Magnetospheric Multiscale (MMS) Project

Project Data Management Plan (PDMP)

V2.0

Submitted: 22 November 2022

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

MAGNETOSPHERIC MULTISCALE (MMS)
Project Data Management Plan (PDMP)

Dr. Barbara Giles, GSFC MMS Project Scientist — 14 November 2022 (Date)

Dr. James Burch, SwRI MMS Science PI — 21 November 2022 (Date)

By signing this document, signatories are certifying that the content herein is acceptable direction for managing the project's data and that they will ensure its implementation by those over whom they have authority.

Copy to: HQ Program Scientist

REVISION HISTORY

Revision Level	DESCRIPTION	EFFECTIVE DATE
Rev 0	SwRI Document No. 10160.18-PDMP-01 –export-controlled internal mission development document	30 Aug 2010
Rev 1	Draft, updated open-access PDMP	2 June 2020
Rev 2	V2.0 Public Release	22 Nov 2022

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Purpose and Scope

This document describes the Project Data Management Plan (PDMP) for the Magnetospheric Multiscale (MMS) mission. It describes the mission's data requirements and how the MMS data system is implemented in order to meet those requirements.

Described in this plan are:

- Overview of the MMS science objectives, mission concept, and instrumentation.
- Roles and responsibilities of all institutions expected to participate in MMS data production, dissemination, and archival activities.
- Identification and description of the various types of MMS data including data volume estimates.
- Description of data flow between key MMS project entities.
- Description of data distribution and access methods.
- Plans for mission data archival.

It is important to note that the MMS mission simultaneously supports four identically instrumented spacecraft flying in formation that operates in different data acquisition modes with significantly different data throughput and storage requirements.

1.2. Development, Maintenance, and Management Responsibility

Developing, maintaining and managing this PDMP is an MMS Project responsibility. The Science Operations Center (SOC) at the Laboratory for Atmospheric and Space Physics (LASP) has been designated responsibility for the development and maintenance of this plan under the direction of the MMS Principal Investigator (PI), Dr. James L. Burch, at the Southwest Research Institute (SwRI).

1.3. Change Control

This PDMP is an MMS Project-controlled document and is under change control once signed by all parties. The initial draft version was completed prior to the MMS Preliminary Design Review (PDR) and was baselined at the MMS Critical Design Review. The first significant update was initiated, as directed by NASA HQ, for the 2020 Senior Review. All changes to this document are submitted to the MMS Principal Investigator, who coordinates reviews of proposed changes.

1.4. Relevant Documents

Relevant documents that support details provided in this PDMP are listed in Table 1-1.

Document Reference	Title
461-PROJ-RQMT-0018	Program Level Requirements for the MMS Project - Appendix C to the STP Program Plan, MMS Level 1 Requirements
461-SYS-RQMT-0019	*MMS Mission Requirements Document (MRD)*
Version 1.2 - 04 October 2016	*NASA Heliophysics Science Data Management Policy*
461-PROJ-PLAN-0071	*MMS Concept of Operations*
461-GS-ICD-00134	*MOC/FDOA-SOC ICD*
461-GS-ICD-0014	*MMS MOC-SOC ICD*
SwI Document No. 10160.17-SOC-ITF-ICD	*MMS SOC-ITF ICD*
SwRI Document No. 10160.17-BADCO-01	*Burst Algorithm Definition and Concept of Operations (BADCO)*
461-PROJ-PLAN-0071	MMS Flight Operations Plan
POC Online Document	Instrument Suite Flight Operations Plan
TBD	*Calibration and Measurement Algorithm Document (CMAD)*

Table 1-1: ***Relevant Documents***

2. MISSION OVERVIEW

2.1. Mission Objectives

The Magnetospheric Multiscale (MMS) mission is a National Aeronautics and Space Administration (NASA) Science Mission Directorate (SMD) Heliophysics Division flight project in the Solar Terrestrial Probes (STP) Program. MMS is a space physics research mission to discover the fundamental plasma physics processes of magnetic reconnection in the Earth's magnetosphere. Magnetic reconnection occurs when the charged particles and wave energy emanating from the sun in the Solar Wind interact with the Earth's magnetic field. Four identically instrumented satellites will measure electric and magnetic fields, fast plasma, energetic particles, and hot plasma composition at time scales of milliseconds to seconds and spatial scales of tens to hundreds of km. The satellites will fly in a tetrahedron formation to explore the dayside of the magnetopause and the night side of the magnetotail in three dimensions. The four satellites are launched together in a stacked configuration into an elliptical Earth orbit with an apogee of 12 Re.

The specific MMS science objectives are:

- Determine the role played by electron inertial effects and turbulent dissipation in driving magnetic reconnection in the electron diffusion region.
- Determine the rate of magnetic reconnection and the parameters that control it.
- Determine the role played by ion inertial effects in the physics of magnetic reconnection.

2.2. Mission Concept

The MMS mission employs four identically instrumented spinning spacecraft orbiting the Earth in a tetrahedral configuration to conduct definitive investigations of magnetic reconnection in key boundary regions of the Earth's magnetosphere. The process of magnetic reconnection, which controls the flow of energy, mass, and momentum within and across plasma boundaries, occurs throughout the universe and is fundamental to our understanding of astrophysical and solar system plasmas. It is only in the Earth's magnetosphere, however, that it is readily accessible for sustained study through the *in situ* measurement of plasma properties and of the electric and magnetic fields that govern the behavior of the plasmas.

Through high-resolution measurements made by each spacecraft, whose separations can be varied from tens of km to a few hundreds of kilometers, MMS probes the crucial microscopic physics involved in these fundamental processes; determines the 3-D geometry of the plasma, field, and current structures associated with them; and relates their micro-scale dimension to phenomena occurring on the mesoscale. By acquiring data simultaneously at multiple points in space, MMS differentiates between spatial variations and temporal evolution, thus removing the space-time ambiguity that has limited single-spacecraft studies of magnetospheric plasma processes.

Over the lifetime of the mission, the MMS low-inclination orbit strategy probed the most likely reconnection sites on both the dayside magnetopause (Dayside mission phases) and in the magnetotail (nightside mission phases). Phase 1 consisted of an elliptical Earth orbit with an apogee of 12 R_E +/- 1 R_E. Prime mission Phase 2 consisted of an elliptical Earth orbit with an apogee of 25 R_E +/- 5 R_E (Figure 2-1). Each extended mission phase has balanced fuel usage, time in the reconnection regions of interest, and eclipse durations to maximize science return.

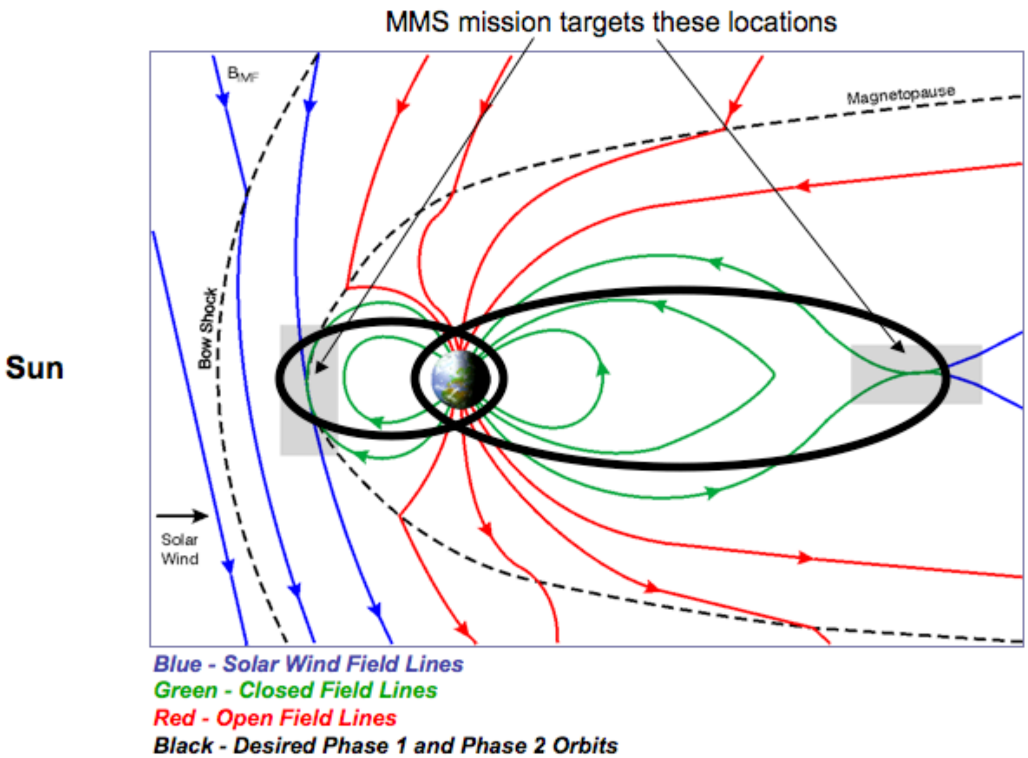

Figure 2-1: General Locations of Magnetic Reconnection for the Dayside/Nightside magnetosphere

Science Regions of Interest (SROI) with observatory formation requirements are defined for each dayside and nightside mission phase (geocentric apogee distances >9 R_E for Prime Mission Phase 1, and >15 R_E for Prime Mission Phase 2.) There are no (or relaxed) formation requirements for regions of science interest during Phase transitions (e.g. from Phase 1 to Phase 2.)

