deliverables as described in sections 8.3, 8.4.1 and 8.4.3; as appropriate for the unit types.

Table 8-1 lists the quantities and delivery dates for deliverables that shall be provided by the investigations, along with accompanying test levels if applicable. The table includes ETU units, flight units and instrument flight spares. (Flight spare electronics are also required to be delivered and are not shown in the table.)

The number of flight units to be delivered (denoted as “n” in Table 8-1 are as required by the GDC PEA (see Section 5.5.1 of the GDC PEA).

Table 8-1. Investigations Deliverables

	Control Electronics Engineering Test Unit	Instrument Engineering Test Unit	Flight Units	Instrument Flight Spare
Quantity	1	1	n	1
Delivery Date	ICDR	ICDR	As stated in PEA	1 month after final flight unit delivery

All Flight Units and spare flight units to be tested to protoflight qualification levels prior to delivery

n = number of instrument copies to be delivered for flight (excluding the spare)

8.1.3.1 Engineering Test Unit (ETU)

Per NPR 7123.1C (Appendix A) Engineering Test Units are defined as:

> A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. Used to validate design, fabrication, and functions – also used to support documentation/procedure development, software development, test beds, and troubleshooting.

8.1.3.2 Flight Units

As shown in Table 8-1, the investigations will provide: A quantity of (n) flight units tested to protoflight qualification levels

The instrument teams shall provide a minimum of 2 sets of all electrical and mechanical GSE needed for shipping, handling, stand-alone testing, integration, system testing and launch operations (including optical and thermal calibration targets and other specialized equipment deemed necessary).

All test cables, safe/arm plugs, connector savers and any protective non-flight covers shall be included with the flight hardware delivery. Instrument software shall be provided with each hardware delivery.

The instrument team should expect the project to provide a command and telemetry spacecraft simulator for development purposes.

8.1.3.3 Flight Spare Unit

A flight spare unit is defined as the set of hardware needed to fully instrument one spacecraft bus. Investigations shall provide a fully integrated and tested instrument flight spare. This will allow rapid replacement of the flight model in the event of a post-delivery failure or anomaly. Spares shall be retained by the investigation unless/until needed by the project.

8.1.3.4 Flight Spare Electronics

The investigation shall develop electrical spares and boards sufficient to build an entire instrument. Investigations shall have a built and tested spare for complex boards like HVPS, cards with multiple large FPGAs, and complicated Analog & RF boards. For simple boards, having kitted spares is adequate. These components shall be available during flight integration, however retained by the investigation unless/until needed by the project.

8.1.3.5 Other Hardware/Software Deliverables

For each unit (i.e., ETU, Flight, Spare), investigations shall design, build, test, calibrate and verify performance of the unit prior to delivery to the GDC project. Unless otherwise stated, instrument software and GSE shall be provided as necessary to support installation, operation and calibration of the delivered hardware.

GDC-PIP-8.3: Investigations shall abide by the software requirements as articulated in NPR 7150.2C (NASA Software Engineering Requirements).

A serialized drill template shall be provided with each delivered unit. The instrument provided drill template shall be capable of being used to match drill locations for clearance holes and shear pins on the spacecraft-side of the interface.

Additional hardware deliverables specific to flight units are listed in section 8.1.3.3.

8.2 Pre-Delivery Verification and Validation

GDC-PIP-8.4: Investigations shall complete instrument verification and validation prior to instrument unit delivery.

Verification and Validation (V&V) is required to provide evidence that an instrument meets its objectives and constraints, at instrument level and when integrated to the observatory. V&V is an integral part of instrument architecting, so it should be started early and carried across the instrument lifecycle. The instruments should develop verification plans in parallel with requirements development to ensure clear meaning and timely V&V capabilities. The anticipated V&V process would address design of the system, quality of implementation, veracity of architectural assertions, viability of operational plans and scenarios, and credibility of models and analyses.

V&V can be accomplished through testing, analysis, inspection, demonstration, or simulation. All of these options should be considered for use in each specific case. It should be recognized that most tests have some non-flight-like aspects and other V&V methods have similar deficits. Therefore, how the results of V&V are collectively extrapolated to flight conditions should be understood and well addressed.

GDC-PIP-8.5: Instruments shall follow NASA/GSFC Rules for the Design, Development, Verification, and Operation of Flight Systems (GOLD Rules), GSFC-STD-1000G for flight electronic hardware operating time. In addition to the GOLD Rules, the flight unit instrument electronics shall accumulate a minimum of 300 hours of functional operation prior to delivery for system I&T.

8.2.1 Flight and Spare Qualification Campaign

GDC-PIP-8.6: The investigations shall abide by the requirements as articulated in the GOLD Rules, GSFC-STD-1000G.

GDC-PIP-8.7: Investigations shall conduct EMI/EMC tests (with the exclusion of the DC Magnetic Test) in accordance with General Environmental Verification Standard, GSFC-STD-7000A Section 2.5.2.

GDC-PIP-8.8: Investigations shall conduct structural, mechanical, EMI/EMC, thermal and mechanical testing as prescribed in Table 8-2. For all applicable tests, protoflight units shall be tested at Protoflight Levels (PF). Testing levels are provided in Appendix A for reference.