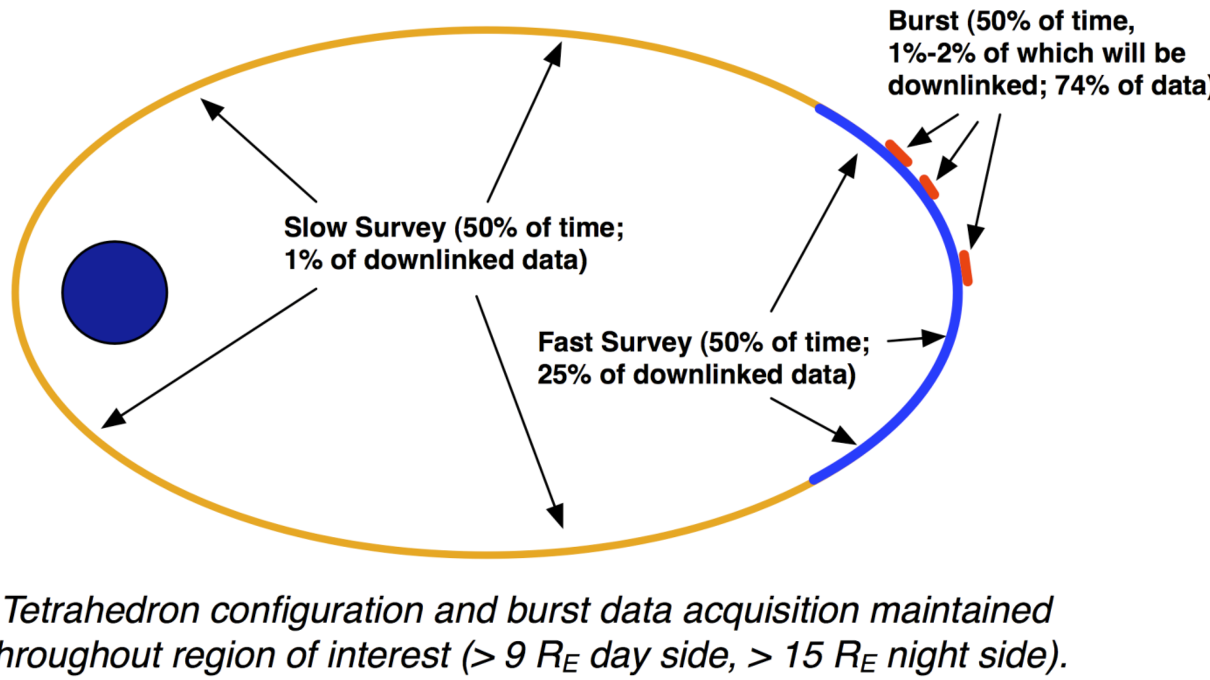

Figure 2-2: General *Data Collection Strategy: Low resolution – Nominal resolution – MMS resolution*

The four MMS spacecraft will operate in the Slow Survey mode approximately 50% of the time during each orbit. Fast Survey mode occurs within the primary science region of interest and is at a resolution equivalent to most previous missions. Burst data – the high resolution data that MMS is known for -- is collected throughout the Fast Survey period, although only a limited number of "SITL-selected segments" are able to be downlinked via the prescribed DSN antenna allocation. MMS continually advocates for additional DSN antenna contact time.

Data types used to meet the mission requirements are:

- *Survey data*: These data are collected continuously from all powered instrumentsand stored in the mass memory module of the CIDP. The orbit is divided into fast survey and slow survey periods. Fast survey data – at a resolution equivalent to most previous missions - are collected during the primary science regions of interest (SROI) period of the orbit while the slow survey data are collected at a lower resolution during the region of the orbit that is of low scientific interest. The fast and slow survey times are set by ground command.
- *Burst data*: The instruments provide a stream of the highest resolution data to the CIDP in parallel with the fast survey data. All burst data collected during the fast survey period are stored in the mass memory module of the CIDP. Burst information is tagged with quality information based on a spacecraft wide trigger system. Only a portion of this data is able to be downlinked via the prescribed DSN antenna allocation.

Trigger data are also generated by all instruments and are used by the CIDP to calculate quality information and by the Science Operations Center (SOC) to support the selection of the priority burst data to optimize science data downlink. Every instrument supplies a set of trigger data once every ~10 seconds.

Inter-spacecraft separation distances between the four spacecraft in the tetrahedron are changed from mission phase to phase (mostly, between 160 km and 10-20 km) by ground command to optimize the opportunities to capture reconnection events.

MMS Mission Phases are currently documented at https://lasp.colorado.edu/galaxy/x/yBQ_Ag and will be summarized in this document (or the CMAD as appropriate) during the proposed FY21 PDMP update.

2.3. Science Instrumentation

The SMART (Solving Magnetospheric Acceleration, Reconnection and Turbulence) Instrument Suite will make the required high-time resolution measurements of plasmas, electric fields and magnetic fields and provide important supporting measurements of energetic particles and ion composition. The SMART IS consists of the following complement of instruments:

- **The FIELDS investigation** includes a sensor suite consisting of axial and spin-plane double-probe electric-field sensors (ADP and SDP), two flux-gate magnetometers (AFG and DFG), a search-coil magnetometer (SCM), and two electron drift instruments (EDI) per spacecraft. These instruments measure DC magnetic field with a resolution of 10 ms, DC electric field with a resolution of 1 ms, electric plasma waves to 100 kHz, and magnetic plasma waves to 6 kHz.
- **The Energetic Particle Detector (EPD)** includes an Energetic Ion Spectrometer (EIS) and an all-sky particle sampler called the Fly's Eye Energetic Particle Sensor (FEEPS) per spacecraft. These instruments measure the energy-angle distribution and composition of ions (20 to 500 keV) at a time resolution of < 30 seconds, the energy-angle distribution of total ions (45 – 500 keV) at a time resolution of < 10 seconds, and the coarse and fine energy-angle distribution of energetic electrons (25 – 500 keV) at time resolutions of < 0.5 and < 10 seconds, respectively.
- **The Fast Plasma Instrument (FPI)** includes four dual electron spectrometers (DES) and four dual ion spectrometers (DIS) per spacecraft for a total of 64 plasma spectrometers across the observatories. These instruments measure the velocity-space distribution of electrons from 10 eV to 30 keV and ions from 10 eV to 30 keV with time resolution of 30 ms, and 150 ms, respectively
- **The Hot Plasma Composition Analyzer (HPCA)** on each spacecraft measures the composition-resolved velocity-space distribution of ions from 1 eV to 40 keV with time resolution of 10 – 15 seconds.
- **The Active Spacecraft Potential Control (ASPOC)** (two per spacecraft) generates beams of indium ions to limit positive spacecraft potentials to +4V in order to improve the measurements obtained by FPI, HPCA, ADP, and SDP.

The instrument suites on each spacecraft are supported by the Central Instrument Data Processor (CIDP), which collects and stores telemetry from each instrument and sends it to the spacecraft for downlink. The CIDP provides time and spin synchronization as well as switched power services to the instruments, and forwards commands received from the Spacecraft Avionics (Figure 2-3).

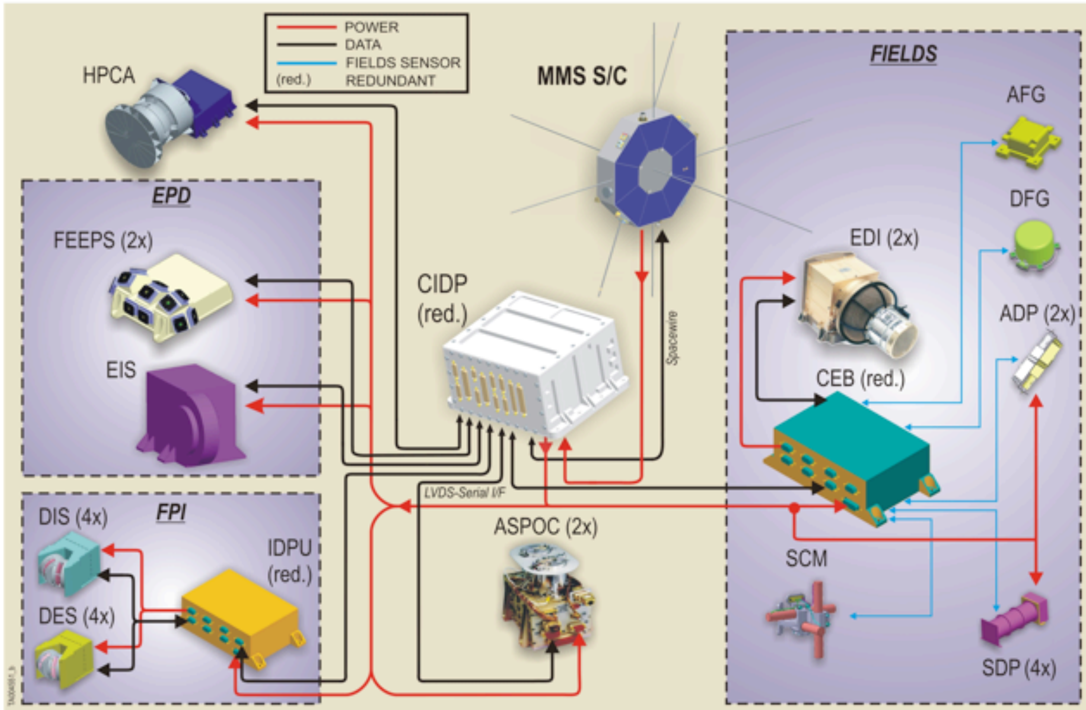

Figure 2-3: ***MMS-SMART Instrument Suite Architecture***

2.4. Orbit Phases and Mission Timeline

MMS's four satellites are launched together in a stacked configuration into an elliptical Earth orbit with an apogee of 12 Re. During the estimated 4-month checkout period, the perigee is raised to 1.2 Re via the spacecraft propulsion systems. At the end of the check out period the orbit apogee is near the dusk magnetopause. Phase 1 will commence at this point and last 16 months. During Phase 1 the MMS apogee will sweep across the dayside magnetopause twice (phase 1a and 1b). At the end of Phase 1b, the apogee is raised gradually to 25 Re. Phase 2 continues for an additional 5.5 months. The orbit is allowed to drift naturally throughout the mission lifetime (i.e., it will not be controlled). During the extended mission, the spacecraft remain in a tetrahedral formation with a 29 Re apogee (see Table 2.1).

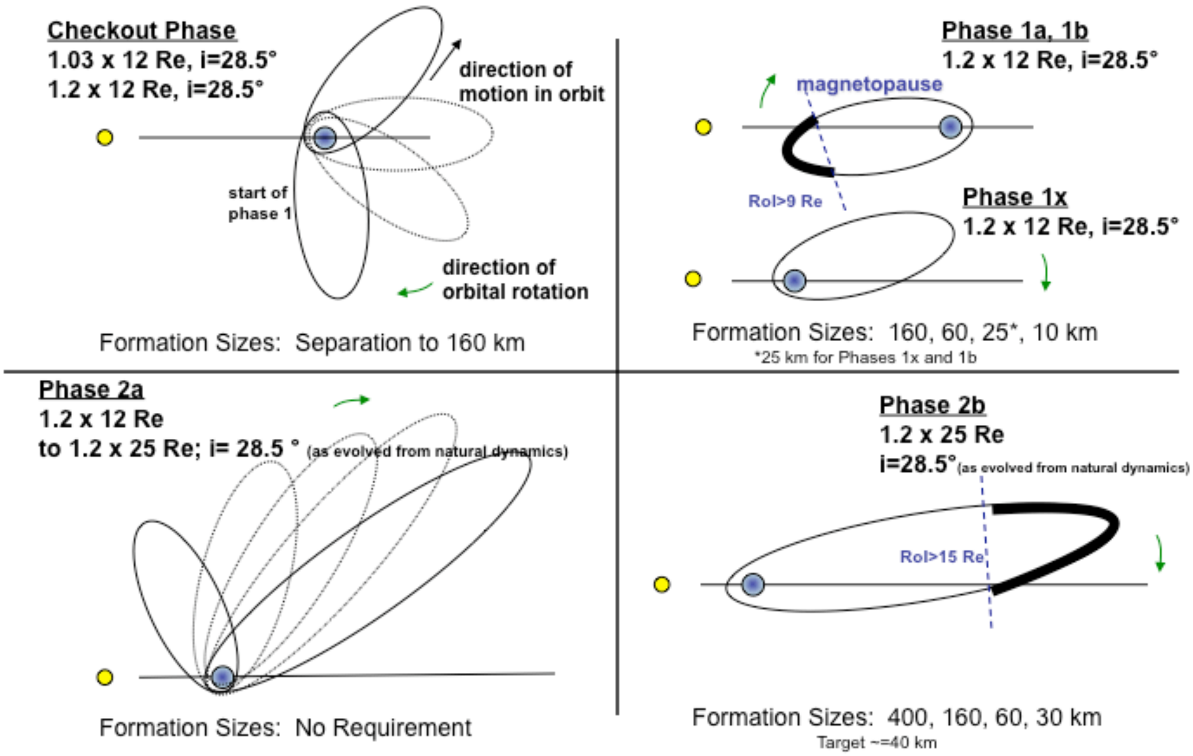

Figure 2-4: *MMS Orbit Phases*

The timeline for collection of science data during each of the MMS mission phases is shown in Figure 2-5.