Table 8-2. GDC Environmental Test Matrix

	Structural & Mechanical								EMI/EMC					Thermal		Mechanical
Item:	Static Loads (Design Strength)	Sine Burst (Quasi-Static Load)	Low Level Sine Sweep (20-2000 Hz)	Sinusoidal Vibration(5-60 Hz)	Random Vibration(20-2000 Hz)	Shock	Acoustic	Mass Properties	Conducted Emissions(CE101/102 + CM)	Conducted Susceptibility	Radiated Emissions(RE102)	Radiated Susceptibility (RS103)	DC Magnetic Test[2]	Thermal Balance	Thermal Vacuum (4 Cycles)	Deployment
Observatory				PF	PF	X	PF	X			X	X	X	X	PF	Deployments and Covers
Instrument[1]		PF	X		PF			X	X*	X*	X*	X*	X*	X*	PF*	Instrument Covers

<u>LEGEND:</u>
Test Level / Duration per specified GEVS Sections and Gold Rules where applicable:

PF: Protoflight levels
X: Test required

Other:
Instrument[1] – Flight Units and Flight Spare

DC Magnetic Test[2] - The magnetic test consists of the DC stability and total magnetic field measurements in both powered on and off configurations. The stability and total field measurements should be expressed in magnetic moments and field intensity.

*Thermal vacuum cycling, thermal balance testing, and EMI testing will be performed with the electronic box & sensor integrated together

8.3 Post Delivery Verification and Validation

GDC-PIP-8.9: Investigations shall provide on-site support for post-delivery activities including, but not limited to: instrument functional test, instrument calibration, thermal blanket integration, instrument integration, all instrument powered activities, post spacecraft integration instrument calibration, and observatory environmental testing.

The integration of the observatories will be performed on a staggered schedule. Specific activities will be performed one observatory at a time to allow a single team to perform the integration. Despite this goal, the instrument team may be required to support different activities on multiple spacecraft.

However, during Thermal Vacuum (TV) and Thermal Balance (TB) testing, two observatories may be tested in a single chamber at the same time. One observatory may be operated, while the second observatory is placed in a safe, quiescent state.

Investigations are responsible for instrument measurement (cross- and inter-)calibration and identifying any special test configurations or handling equipment required at observatory level. The performance of each instrument will be checked and trended throughout testing to monitor for consistency with instrument level testing and previous calibration activities. Investigations are responsible for providing a list of trending parameters that capture the health, safety and performance of their instruments.

The full observatory test program will include the following tests at a minimum:

- EMI/EMC (including DC Magnetic Test)
- Vibration
- Acoustics
- Shock, both launch vehicle shock environments and self-induced shocks
- TB with three thermal cases (hot operational, cold operational, and cold survival)
- TV testing, 4 thermal cycles
- Comprehensive performance testing (one before any environmental testing, one at hot plateau in TV, one at cold plateau in TV, and one after all environmental testing has been completed)
- Functional tests are to be performed:
    - between all major tests,
    - at the launch site after arrival,
    - delivery on the launch pad, and
    - every two months spanning between time of launch site arrival and delivery on the launch pad
- Alignment of the instruments before and after mechanical environments and after thermal vacuum testing with respect to a representative spacecraft mounting interface
- Deployment testing of any mechanisms before and after mechanical environments
- RF compatibility (NEN and SN)

8.3.1 End-to-end Performance

GDC-PIP-8.10: Investigations shall ensure that the instrument design supports comprehensive performance testing at ambient and end-to-end testing in a thermal vacuum. This testing will be performed to simulate the flight environment as close as possible.

8.4 Delivered Hardware Support

8.4.1 Control Electronics ETU

Early in the development cycle, Investigations will deliver a Control Electronics ETU (see Table 8-1). The Control Electronics ETU will be used for an interface test to make sure communications can flow both ways (commands and telemetry). This will be performed to verify harness, cables, data interfaces (commands and telemetry), time distribution, etc. Additionally, the Control Electronics ETU can be used as an instrument simulator. This will become part of the FLATSAT and will be used for software maintenance post launch.

8.4.2 Instrument ETU

Prior to the production of flight units, the investigations will provide an instrument ETU to the GDC testbed for a hardware and software interface test (see Table 8-1). The purpose of the test is to verify that the instrument and spacecraft teams have implemented the interfaces in a cohesive manner.

Investigations will plan to provide support for program level documents. Example documents include:

- the development of system testbed I&T procedures
- the development of system V&V test objectives
- instrument V&V procedures
- integration of the science instrument into the system testbed
- instrument specific support for system testbed V&V

System V&V within the testbed would consist of scripted tests conducted by trained test conductors and systems engineers, along with investigations support. Flight software would be used to interact with the instrument.

8.4.3 Flight Units

8.4.3.1 Integration

Integration of the flight instruments with the spacecraft occurs in the project I&T phase. A System Integration Review (SIR) is held to verify that the project is ready to begin and conduct assembly, test, and launch operations of the flight and ground systems.

After the delivery of each payload instrument, and prior to integration onto the spacecraft, each investigation shall: a) perform a hardware inspection, b) pass a stand-alone acceptance test to verify the health of the delivered instrument, and c) perform a brief calibration test. Instrument hardware delivery dates shall accommodate any instrument-required pre-integration activities, as well as adequate time to accomplish stand-alone bench acceptance test.

All of the design, analysis, development, and fabrication activities for the payload module are the responsibility of the spacecraft team. Integration of the individual instruments to the payload module will be conducted at the spacecraft team facility.

Investigations shall provide on-site support for instrument integration activities. Dates for support are dependent on actual instrument delivery dates and I&T dates for instrument integration to the spacecraft.