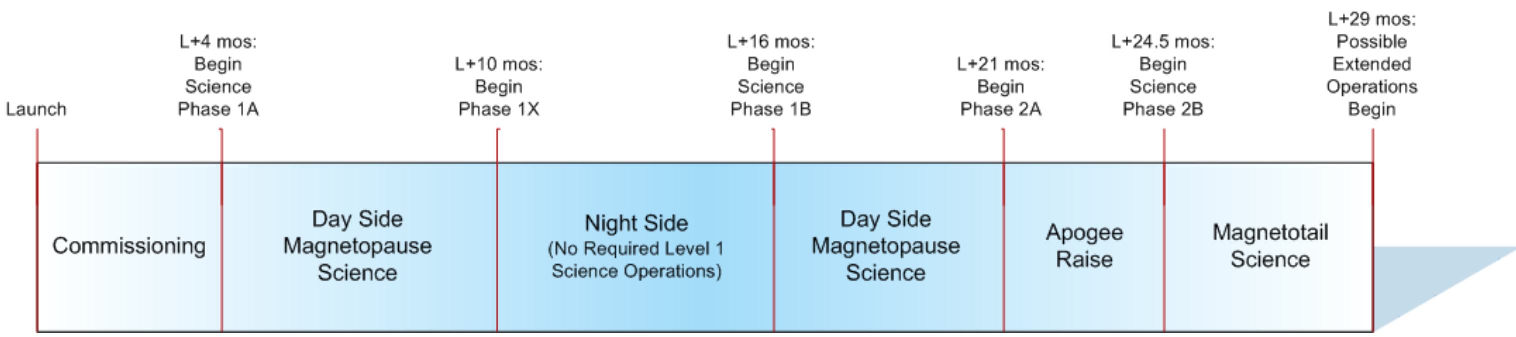

Figure 2-5: *MMS Science Acquisition Timeline*

	Phase	Region
Year 5	Extended Mission Year 3 Phase 5a: ~09/30/19-11/24/19	29 R_E Dusk Flank
	Phase 5b: ~11/24/2019 - 04/23/20	29 R_E Dayside
	Phase 5c: ~04/23/20-06/19/20	29 R_E Dawn Flank
	Phase 5d: ~06/22/20-10/02/20	29 R_E Nightside
Year 4	Extended Mission Year 2 Phase 4a – Sept 28, 2018	25R_E Dusk Flank
	Phase 4b – Nov 29, 2018	25R_E Dayside
	Phase 4c - ~April 16, 2019 - ~June 28, 2019	29R_E Dawn Flank
	Phase 4d - ~June 29, 2019 - ~July 25, 2019	1st 29R_E Nightside
Year 3	Extended Mission Year 1 Phase 3a – Sept 1, 2017	25R_E Dusk Flank
	Phase 3b – Nov 14, 2017	25R_E Dayside
	Phase 3c – Mar 13, 2018	25R_E Dawn Flank
	Phase 3d – May 25, 2018	2nd 25R_E Nightside
Year 2	Prime Mission Phase 2a – January 31, 2017	Apogee raise, Dawn
	Prime Mission Phase 2b – May 1, 2017	1st 25R_E Nightside Completion of Prime Mission
Year 1	Prime Mission Phase 1a – September 1, 2015	1st 12R_E Dayside
	Prime Mission Phase 1x – March 8, 2016	12R_E Dawn, Nightside, Dusk
	Prime Mission Phase 1b – Sept 12, 2016	2nd 12R_E Dayside
Commissioning	March 15, 2015 – Sept 15, 2015	Nightside --> Dusk Flank

Table 2-1: ***Mission Phases and Science Regions of Interest***

3. ROLES AND RESPONSIBILITIES

3.1. Overview of Ground System

The MMS ground system supports on-orbit operations of the MMS observatories, as well as the production, storage, management, and dissemination of MMS science data products. The MMS ground system consists of the following functional elements:

- Mission Operations Center (MOC). Located at Goddard Space Flight Center (GSFC) in Greenbelt, MD. Responsible for spacecraft operations and telemetry capture.

- Flight Dynamics Operations Area (FDOA). Located at Goddard Space Flight Center (GSFC) in Greenbelt, MD. Responsible for orbit and attitude determination and control.
- Science Operations Center (SOC). Located at the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado in Boulder, CO. Responsible for Instrument Suite (IS) operations, instrument data processing, archiving, and distribution.
- SMART Instrument Team Facilities (ITF). Specific institutions are identified in Section 3-4. Instrument teams are responsible for data analysis and validation; instrument monitoring and special operations requests; software for producing data products; Level-2 data processing (FPI and HPCA only); analysis tools for publicly available data products.
- Education and Public Outreach (EPO). Located at Rice University. Responsible for dissemination of educational materials to schools and the general public.

Descriptions and operational responsibilities for each of these elements are summarized in Figure 3-1 and described in the sections that follow.

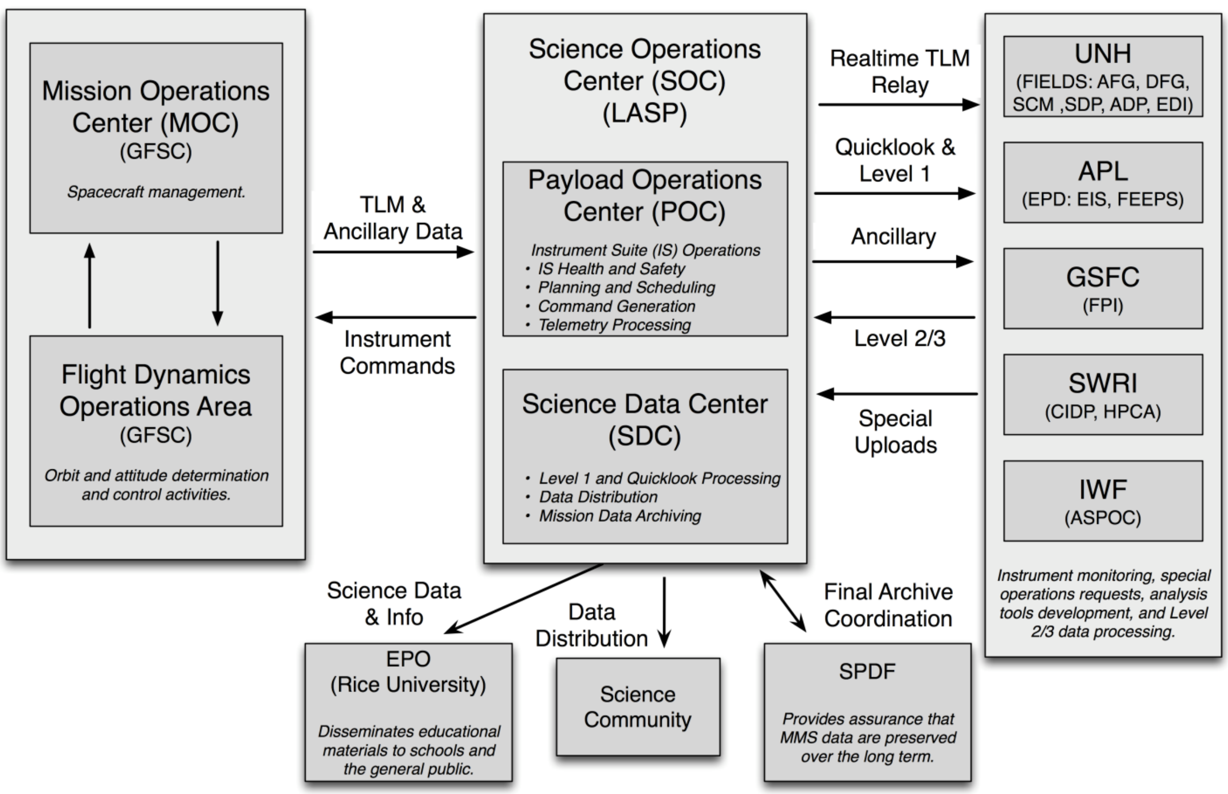

Figure 3-1: ***MMS Ground Data System Responsibilities***

3.2. Mission Operations Center (MOC)

The Mission Operations Center is located at Goddard Spaceflight Center (GSFC) and is responsible for all spacecraft-related operations. These functions include:

- Health and safety monitoring of the spacecraft bus and selected critical instrument safety parameters.
- Generation of spacecraft commands.
- Merge and uplink of spacecraft and Instrument Suite (IS) stored commands.

- Station pass planning and scheduling.
- Spacecraft and Instrument Suite engineering data capture.
- Engineering and Instrument Suite science data capture.
- Spacecraft engineering Level-0 data processing.
- Spacecraft telemetry/command definitions configuration management.

Additionally, the MOC is responsible for providing the SOC with various data, as outlined in the MOC-SOC ICD, including the following:

- All instrument telemetry and select spacecraft telemetry (real-time and playback).
- Planning aids/products.
- Spacecraft health/safety and status reports.
- Ancillary data.

3.2.1. Flight Dynamics Operations Area (FDOA)

The FDOA is co-located within the MOC at GSFC and is responsible for the following:

- All orbital dynamics.
- Constellation formation.
- Observatory spin axis and spin rate control.
- Definitive orbit and attitude determination, planning, calibration, and control.
- Tracking station acquisition.
- Data generation/distribution.
- NAV performance, calibration, configuration.
- Attitude/orbit related product generation.

3.3. Science Operations Center (SOC)

The Science Operations Center (SOC) is located at the University of Colorado in the Laboratory for Atmospheric and Space Physics (LASP). It is responsible for managing and conducting instrument operations and serves as the central hub for all instrument and ancillary data required for instrument suite operations support, data processing, data distribution, and science analysis. The SOC is also be responsible for archiving all MMS data during the active mission and will help plan and provide for subsequent archive phases prior to mission termination. Specific responsibilities include:

- All Instrument Suite operations including health and safety monitoring, IS operations planning and scheduling, and IS command generation/integration.
- Mission-level data storage.
- IS recorder management.
- Levels 0, 1, 2, and 3 data processing.
- IS calibration support.
- Mission data archiving/distribution.
- IS telemetry/command definition configuration management.
- Housing the Instrument Team during post-launch IS activation and checkout activities.
- Providing data in a variety of coordinate systems.