Each instrument is integrated using assembly and test procedures that ensure mechanical and electrical safety. Investigations will be responsible for providing inputs to plans and procedures monitoring instrument telemetry during testing, troubleshooting anomalies, and providing post-test analyses for system level tests involving the instrument.

8.4.3.2 Observatory Functional and Environmental Testing

Following instrument integration and checkout, functional tests will be conducted on the flight observatory system. Functional tests using the flight instruments will be conducted throughout the I&T flow and are aimed at proving out the system requirements. Investigations shall provide on-site or remote support for these tests.

Functional tests will also be repeated after each environmental test to ensure that the test effects have not degraded system performance. Post environmental tests facilitate verification of any modification to flight software or flight sequences.

These tests will include instrument operations and will require support from the investigation principal investigations, the instrument development team, and project instrument engineers.

8.4.3.3 Operational Readiness Tests (ORTs)

Throughout I&T there will be opportunities to conduct tests of the flight system using the ground system and mission operations system procedures. These flight-like tests draw on operations personnel to “fly” the spacecraft in a configuration that mimics flight for all mission phases.

I&T system engineers will perform all testing with extensive support from subsystem and instrument engineers and the operations team. Instrument operators will participate in these tests and follow procedures as if the vehicle were on-orbit. These are tests of personnel, procedures, and ground equipment as well as flight equipment and software. Investigations support for science team training and ORTs shall be scheduled.

8.4.3.4 Prelaunch

Investigations will support instrument unique closeouts, final inspections and final functional tests.

8.4.3.5 Post-Launch

Investigations shall plan to support launch and early orbit, anomaly resolution in orbit and in-orbit checkout activities as needed.

9. RISK MANAGEMENT AND MISSION ASSURANCE

The GDC spacecraft and instrument payload complement will be developed as a Risk Class C per NPR 8705.4.

The Safety and Mission Assurance (SMA) requirements are defined in GDC-SMA-PLAN-0002, the GDC Instrument Mission Assurance Requirements (IMAR) document, found in the GDC Program Library. The processes described in the IMAR are based upon practices used to develop similar NASA missions in the past.

GDC-PIP-9.1: Investigations shall fully comply with GDC-SMA-PLAN-0002, Instrument Mission Assurance Requirements (IMAR); and shall adhere to the SMA processes, perform analyses, and provide documentation as described in the IMAR. Unless otherwise stated, the document delivery dates in the IMAR refer to instrument level reviews.

As a requirement in the IMAR, under Section 1.1, “A developer shall provide a IMAR Compliance Matrix with proposal”. “Proposal submittal”, as worded in the IMAR, refers to proposal submittal (for selected investigations) to the Living With a Star Program Office. Selected investigations will be required to submit a IMAR compliance matrix after selection and prior to the initiation of contract award.

On a monthly basis, investigation teams will report risk status to the Project Office. All investigations will utilize Continuous Risk Management (CRM) as a decision-making tool to ensure safety and to enable programmatic and technical success. Risk decisions will be made based on an orderly risk management effort that includes the identification, assessment, mitigation, and disposition of risks throughout the instrument lifecycle. Applying the CRM process also ensures that risk documentation and communication are maintained within the instrument team and critical risk information is communicated to the GDC project management.

GDC-PIP-9.2: Investigations shall implement a Continuous Risk Management system that utilizes processes, analysis and risk likelihood and consequence definitions described in GPR 7120.4D, *Risk Management*.

10. SCIENCE AND PAYLOAD MANAGEMENT

10.1 Management Approach

This section describes the roles and responsibilities of key science and payload management personnel on the GDC project in support of the selection, development, and operations of investigations for the GDC mission.

GDC project payload management supports the Investigation Principal Investigations (IPIs) for each investigation and the Interdisciplinary Scientists (IDS). As such, the project provides a contract to:

- Manage and fund the investigation,
- Manage the interfaces and accommodation of the instrument onto the S/C and into the mission,
- Engineering guidance and advice to investigations,
- Technical and programmatic decisions as required to successfully accommodate the selected payload on the spacecraft, and
- Expert review panels to assess progress and plans.

To enable effective support, IPIs will be required to provide documentation of their investigation plans and schedules with monthly updates on instrument development progress, financial status, and technical performance. Refer to the CDRL for a list of required deliverables.

While each IPI is encouraged to utilize techniques that have proven successful on previous space missions, the following specific principles apply:

- The IPIs bear the primary responsibility for ensuring that the instruments are designed and developed in a manner that meets the objectives of the selected investigations. The IPIs will demonstrate to the project that this responsibility has been fulfilled and that the detailed design is compatible with performance and interface requirements.
- The GDC project will work with the IPIs on the interfaces of the instrument with the flight and ground systems including launch vehicle safety, system-level test, instrument operations, mission operations, and mission design.
- The GDC project shares with the IPIs the responsibility for ensuring that the mission assurance aspects of the instrument development are consistent with both the mission duration and the expected environments. Consequently, the project will assess the development effort to verify that the mission assurance aspects of the project-approved Mission Assurance Plan are being properly implemented.

Each IPI will be fully responsible for ensuring that their selected investigations are implemented within the resource allocation, except as modified by written project approval.

10.2 Project Roles and Responsibilities

10.2.1 Project Organization

The Goddard Space Flight Center (GSFC) is assigned management of the GDC project and will provide the Project Manager (PM) and Deputy PMs, Project Scientist (PS) and Deputy PSs, Mission Systems Engineer, Chief Safety and Mission Assurance Officer, Instrument System Manager, Ground Segment Manager, Observatory Manager, and Launch Segment Manager.