For organizational purposes, the SOC is functionally divided into a Payload Operations Center (POC) for operations-related functions and a Science Data Center (SDC) for data production, management, and distribution functions.

3.3.1. Payload Operations Center (POC)

The Payload Operations Center (POC) has primary responsibility for monitoring and controlling the MMS suite of instruments. The POC to MOC operational interface used for commanding the IS and receiving telemetry is described in the *MMS MOC-SOC ICD*.

In close collaboration with the ITFs and each instrument's PI and systems engineers, the POC establishes baselines of nominal operational and instrument calibration sequences given each mission phase, respective spacecraft state, and orbit location. The POC notifies the ITFs of anomalous conditions as they occur and wait for Anomaly Review Board (ARB) resolution before recovering an instrument and resuming nominal operations. The POC also notifies the ITFs of spacecraft, constellation, or ground segment configuration changes affecting previously established nominal operational command sequencing. To safely implement commanding, the POC works closely with the MOC to schedule and implement loading the ATS (Absolute Time Sequences) commands and the RTS (Relative Time Sequences) commands, as well as setting the needed Real-Time IS commanding windows. The POC works closely with the MMS science team to plan and prepare instrument observing sequences and command loads, and monitors and maintains the health and safety of the MMS instruments.

For a detailed description of the POC operations approach and implementation, see the *MMS Flight Operations Plan* and the *Instrument Suite Flight Operations Plan*. This list summarizes the principal POC responsibilities:

- Plan and schedule instrument activities.
- Generate and transmit instrument operational command loads (via the MOC).
- Deliver Level 0 data to the SDC.
- Monitor Instrument Suite health and safety.
- Support routine real-time operations and commissioning of the Instrument Suite.
- Produce and transmit real-time instrument suite commands (via the MOC).
- Relay IS health and safety telemetry to ITFs.
- Notify the ITFs of IS anomalous conditions and respond as instructed.
- Coordinate IS planning and commanding among the different instruments and MOC activities.
- Manage Instrument Suite command and telemetry definition.
- Produce POC-resident spacecraft telemetry definitions subset needed by the POC to monitor the spacecraft configuration.
- Produce MOC-resident IS telemetry definitions subset needed by the MOC to monitor the IS state or perform activities that could potentially affect the IS.
- Manage POC to MOC command and telemetry interface.
- Process and disseminate low-level instrument suite engineering telemetry.

3.3.2.Science Data Center (SDC)

The Science Data Center (SDC) is responsible for MMS science data management, distribution, and processing of selected data sets. In collaboration with the SMART-IS team, the SDC determines data storage and distribution mechanisms and ensures that data are processed and released to the public within the required timeframes (indicated in Table 5-1). In addition, the SDC develops web-based interfaces for accessing data and analysis tools, serves news items that are relevant to the MMS mission, and coordinates the development of data analysis and visualization tools with the MMS science team. These tools, higher level data products (Level 2+), and associated documentation are available to the science community via the Internet.

Specific SDC responsibilities are summarized as follows:

- Provide oversight and coordination of the distributed MMS data processing system.
- Generate Level-1, Quicklook, Level-2, and Level-3 science products.
- Provide ITFs access to all Level-0 data, Level-1 data, Quicklook science data, and ancillary data within 24-hours of receipt from each spacecraft.
- Provide tools to transform data into a variety of coordinate systems.
- Receive and manage processed science data products from ITFs.
- Collect and archive associated software and documentation from ITFs.
- Disseminate science data products to the science community via SDC web interfaces.

- Coordinate with NASA's Virtual Observatory (VxO) framework and the Space Physics Data Facility (SPDF) for additional dissemination of science products and analysis tools.

3.4. Instrument Team Facilities (ITF)

MMS-SMART Instrument Team Facilities (ITFs) are the principal institutions associated with each of the MMS-SMART science investigations. These facilities and their personnel provide support to the operation of their instruments and the overall data processing and distribution effort for MMS science data products.

The institutions listed in Table 3-1 have responsibility for each of the SMART investigations and their corresponding instruments, together constituting the MMS instrument suite:

MMS Investigation	Managing Institution
Fast Plasma Instrument (FPI)	Goddard Space Flight Center (GSFC)
Hot Plasma Composition Analyzer (HPCA)	Southwest Research Institute (SwRI)
Fields	University of New Hampshire (UNH)
Energetic Particle Detector System (EPD)	Johns Hopkins University (JHU) Applied Physics Laboratory (APL)
Active Spacecraft Potential Control (ASPOC)	Space Research Institute of the Austrian Academy of Sciences

Table 3-1: ***MMS-SMART Instrument Team Facilities (ITF)***

ITFs are responsible for the following:

- Operations Support:
  - Participate in the routine planning process, attend routine planning teleconferences, and review operational plans, as necessary.
  - Routinely perform detailed health and safety assessment of their respective instruments and provide the POC with instrument health and status reports.
  - Provide any needed instrument-planning requests and corresponding data to the POC for incorporation into instrument operations plans.
  - Maintain instrument flight software and tables and work with the SOC to facilitate uplink of any needed updates.
  - Support POC in developing flight procedures and scripts

- Science Data Production and Corresponding Support:
  - Provide the SDC with data product documentation.
  - Generate and maintain documentation of science algorithms and processing software systems.
  - Validate all science data that originate from their respective instruments.
  - Beginning as soon as possible but no later than 6-months after instrument commissioning, begin routinely generating Level-2 science data products and deliver to the SOC within 30 days of downlink from each spacecraft. Note that Level-2 processing for ASPOC and magnetometer (e.g. AFG/DFG) data are expected to be performed at the SDC instead of the ITF as described in Sec. 5.
  - Provide data access and visualization tools to the SDC. These tools will support SDC provided interfaces and will also be made available to the science community.
  - Provide the SDC with science product metadata as defined in the *MMS SOC-ITF ICD*. This metadata is compliant with the SPASE standard as per the *NASA Heliophysics Science Data Management Policy* document.
  - Provide the SDC with software needed for creating Quicklook products. The SDC works with ITF teams to adapt their software to execute on SDC computer systems, such that Quicklook

data products are routinely generated shortly after data downlink from each spacecraft. The ITFs assist the SDC in maintaining this software.

- Support end-to-end testing of interfaces with the SDC.
- Provide detailed descriptions of software and data version changes to the SDC so these changes can be communicated to the scientific community.
- Provide science news items to the SOC for posting on the SOC web site.

3.5. Education and Public Outreach (EPO)

The SMART EPO program, coordinated by Rice University, will focus on teacher training, educational software, and science videos for regular venues as well as planetariums during the primary mission. Student modules, museum exhibits, and planetarium and television shows are disseminated through an existing network of teachers and museums in coordination with ongoing programs. Additionally, the SMART EPO team will create a web site with up-to-date mission information, webcasts of major events, and educational broadcasts, utilizing data products and information provided through the SDC web site. Note that the EPO website is hosted at Rice University and serves a different audience than the data and analysis oriented website hosted at the SOC.

3.6. Space-Ground Network

Three ground tracking networks are used in support of MMS: Tracking and Data Relay Satellite System (TDRSS), Universal Space Network (USN, 13m dishes), and Deep Space Network (DSN, 34m dishes). TDRSS is used for launch and early orbit critical event coverage, Phase 0 (post launch checkout) Perigee coverage, backup command support, and Phase 2a orbit maneuver support. The USN is used for maneuver support. The Deep Space Network is used primarily for playback of recorded data, uplink of stored commands, and observatory health and safety monitoring.

All communications with the spacecraft (up/down) use S-Band frequency, and share a common frequency for all spacecraft. Protocols are in accordance with the Consultative Committee on Space Data Systems (CCSDS) recommendations.