A development phase organization chart is shown in Figure 10-1. The Instrument Systems Manager (ISM) will manage the science instruments. A different NASA organization will be responsible for managing the mission during the operations phase of the mission.

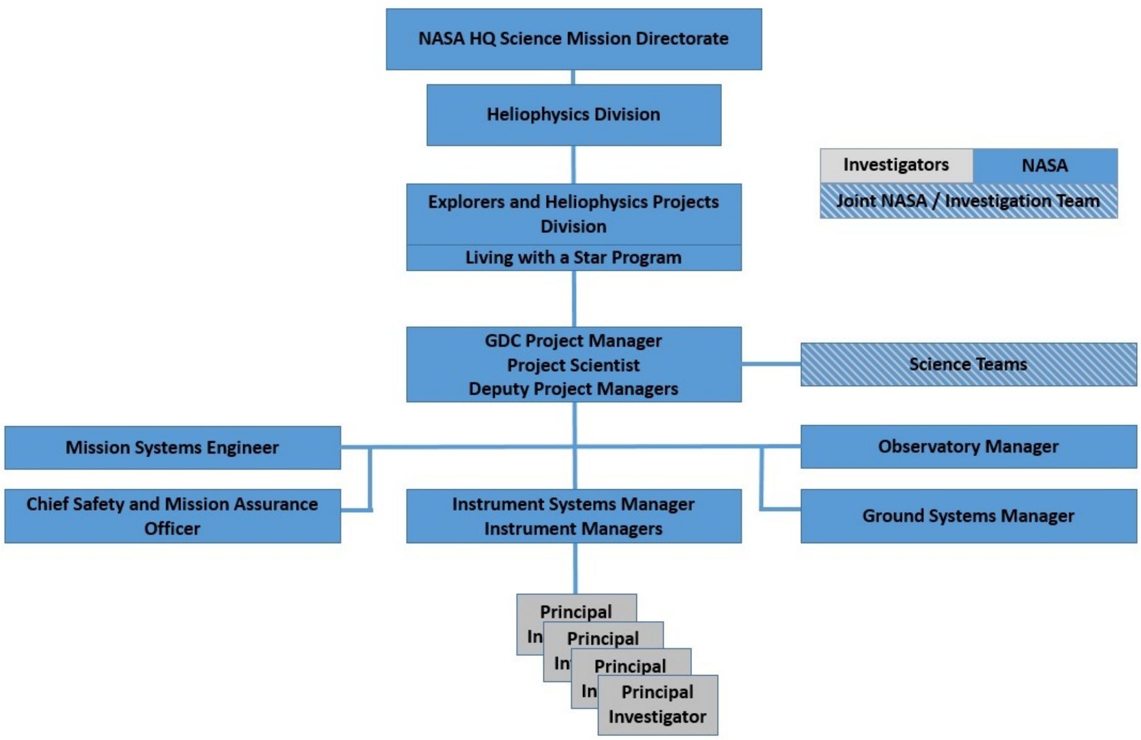

Figure 10-1. GDC Project Development Phase Organization Chart

10.2.2 Project Manager Responsibilities

The Project Manager (PM) is responsible and accountable for all aspects of mission success and maintains management oversight of project activities including ensuring timely detection and correction of problems. Regarding the instrument procurement, the PM is responsible for ensuring that the prospects for scientific return are maximized within project constraints; oversees all systems trades; forms a qualified project team (except the investigations, which are selected by NASA via a competitive AO process); coordinates and oversees the identification of systems engineering design issues; and leads the planning and integration of technical and operational approaches for the project. The PM ensures an effective communications process is in place across the entire project and that peers and independent reviewers properly review all critical work. The PM reports to the LWS Program Manager and coordinates with the NASA Program Executive to assure technical and programmatic compliance for the mission.

10.2.3 Project Scientist Responsibilities

The Project Scientist (PS) is responsible for the scientific integrity and overall scientific success of the project. The PS represents science interests to the project, NASA, the broader science community, and the general public. The PS reports to, and is co-located with, the Project Manager as a member of the project staff. The PS will chair the Science Working Team.
The PS is the liaison between the science team and the project. The PS is responsible for ensuring that the Level 1 science requirements are met, including ensuring the scientific investigations are properly supported within the resource allocation to achieve the optimal scientific outcome and that the investigations properly carry out their scientific responsibilities. If necessary, the PS will work with the PM and NASA Headquarters Program Scientist to recommend descope options as required to stay within resources. The PS supports and cooperates with the NASA Headquarters Program Scientist in carrying out their joint roles and responsibilities.

10.2.4 Instrument Systems Manager Responsibilities

The GDC Instrument Systems Manager (ISM) reports to the PM and oversees and coordinates the individual instrument developments to ensure timely instrument hardware, software, and documentation deliveries that are compliant with the requirements, policies, and resources of the GDC project.

Specifically, the ISM will:

1. Act as the Contracting Officer's Representative (COR) to develop and negotiate work scope and funding vehicles, using work agreements, subcontracts, or memoranda of understanding as appropriate, for each instrument through delivery, integration with the spacecraft, launch, and commissioning.
2. Be responsible for ensuring that all instruments are compatible with the GDC design, the interfaces are properly defined and controlled, and that sufficient spacecraft resources are allocated.