3.7. Associated Organizations

Organization	Role
MMS Science Working Group	The MMS Science Working Group (SWG) is chartered by the Heliophysics Division at NASA Headquarters and provides scientific and technical findings to the MMS Project Scientist and the MMS Project Manager. The SMART PI will chair the SWG, the MMS Project Scientist is vice chair, and membership will include the five SMART Instrument Team Leaders, the SMART Theory and Modeling Team Lead, the SMART Burst System Lead, and the SMART Plasma Science Lead. Additionally, three Interdisciplinary Scientists (IDS), selected via *ROSES-2005 Appendix A.32,* are tasked by the SWG with specific deliverables. These IDS will serve as members of the MMS SWG in addition to conducting science investigations addressing the MMS science objectives independently of the SMART science efforts.
NASA HQ's Heliophysics Division	The goal of Heliophysics at NASA is to "Understand the Sun and its interactions with the Earth and the solar system". Early NASA spacecraft confirmed the theory that interplanetary space is completely filled with streams and clouds of material ejected by the Sun. Thus, a new view of our solar system was born. At its center is a magnetically variable star that governs the motions of the planets, drives the Earth's climate system, and modulates the interplanetary medium. From this view, the solar system appears as a heliosphere moving through interstellar space, the study of which NASA calls Heliophysics. The Heliophysics spaceflight strategy is to deploy modest-sized missions as frequently as possible to form a small fleet of solar, heliospheric, and geospace spacecraft that operate simultaneously to understand the coupled Sun-Earth system.
Space Physics Data Facility (SPDF)	The SPDF is a function of the Heliospheric Science Division (HSD) at NASA's Goddard Space Flight Center. The Facility supports data from most NASA Heliophysics missions to promote correlative and collaborative research across discipline and mission boundaries. The SPDF provides multi-mission data services such as CDAWeb, software tools used for working with CDF data files, and is responsible for long-term MMS data archival.
Virtual Observatories (VxO)	NASA's Heliophysics Virtual Observatories (VxO) provide simple, uniform access to data from distributed, heterogeneous sources. VxOs do not typically hold data but provide a framework for linking users to data and services that enhance the use of these data. In accordance with the NASA Heliophysics Science Data Management Policy, the MMS-SMART team will make its data available to NASA's VxO framework and is expected to work directly with the Virtual Magnetospheric Observatory.

Table 3-2: ***MMS Associated Organizations***

4. DATA IDENTIFICATION

The MMS project uses the data level definitions indicated in Table 4-1.

Data Level	Brief Description
Raw	Raw telemetry data as received at the ground receiving station or ground test GSE, organized by contacts or ground test. Data sets may overlap and/or contain communication artifacts.
Level-0	Reconstructed, unprocessed instrument, payload, and spacecraft data; any and all communications artifacts, e.g. synchronization frames, communications headers, duplicate data are removed. These data will typically consist of binary CCSDS packets.
Level-1A	Fully decommutated but uncalibrated raw data at full resolution; time-referenced; "extracted telemetry items"
Level-1B	Level-1A (extracted telemetry items) to which engineering (e.g. simple polynomial) calibrations have been applied; data have been annotated with ancillary information (e.g., ephemeris, attitude data) and initial instrument-level science calibrations have been applied.
QuickLook	Scientific data products that are generated using simplified science processing algorithms and/or with provisional calibrations. These data are intended to provide basic scientific insight. Generation of these data will occur as quickly as possible, whereas routine production of Level-2 and Level-3 products may take considerably longer. In many cases, Level-1B products will serve as Quicklook data.
Level-2	Level-1 data that have been processed to physical units and/or derived geophysical parameters by combining calibration, ancillary, and other data. These data represent the lowest level of research grade scientific data, and exist at the same time and/or spatial resolution as Level-1 data.
Level-3	Mission Level Data Products. These data have been resampled spatially and/or temporally and may have been combined with measurements from other MMS instruments to produce a merged data set.

Table 4-1: ***MMS-SMART Data Level Definitions***

4.1. Data Product File Formats

The SMART-IS team uses a common format for all publicly available MMS scientific data products. This facilitates the use of MMS data in multi-mission science studies and allows the data to be used with existing tools. The Common Data Format (CDF) was selected based on its proven capabilities, its familiarity to the instrument teams and corresponding scientific communities, its use and planned use by missions including Cluster, THEMIS and RBSP, and its status as a currently supported product of NASA's Space Physics Data Facility.

MMS produces and provides pre-processed, standard data product *files* that are versioned and directly traceable to algorithms, code, and calibration data used to generate them. In this fashion, publications that cite MMS data by version number enable provenance and reproducibility.

4.2. Calibration Data

Details about MMS instrument calibration data are included as part of the Calibration and Measurement Algorithm Document (CMAD).

4.3. Level-1 Data

Level-1 data products are fully decommutated but uncalibrated raw data at full resolution; time-referenced; "extracted telemetry items." Data volumes are identified in Table 4-13 and each instrument team's Level-1 products are described in the tables below:

Fast Plasma Instrument (FPI) Level-1 Products	
Sensor(s)	**Description**
DES	Efficiency/dead-time corrected, decompressed DES data [counts and/or $f(\boldsymbol{v})$]
DIS	Efficiency/dead-time corrected, decompressed DIS data [counts and/or $f(\boldsymbol{v})$]

Table 4-2 ***Fast Plasma Instrument (FPI) Level-1 Data Products***

Hot Plasma Composition Analyzer (HPCA) Level-1 Products	
Sensor(s)	**Description**
HPCA	Decompressed counting rates as a function of E, PO, AZ, TOF
HPCA	Gain, background, cal data

Table 4-3 ***Hot Plasma Composition Analyzer (HPCA) Level-1 Data Products***

FIELDS Level-1 Products	
Sensor(s)	**Description**
AFG	3-component B-field from Analog Flux Gate (AFG), to 128 vectors/sec
DFG	3-component B-field from Digital Flux Gate (DFG), to 128 vectors/sec
SDP	2-component E-field from Spin-plane Double Probe (SDP), to 8192 samples/sec
ADP	1-component E-field from Axial Double Probe (ADP), to 8192 samples/sec
SDP-ADP	Sweep calibration data from SDP and ADP
SDP-ADP	1 spacecraft potential sample from combination of ADP and SDP
SDP-ADP	3 sphere voltages from ADP and SDP
SDP-ADP	3-component Low Frequency (LF) electric Spectra
SDP-ADP	3 sampled Medium Frequency (MF) electric Waveform
SCM	3-component AC B-field from Search Coil Magnetometer (SCM)
SCM	Sweep calibration data
SCM	3-component LF magnetic Spectra
SCM	3-component sampled MF Magnetic waveform
EDI	Beam angles of successful Beam hits from Electron Drift Instrument (EDI)
EDI	Ambient electrons at two directions

Table 4-4: ***FIELDS Level-1 Data Products***

Energetic Particle Detector System (EPD) Level-1 Products	
Sensor(s)	**Description**
FEEPS	Burst: uncalibrated (counts) electron data cubes: Counts x Pseudo Energy x Detector versus time, sampled at the instrument sampling rate combined for both heads (18 detectors total) with each detector mapped to a Geophysical-Coordinate look direction (64 spin sectors).
FEEPS/EIS	Burst: uncalibrated (counts) Fast Ion data cube: Counts x Pseudo Energy x Detector versus time, at the slower of the 2 instrument sampling rates, combined 2 FEEPS heads (6 detectors) and the 1 EIS head (6 detectors) with each detector mapped to a Geophysical-Coordinate look direction (32 spin sectors).
FEEPS/EIS	Fast & Slow Survey: uncalibrated (Counts) electron data cubes: Counts x Pseudo Energy x Sector Elevation x Sector Longitude versus time, sampled at 1/8 spin period combined for both heads with each sector mapped to a Geophysical-Coordinate look direction.
FEEPS/EIS	Fast & Slow Survey: uncalibrated (Counts) Fast Ion data cube: Counts x Pseudo Energy x Sector Elevation x Sector Longitude versus time, at 1/8 spin period timing, combined 2 FEEPS heads (6 detectors) and the 1 EIS head (6 detectors) with each sector mapped to a Geophysical-Coordinate look direction.
EIS	Fast & Slow Survey: uncalibrated (Counts) Ion Composition data cube: Ion Species counts x Pseudo Energy x Sector Elevation x Sector Longitude versus time, with each 6 EIS sector mapped to a Geophysical-Coordinate look directions.
EIS	Burst: uncalibrated (Counts) Ion Composition data cube: Ion Species counts x Pseudo Energy x Sector Elevation x Sector Longitude versus time, with each 6 EIS sector mapped to a Geophysical-Coordinate look directions.