3. Provide the overall technical and managerial leadership of the IPIs as the IPIs perform the design, development, manufacture, and delivery of their instruments and instrument operations centers.
4. Plan, direct, monitor and control instrument resources, schedule, risk, and performance commitments in fulfilling the science objectives.
5. Establish and approve instrument functional requirements, in cooperation with the GDC PS and IPIs.
6. Establish and approve interface agreements between each IPI and the GDC project.
7. Ensure that investigations apply a Mission Assurance program that is consistent with the project Instrument Mission Assurance Requirements (IMAR) at and across the interface to the spacecraft.
8. Provide technical representatives and advisors from instrument systems engineering, mission assurance, mission operations, and other selected disciplines as needed. Provide support for: a) the integration of each instrument flight unit with the spacecraft, b) observatory end-to-end test, and c) the observatory environmental test program.
9. Provide support for the integration of each instrument to the ground system and instrument operations center.
10. Provide support for the integration of each instrument to the flight operations for launch and the transition to routine operations.
11. Ensure the quality, accuracy, integrity, and timeliness of each instrument analytical model including its technical documentation, reports, and other correspondence.

GSFC Instrument Managers will support the ISM in fulfilling the ISM responsibilities listed above.

10.2.5 Mission Systems Engineer Responsibilities

The Mission Systems Engineer (MSE) ensures that the science requirements are implemented such that the mission science objectives are met and bears the responsibility for ensuring the technical performance of the mission and all of its segments. The MSE leads project technical reviews and the resolution of action items from those reviews.

The MSE works integrally with the Project Scientist and all project technical elements to ensure that the overall mission science (and other) requirements are negotiated, documented, articulated, and implemented. This starts with the MSE’s development of the Mission Requirements Document, which includes definition of requirements to mission segments and major elements. The MSE develops and documents plans to meet the science project level requirements in terms of mission design, science operations concept development, science data management plan, and data archiving plan and science scenario development. The MSE develops a SWT-approved science operations and planning process for the mission.

GSFC systems and discipline engineers would support the MSE in fulfilling the MSE responsibilities listed above.

10.3 Instrument Principal Investigator and Science Team Roles and Responsibilities

10.3.1 Instrument Principal Investigator Responsibilities

Each IPI is responsible for all aspects of their investigation. These include instrument design and development, fabrication, integration, test, calibration, and delivery of flight hardware, software, and associated support equipment and documentation within project schedule and payload resources. The IPI is also responsible for planning and supporting instrument operation and production and validation of science data products. The IPI oversees their selected investigation while participating in joint data analysis efforts with other members of the full GDC science team. Key functions of the IPI and/or their designees include, but are not limited to, the following:

1. Be the investigation team's primary point of contact with other project elements regarding investigation requirements, risks, schedules, and funds. Represent the investigation team in relevant project reviews and meetings.
2. Generate and maintain documentation regarding the investigation and any instruments that are part of that investigation.
3. Ensure delivery and operation of instrument(s) able to achieve the investigation science objectives within allocated mission resources.
4. Participate in the SWT and other GDC science team meetings and associated working groups.
5. Support mission operations planning and execution.
6. Conduct instrument operations consistent with the Mission Operations Plan and GDC resources.
7. Develop any required systems, software or products needed to operate instruments and produce higher level data products, including those used in the MOC or SOC.
8. Ensure that data reduction, analysis, reporting, and archiving of investigation results meet the highest scientific standards and completeness, consistent with budgetary and other recognized constraints.

10.3.2 Science Working Team (SWT) Responsibilities

The Science Working Team consists of the Project Scientist, Deputy Project Scientist(s), Investigation Principal Investigations, Interdisciplinary Scientists (IDSs), and any other individuals designated by NASA Headquarters. The Project Scientist sets scientific requirements and priorities on behalf of the SWT, which the PS chairs. The NASA Headquarters Program Scientist is a SWT *ex-officio* member. The SWT helps to optimize mission science return and efficiency and prioritize science requirements, in accordance with the governing and unified GDC science team operating rules defining how it manages its activities and data as a team. The rules would apply uniformly to the full GDC science team (which also includes all other investigation Co-Is, IDSs, and other individuals designated by NASA).

10.4 Payload Resource Management

After the final payload selection, the GDC project will assign payload mass, power, data, volume and other physical resources to the instruments. The investigations shall provide tracking of their resources along with any instrument-controlled contingency that may be provided. The GDC MSE will provide overall resource tracking for the mission, and the project will hold overall technical margins beyond allocated contingency levels. The GDC MSE may recommend additional resource allocations, as needed, to the Project Manager for approval.

10.5 U.S. Export Control Compliance

U.S. proposers shall comply with all U.S. export control regulations for exchange of technical data with foreign entities. To that end, investigations proposing joint instrument developments with non-U.S. partners shall prepare and complete Technical Assistance Agreements (TAAs) with any other non-U.S. entities with whom they will be sharing technical data. Such agreements must be signed and in place before exchange of technical data between such partners is possible. Therefore, in order to meet the GDC project development schedule, U.S. proposers should plan the necessary legal work during proposal preparation.

10.6 Review Schedule

10.6.1 Reviews

GDC-PIP-10.1: Investigations shall attend and support, as needed, design and management reviews and meetings for the project, spacecraft, and ground systems, as well as occasional informal reviews scheduled by the project. Investigations shall plan to support project-level reviews and meetings comparable to those described in the sample CDRL (provided for planning purposes), and instrument-level reviews and meetings as described in Section 10.6.2.

10.6.2 Instrument Level Reviews and Meetings

Instrument specific reviews will be held for all investigations. Investigations are responsible for conducting the reviews listed in Table 10-1, unless there are specific, GDC project- approved rationale for changes. Refer to the Representative Instrument CDRL for a description of each review and a list of criteria/deliverables required for successful completion.

In general, the instrument design reviews will be held at the IPI's home location, unless negotiated otherwise. Instrument Lifecycle reviews (ISRR, IPDR, ICDR, IPER and IPSR) should follow the guidelines stated in the Criteria for Flight and Flight Support Systems Lifecycle Reviews (GSFC-STD-1001A). Findings for the instrument Lifecycle reviews will be presented at the corresponding project milestone reviews, with the IPI in a supporting role.

NASA will select and convene a standing payload review board for the instrument milestone reviews. This board will participate throughout the investigation lifecycle to provide continuity of reviews. Review board membership will include science, engineering, project management, operations, and mission assurance representatives. As appropriate, the standing payload review board may be augmented by technical and discipline experts for any particular review.

Table 10-1. Notional Instrument Review and Meeting Schedule

Event	Definition	Date
Kick Off	---	~1 month after selection (1)
Award	---	~2 months after selection
IMRs	Instrument Monthly Reviews	Monthly
TIM	Technical Interchange Meeting	As needed (at a minimum quarterly)
Peer Reviews	---	As required
ISRR	System Requirements Review	~8 months after selection (2)
IPDR	Instrument Preliminary Design Review	~9 months after ISRR (2)
ICDR	Instrument Critical Design Review	~9 months after IPDR (2)
ITRR	Instrument Test Readiness Review	As needed, prior to planned test
IPER	Pre-Environmental Review	Prior to instrument level environmental testing (2)
IPSR	Pre-Ship Review	Prior to instrument delivery (2)

(1) Selected investigations will receive support to attend the kick-off meeting before a full award is in place. Establishing that support will immediately follow selection.
(2) The instrument review dates for selected investigations will be finalized based upon instrument readiness, per on GSFC's Criteria for Flight and Flight Support Systems Lifecycle Reviews (GSFC-1001A) and discussions with the GDC Project Office during the instrument development process.

10.6.2.1 Kickoff Meeting

The Kickoff meeting will formally integrate selected flight instrument IPIs, instrument managers, and systems engineers with the GDC project team. It is anticipated that this meeting will immediately follow the first SWT meeting, which will formally introduce the full GDC science team.

The objective of this meeting is both programmatic & technical. This meeting will provide the opportunity for:

- The investigation team to brief the project on what they proposed. This includes technical, cost & schedule.
- The investigation team to provide and review the GDC project Work Breakdown Structure and Dictionary.
- The investigation team to provide an overview of how the instrument design and implementation applies to the GDC mission objectives, operation, and environment.
- The investigation team to brief the project on the pedigree and heritage of the instrument design. This includes a description of previous flight heritage and/or design implementation, and a description of how previous design implementations differ from the GDC application. (For example, differences in instrument interfaces and operation, changes to the environment, etc.)
- The investigation team to describe plans for design evolution, improvement, increased performance, etc.
- The investigation team to provide an overview of technology development plans, if applicable.
- GDC project management to establish a line of communication and set expectations on the IPI meeting its commitments to GDC.

10.6.2.2 Instrument Monthly Reviews (IMRs)

IMRs of programmatic, financial, and technical status would be hosted at either the IPI's or the instrument hardware developer's home site and attended by the project either in person or via teleconference and/or videoconference. The intent of the IMRs is to provide timely insight into instrument progress with minimal impact on work effort. Major topics to be addressed are included in the Representative Instrument CDRL (Instrument Monthly Report).

10.6.2.3 Technical Interchange Meetings (TIMs)

To foster close interactions between the investigations and spacecraft system technical personnel, a series of meetings will be scheduled to work out interface issues and document the design in the Interface Requirements Documents (IRDs) and Interface Control Documents (ICDs). The GDC project will host the initial TIM meeting. Some TIMs that follow can become "virtual" meetings, with the investigation teams supporting by a combination of telecons, videoconferences, and e-mails. As a minimum, vendors should plan for quarterly TIMs, however additional TIMs will be conducted during critical times/events and prior to Instrument and Project Lifecycle reviews.

These are not formal reviews, but rather technical meetings between the investigation engineers, the spacecraft engineers, and the payload system engineers. The initial focus will be on hardware and software interfaces, but will transition into resource sub-allocation discussions and operational strategies.

10.6.3 Cost and Schedule Reports

A NASA-funded IPI must establish cost accounts according to an agreed upon Work Breakdown Structure and Dictionary at the Kickoff meeting.

A NASA-funded IPI will provide cost and schedule input to the ISM to support the GDC project's financial reporting, which will begin after the Kickoff meeting. In addition, earned value reporting will be provided in accordance with the Representative Instrument CDRL (EVM Reporting). Investigations that include any non-U.S. contribution will include cost and schedule input from the non-U.S. institutions, as called for and/or deemed appropriate by their funding agencies.