Table 4-5: ***Energetic Particle Detector System (EPD) Level-1 Data Products***

Active Spacecraft Potential Control (ASPOC) Level-1 Products	
Sensor(s)	**Description**
ASPOC	Ion and total beam current, ion beam energy and S/C potential value (provided by SDP) for each of the two ASPOC instruments at highest time resolution (1 second).
ASPOC	Status and housekeeping information (emitter heater current and voltage, secondary voltages, internal temperatures for each of the two ASPOCs (40 seconds resolution).
	All ASPOC Level-1 Data Product Files are generated at SDC.

Table 4-6: ***Active Spacecraft Potential Control (ASPOC) Level-1 Data Products***

4.4. Quicklook Data

Quicklook data are scientific data products that are generated using simplified science processing algorithms and/or with provisional calibrations. These data are intended to provide basic scientific insight. Generation of these data occurs as quickly as possible, whereas routine production of Level-2 and Level-3 products may take considerably longer. In many cases, Level-1B products serve as Quicklook data.

The MMS SDC routinely produces Quicklook science data products, which are readily browsed via a website interface hosted by the SOC. Quicklook data are made available to the science community within 24 hours of telemetry receipt at the SOC. These data products are generated using simplified science processing algorithms and/or provisional calibrations. While expected to be useful for providing scientific insight into recent magnetospheric activity, they are not appropriate for research use.

Data volumes are identified in Table 4-13 and Quicklook data products are described below:

Quicklook Data Products	
Investigation	**Description**
Fast Plasma Instrument (FPI)	Energy-azimuth-zenith angle vs. time spectrograms (survey "sky-maps"), and survey moment time-series including densities, velocities, and temperatures. Unpacked and de-spun FPI Trigger Terms (electron/ion "pseudo-moments").
Hot Plasma Composition Analyzer (HPCA)	Particle flux as a function of energy and ion species. Flux data are displayed primarily as spectrograms (energy vs. time for H^+, He^+, He^{++}, and O^+ ions).
FIELDS	DC electric field vector, DC magnetic field vector, spacecraft potential, E and B wave spectra, EDI ambient electron counts when available.
Energetic Particle Detector System (EPD)	Electron spectra, ion spectra, omni-directional intensities, selected energy angular distributions, selected-energy pitch angle distribution, ion composition index.
Active Spacecraft Potential Control (ASPOC)	Ion and total beam current, ion beam energy, S/C potential (as provided by SDP), filament power and impedance and the emission quality for each of the two ASPOC units. The ASPOC Quicklook Plots are generated at SDC.

Table 4-7: ***MMS-SMART Quicklook Products***

4.5. Level-2 Data

Level-2 data are Level-1 data that have been processed to physical units and/or derived geophysical parameters by combining calibration, ancillary, and other data. These data represent the lowest level of research grade scientific data, and exist at the same time and/or spatial resolution as Level-1 data. All data products include data quality flags and uncertainties as appropriate to aid in accurate understanding of correct data use.

Production software to produce Level-2 science data products is the responsibility of each ITF. For convenience, some Level-2 data products are generated locally at the ITF (FIELDS, HPCA, FPI), with the remainder generated locally at the SDC. Data volumes are identified in Table 4-13 and Level-2 data products are described below:

Fast Plasma Instrument (FPI) Level-2 Science Products		
Sensor(s)	**Description**	**Notes**
DES/DIS	Energy, azimuth, zenith-angle spectrogram ("sky/burst-map") time-series supporting various levels of time axis zoom for survey and burst modes	• Files generated at ITF. • FPI's processed data volume is very large. An important and achievable goal is to minimize any unnecessary growth of this volume due to FPI-ITF re-processing.
DES/DIS	Velocity distribution functions in 3D per energy bin in despun body coordinate frame for survey and burst modes	
DES/DIS	Moments (density, velocity vector, temperature vector, pressure tensor, heat flux vector) with corrections (calibration, spacecraft potential, and photo-electron) for survey and burst modes	
DES/DIS	Partial moments (density, velocity vector, temperature vector, pressure tensor) integrated starting from each energy step for survey and burst modes	

Table 4-8 ***Fast Plasma Instrument (FPI) Level-2 Science Products***

HPCA Level-2 Science Products	
Description	**Notes**
Calibrated & background-corrected energy flux for H^+, He^+, He^{++}, and O^+ ions	• Files generated at ITF. • These are generated with varying fidelity depending on the operating mode of the instrument. In the highest resolution mode, each species will result in 18432 data values (64 Energy x Polar x 18 Azimuth at a ten second cadence.
Velocity distribution functions of H^+, He^+, He^{++}, and O^+ ions derived from j(E)	
Moments (density, velocity, temperature)	
Time of Flight (TOF) raw counts	

Table 4-9: ***Hot Plasma Composition Analyzer (HPCA) Level-2 Science Products***

FIELDS Level-2 Science Products		
Sensor(s)	**Description**	**Notes**
FGM	3-component B-field to 128 vectors/sec in GSE	Files generated at ITF
EDP	3-component E-field to 8192 samples/sec in GSE	Files generated at SDC
EDP	1 spacecraft potential	Files generated at SDC
EDP	3-component LF electric spectra	Files generated at SDC
EDP	3-component MF electric spectra	Files generated at SDC
SCM	3-component LF magnetic spectra	Files generated at SDC
SCM	3-component AC B-field	Files generated at SDC
EDI	3-component electric field	Files generated at ITF
EDI	Ambient electrons at two directions	Files generated at ITF

Table 4-10: ***FIELDS Level-2 Science Products***

Energetic Particle Detector System (EPD) Level-2 Science Products		
Sensor(s)	**Description**	**Notes**
EIS	Burst: Calibrated (intensity) Ion Composition ExTOF data cube - Ion Species Intensity x Energy (~50 – 500 keV) x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF
EIS	Burst: Calibrated (intensity) Ion Composition PHxTOF data cube - Ion Species Intensity x Energy (~20 – 50 keV) x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF
EIS	Burst: Calibrated (intensity) electron data cube – Electron Intensity x Energy x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF
EIS	Fast & Slow Survey: Calibrated (intensity) Ion Composition ExTOF data cube - Ion Species Intensity x Energy (~50 – 500 keV) x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF
EIS	Fast & Slow Survey: Calibrated (intensity) Ion Composition PHxTOF data cube - Ion Species Intensity x Energy (~20 – 50 keV) x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF
EIS	Fast & Slow Survey: Calibrated (intensity) electron data cube - Electron Intensity x Energy x Telescope versus time for each of the 6 telescopes, with each sector mapped to a Geophysical-Coordinate look direction (8 spin sectors) and magnetic field direction.	Files generated at ITF

Table 4-11: ***Energetic Particle Detection System (EPD) Level-2 Science Products***

Active Spacecraft Potential Control (ASPOC) Level-2 Science Products	
Description	**Notes**
Interpolated ion beam current and energy for each of the two ASPOCs, as well as the sum of the individual beam currents (1 second resolution).	Files generated at SDC
Interpolated status information (modes of both ASPOCs, ON/OFF status) and data quality information at a resolution of 1 second.	

Table 4-12: ***Active Spacecraft Potential Control (ASPOC) Level-2 Science Products***

4.6. MMS Mission Level Science Products (Level-3)

The MMS Mission Level Data (MLD) products are combined from the instrument-specific Level-2 data products. MLDs specifically address the need for multi-instrument analyses central to the SMART project. Level-3 data may include other publicly available data products if they are of significance to the SMART science efforts *and* can be merged into the data system at the SDC (e.g. geomagnetic indices, solar UV fluxes, etc.).

Specific MMS Level-3 products, along with responsibility for their generation, are identified in the *MMS-SMART Instrument Suite Calibration and Measurement Algorithm Document.*

4.7. Data Volume

The MMS-SMART IS produces a substantial volume of data on a daily basis. Level-2, alone, accounts for more than 50 GB per day for all four observatories. Within the MMS team, systems are scaled accordingly to accommodate data transmission and storage needs. To facilitate use by the general science community, online analysis tools provide the ability to zero in on specific data of interest prior to download. For scientists working with the data, this can minimize the amount of data that needs to be downloaded and managed on local systems. The following table indicates the expected data volumes for each MMS-SMART investigation's data products.