APPENDIX A GENERAL ENVIRONMENTAL VERIFICATION STANDARDS (GEVS) TABLES

Table A-1. GEVS Table 2.2-2 defining Test Factors/Durations for Prototype, Protoflight and Acceptance Qualification Levels

Table 2.2-2
Test Factors/Durations

Test	Prototype Qualification	Protoflight Qualification	Acceptance
Structural Loads[1] Level Duration Centrifuge/Static Load[6] Sine Burst	 1.25 x Limit Load 1 minute 5 cycles @ full level per axis	 1.25 x Limit Load 30 seconds 5 cycles @ full level per axis	 1.0 x Limit Load 30 seconds 5 cycles @ full level per axis
Acoustics Level[2] Duration	Limit Level + 3dB 2 minutes	Limit Level + 3dB 1 minute	Limit Level 1 minute
Random Vibration Level[2] Duration	Limit Level + 3dB 2 minutes/axis	Limit Level + 3dB 1 minute/axis	Limit Level 1 minute/axis
Sine Vibration[3] Level Sweep Rate	1.25 x Limit Level 2 oct/min	1.25 x Limit Level 4 oct/min	Limit Level 4 oct/min
Mechanical Shock Actual Device Simulated	 2 actuations 1.4 x Limit Level 2 x Each Axis	 2 actuations 1.4 x Limit Level 1 x Each Axis	 1 actuations Limit Level 1 x Each Axis
Thermal-Vacuum	Max./min. predict. ± 10°C	Max./min. predict. ± 10°C	Max./min. predict. ± 5°C
Thermal Cycling[4,5]	Max./min. predict. ± 25°C	Max./min. predict. ± 25°C	Max./min. predict. ± 20°C
EMC & Magnetics	As Specified for Mission	Same	Same

APPENDIX B REQUIREMENTS

Requirement ID Number	Requirement	Page Number
GDC-PIP-4.1	: Investigations shall design their instruments for accommodation on a spacecraft that possesses the characteristics and design elements described in Section 4 of this PIP.	12
GDC-PIP-4.2	: Proposals shall clearly identify any need for a spacecraft-mounted boom longer than 1.2m, detail required boom technical specifications, and encumber reserves for the boom's procurement. Proposals shall clearly identify the spacecraft interference's impact on instrument performance driving this need and the acceptable level of spacecraft interference in flight. Proposals shall assume the required boom specifications in the baseline investigation, and shall clearly identify and describe the scientific and technical risks if only the 1.2m boom is provided.	14
GDC-PIP-7.1	: Instruments shall only have exterior exposed surfaces that can survive an atomic oxygen fluence of 3x1022 AO per cm2 over the duration of the mission life.	24
GDC-PIP-7.2	: Instruments shall be able to survive a 3 krad-Si per year of mission life for 100 mils Al equivalent shielding (with a total mission life of 9 krad-Si at 100 mils Al) which includes a confidence level of 95%.	24
GDC-PIP-7.3	: Instruments shall be designed to avoid or tolerate errors to single event effects.	24
GDC-PIP-7.4	: Instruments and associated Ground Support Equipment (GSE) shall be compatible with being in a class 7 cleanroom environment per ISO-14644-1.	25
GDC-PIP-7.5	: Instruments shall only have external surfaces where no more than an area of 6 cm2 has a resistivity >1E9 Ohms/ cm2.	26
GDC-PIP-7.6	: Investigations shall design and test in accordance with the GDC "Representative Launch Environment" document in the GDC Program Library.	26
GDC-PIP-8.1	: Investigations shall budget and schedule for the composition and provision of input to controlling data document. Investigations shall use the GDC Representative Instrument CDRL for planning purposes.	27
GDC-PIP-8.2	: Investigations shall test and deliver instrument units as described by Table 8-1. These instrument unit	28

	deliveries will include the specifications and additional items identified in Sections 8.1.3.1 through 8.1.3.5, and the support and accompanying deliverables as described in sections 8.3, 8.4.1 and 8.4.3; as appropriate for the unit types.	
GDC-PIP-8.3	: Investigations shall abide by the software requirements as articulated in NPR 7150.2C (NASA Software Engineering Requirements).	30
GDC-PIP-8.4	: Investigations shall complete instrument verification and validation prior to instrument unit delivery.	30
GDC-PIP-8.5	: Instruments shall follow NASA/GSFC Rules for the Design, Development, Verification, and Operation of Flight Systems (GOLD Rules), GSFC-STD-1000G for flight electronic hardware operating time. In addition to the GOLD Rules, the flight unit instrument electronics shall accumulate a minimum of 300 hours of functional operation prior to delivery for system I&T.	30
GDC-PIP-8.6	: The investigations shall abide by the requirements as articulated in the GOLD Rules, GSFC-STD-1000G.	31
GDC-PIP-8.7	: Investigations shall conduct EMI/EMC tests (with the exclusion of the DC Magnetic Test) in accordance with General Environmental Verification Standard, GSFC-STD-7000A Section 2.5.2.	31
GDC-PIP-8.8	: Investigations shall conduct structural, mechanical, EMI/EMC, thermal and mechanical testing as prescribed in Table 8-2. For all applicable tests protoflight units shall be tested at Protoflight Levels (PF). Testing levels are provided in Appendix A for reference.	31
GDC-PIP-8.9	: Investigations shall provide on-site support for post-delivery activities including, but not limited to: instrument functional test, instrument calibration, instrument integration, all instrument powered activities, post spacecraft integration instrument calibration, and observatory environmental testing.	32
GDC-PIP-8.10	: Investigations shall ensure that the instrument design supports comprehensive performance testing at ambient and end-to-end testing in a thermal vacuum. This testing will be performed to simulate the flight environment as close as possible.	33
GDC-PIP-9.1	: Investigations shall fully comply with the IMAR; and shall adhere to the SMA processes, perform analyses, and provide documentation as described in the IMAR. Unless otherwise stated, the document delivery dates in the MAR refer to instrument level reviews.	36

GDC-PIP-9.2	: Investigations shall implement a Continuous Risk Management system that utilizes processes, analysis and risk likelihood and consequence definitions described in GPR 7120.4D, *Risk Management*.	36
GDC-PIP-10.1	: Investigations shall attend and support, as needed, design and management reviews and meetings for the project, spacecraft, and ground systems, as well as occasional informal reviews scheduled by the project. Investigations shall plan to support project-level reviews and meetings comparable to those described in the sample CDRL (provided for planning purposes), and instrument-level reviews and meetings as described in Section 10.6.2.	42

APPENDIX C ABBREVIATIONS AND ACRONYMS

3D	3-Dimensional
A	Amperes
A	Acceptance
AC	Alternating Current
ACS	Attitude and Control System
AO	Atomic Oxygen
AO	Announcement of Opportunity
arcsec	arc second
ASIC	Application-Specific Integrated Circuit
C	Celsius
CAD	Computer-Aided Design
CCDS	Consultative Committee for Space Data Systems
CDH	Command and Data Handling
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CG	Center of Gravity
cm	centimeters
COR	Contracting Officer's Representative
CP	Center of Pressure
CRM	Continuous Risk Management
CVCM	Collected volatile condensable material
DC	Direct Current
deg	degrees
DID	Document Identification
DRM	Design Reference Mission
DRMPED	Design Reference Mission Predicated Ephemeris Description
EIADP	End Item Acceptance Data Package
EM	Engineering Models
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETU	Engineering Test Unit
EUV	Extreme ultraviolet
FOT	Flight Operations Team
FPGA	Field-Programmable Gate Array
Gbits	Gigabits
GDC	Geospace Dynamics Constellation
GEVS	General Environmental Verification Standards

GITM	Global Ionosphere Thermosphere Model
GOLD	NASA/GSFC Rules for the Design, Development, Verification, and Operation of Flight Systems
GPR	Goddard Procedural Requirement
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HQ	Headquarters
HVAC	Heating, ventilation, and air conditioning (HVAC)
HVPS	High Voltage Power Supply
Hz	Hertz
I&T	Integration and Test
ICDR	Instrument Critical Design Review
ID	Identification
IDS	Interdisciplinary Scientists
IEST	Institute of Environmental Sciences and Technology
IMAR	Instrument Mission Assurance Requirements
IMR	Instrument Monthly Review
IOC	In-Orbit Checkout and Calibration
IPDR	Instrument Preliminary Design Review
IPER	Instrument Pre-Environmental Review
IPI	Investigation Principal Investigator
IPSR	Instrument Pre-Ship Review
ISM	Instrument Systems Manager
ISO	International Organization for Standardization
ISRR	Instrument System Requirements Review
KDP	Key Decision Point
krad-Si	kilorad - Silicon
LET	Linear Energy Transfer
LWS	Living With a Star
m	meter
MDR	Mission Definition Review
MeV	Mega ElectronVolt
mg	milligram
min	minutes
MLI	multi-layer insulation
MM	Mission Manger
MOC	Mission Operations Center
MOI	Moment of Inertia
MOR	Mission Operations Review

MSE	Mission Systems Engineer
MΩ	Mega Ohms
NASA	National Aeronautical and Space Administration
NEA	Non-Explosive Actuator
NEN	Near Earth Network
NPR	NASA Procedural Requirement
nT	nanoTesla
OFV	Field-of-View
ORR	Operations Readiness Review
ORT	Operational Readiness Tests
PCU	Power Conversion Unit
PDR	Preliminary Design Review
PEA	Program Element Appendix
PER	Pre-Environmental Review
PF	Protoflight
PIP	Proposal Information Package
PLAR	Post-Launch Assessment Review
PM	Project Manager
PPS	Pulse per Second
PS	Project Scientist
PSR	Pre-Ship Review
QTY	Quantity
RF	Radio Frequency
RS	Recommended Standard
RSS	Root Square Sum
RW	Reaction Wheel
S/C	Spacecraft
SAA	South Atlantic Anomaly
SALMON	Standalone Mission of Opportunity Notice
SE	System Engineering
SEB	Single Event Burnout
SEE	Single Event Effects
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SIR	System Integration Review
SMA	Safety and Mission Assurance
SN	Space Network
SOC	Science Operations Center
SOT	Science Operations Team
SRR	System Requirements Review

SSA	S-Band Single Access
STD	Standards
STDT	Science Technology Definition Team
SWT	Science Working Team
SYNATMUG	Synthetic Atmospheres: A User's Guide
TAD	Traveling Atmospheric Disturbances
TBD	To Be Decided
TDRS	Tracking and Data Relay Satellite
TID	Traveling Ionospheric Disturbances
TIM	Technical Interchange Meeting
TML	Total Mass Loss
TQCM	Temperature-controlled Quartz Crystal Microbalance
TRR	Test Readiness Review
TV	Thermal Vacuum
UTC	Coordinated Universal Time
UV	Ultraviolet
V	Volts
V&V	Verification and Validation
Vce	Collector-Emitter Voltage
Vds	Drain-Source Voltage