MMS Data Volume (daily, per spacecraft)						
Instrument	**Raw Volume**	**Level-0 Volume**	**Level-1 Volume**	**Level-2 Volume**	**Level-3 Volume**	**Total**
Fast Plasma Instrument (FPI)	262 MB	262 MB	1310 MB	11200 MB	TBD	13034 MB
Hot Plasma Composition Analyzer (HPCA)	59 MB	59 MB	295 MB	443 MB	TBD	856 MB
Fluxgate magnetometer - AFG	3 MB	3 MB	15 MB	38 MB	TBD	59 MB
Fluxgate magnetometer - DFG	2 MB	2 MB	10 MB	32 MB	TBD	46 MB
Search-coil magnetometer (SCM)	35 MB	35 MB	175 MB	260 MB	TBD	505 MB
Spin-plane electric field instrument (SDP)	77 MB	77 MB	385 MB	600 MB	TBD	1139 MB
Axial double-probe electric field instrument (ADP)	39 MB	39 MB	195 MB	300 MB	TBD	573 MB
Electron-drift electric field instrument (EDI)	7 MB	7 MB	35 MB	100 MB	TBD	149 MB
EPD	5.0 MB	5.0 MB	25 MB	151 MB	TBD	186 MB
Active Spacecraft Potential Control (ASPOC)	1.2 MB	1.2 MB	8 MB	8 MB	0	18 MB
Total	.49 GB	.49 GB	2.5 GB	13.1 GB	TBD	16.6 GB

Table 4-13: ***MMS-SMART Data Volume (daily, per spacecraft)***

Of the data volume numbers in the above table, approximately 74% are burst data, 25% are Fast Survey, and the remaining 1% is Slow Survey data.

5. DATA HANDLING

5.1. Overview of End-to-End Data Flow

Data capture of both instrument and spacecraft recorded telemetry occurs at the MOC. During ground station contacts, real-time telemetry are relayed from the MOC to the SOC. Following each ground station contact, the MOC provides the SOC with recorded telemetry frames containing instrument and spacecraft data, along with appropriate status and ancillary information. The SOC performs Level-0 processing on these data, dividing the telemetry data streams into packets. The packet sets are then processed at the SOC, using software developed by LASP and the investigator teams, to form Level-1 data products, which are used to monitor state-of-health and to support operations. Quicklook science data products are also be created to provide a preliminary view of MMS science measurements and are be accessible to the science community via the Internet. Generation of Level-1 data takes place within 6-hours of ground receipt, with Quicklook products nominally being generated within 24 hours.

Within one day of receipt, the SDC makes available telemetry and ancillary data to the ITFs for Level-2 data processing. Each ITF is responsible for ensuring the generation of Level-2 data products based on best current calibration factors and (where applicable) delivering these products to the SDC for distribution and archival within 30 days.

Since magnetometer and ASPOC data are needed by other ITFs to perform their Level-2 data processing, Level-2 magnetometer and ASPOC processing occur at the SDC in close collaboration with the corresponding ITF. In these cases, maintenance and development of the processing software, data validation, and calibrations are the responsibility of the ITF and the SDC will execute the provided Level-2 software on production systems. Subsequently, these data products are made available to all the teams within 24 hours of receipt of telemetry at the SOC.

Updates to calibrations, algorithms, and/or processing software occur regularly, resulting in appropriate production system updates followed by reprocessing of science data products. Systems at the SOC and ITFs are designed to handle these periodic version changes. Likewise, publicly available software tools are updated as needed.

Responsibilities for data product generation and dissemination are discussed in Section 3 and the timeline and schedule for production and availability of MMS data products is shown in Table 5-1. Details regarding data distribution to/from the ITFs, magnetometer and ASPOC Level-2 software deployment, data validation, and reprocessing strategies are provided in the *Calibration and Measurement Algorithm Document (CMAD).*

Data Level	Responsible Team	Availability Schedule
Level-0	MMS SOC	Beginning at the start of instrument commissioning, Level-0 data are routinely available within 6 hours of science telemetry receipt at the SOC.
Level-1	MMS SOC	Beginning at the start of instrument commissioning, Level-1 data are routinely available within 6 hours of science telemetry receipt at the SOC.
Quicklook	MMS SOC	Beginning at the start of instrument commissioning, Quicklook data are routinely available within 24 hours of science telemetry receipt at the SOC.

Data Level	Responsible Team	Availability Schedule
Level-2	Instrument Team Facilities (ITFs) are responsible for all Level 2 data production and validation. In the case of ASPOC and magnetometer data, Level 2 processing occurs at the SOC on behalf of the corresponding ITF. In these cases, the ITF provides the SOC with processing software, documentation, maintenance, and data validation as needed. Producing these data at the SOC allows for fast turnaround time of the products that the other ITFs depend on.	Beginning as soon as possible but no later than 6 months after commissioning, Level-2 products are routinely produced within 30 days of science telemetry receipt from each spacecraft. Further, since all teams depend on both ASPOC and magnetometer data, ASPOC and magnetometer data products are made available within 24 hours of the raw data being received at the SOC.
Level-3	Generation of Level-3 data products is the responsibility of individual instrument teams and is described within each team's Data Product Guides.	Beginning as soon as possible, Level-3 products are produced by individual instrument teams as developed.

Table 5-1: ***Timeline for Availability of MMS-SMART Data Products***

The SOC maintains an active archive of all MMS data levels, and provides direct access to the MMS science team and science community through the entire lifecycle of the MMS mission, beginning with management of telemetry data during observatory I&T. As is documented in the *MMS Mission Archive Plan*, following the operational phase of the mission MMS data products are expected to continue to be made available to the science community through an MMS Resident Archive, possibly the MMS SDC, to maintain continuity. Once it is no longer cost effective, the SOC is expected to transfer MMS data holdings to a Final Archive (the SPDF), which provides long-term preservation.

5.2. Data Acquisition

The MMS scientific questions require high-time-resolution measurements within boundary regions that often comprise only a small part of the MMS orbit. In the subsolar reconnection region, for example, high time resolution observations are needed for ~10 minute periods as the spacecraft cross the magnetopause regions, but only moderate time resolutions in the surrounding regions. Within the ion and electron diffusion regions, electron distributions at ~30 ms resolution are needed as well as electric and magnetic wave-form captures with resolution to 1-10 ms. The requirements in the magnetotail reconnection region are somewhat less stringent. To accommodate these different data acquisition needs while keeping within telemetry downlink limits, the SMART Instrument Suites generate two science data streams, Burst and Survey.

The Survey data stream is collected nearly continuously. When the spacecraft are not in or near targeted regions of scientific interest (about half of each orbit), data are collected in "Slow Survey" mode. In this mode, the instruments acquire data at significantly less than maximum data collection rates. As the four spacecraft approach targeted regions of scientific interest (the remaining half of each orbit), the instruments are configured in "Fast Survey" mode and acquire data at moderate time resolution. All of the data collected in survey mode is downlinked.

The Burst data stream is collected concurrently with the collection of Fast Survey data. Burst data are high time resolution, continuous data sets. At this resolution, the SMART IS produces scientific measurements many times faster than the orbit-averaged telemetry rate. Since it is not practical to downlink all of the burst data and since only a small fraction of the collected burst data are expected to be essential anyway, a buffer selection scheme is used to prioritize burst data for downlink. This scheme employs onboard algorithms to determine Cycle Data Quality factors (CDQs), which provide a quantitative measure of each burst buffer's data values. The CDQs are much smaller than the data they represent and are easily transmitted to the ground. Once at the SOC, the CDQs are used to determine the periods of time that have the most valuable concurrent burst data on all 4 spacecraft.

This scheme focuses data collection on the most interesting parts of the orbit, helps to ensure that the best synchronous data is downlinked from all 4 spacecraft, and optimizes the 96 GB of on-board storage provided by the Central Instrument Data Processor (CIDP). For a detailed description of the burst buffer selection system, see the *Burst Algorithm Definition and Concept of Operations* (10160.17-BADCO-01).

5.3. MOC ⇔ POC Data Transfers

In order to support operations of the MMS Instrument Suites and capture and processing of science data, data and information exchanges between the MOC and the POC are necessary. The principal transfers are illustrated in Figure 5-1. Interfaces pertaining to science-related data flows are emphasized in this document; operations-related data flows are further described in the *MMS Concept of Operations* (461-PROJ-PLAN-0071), and are also indicated in Figure 5-1 and Figure 5-2.

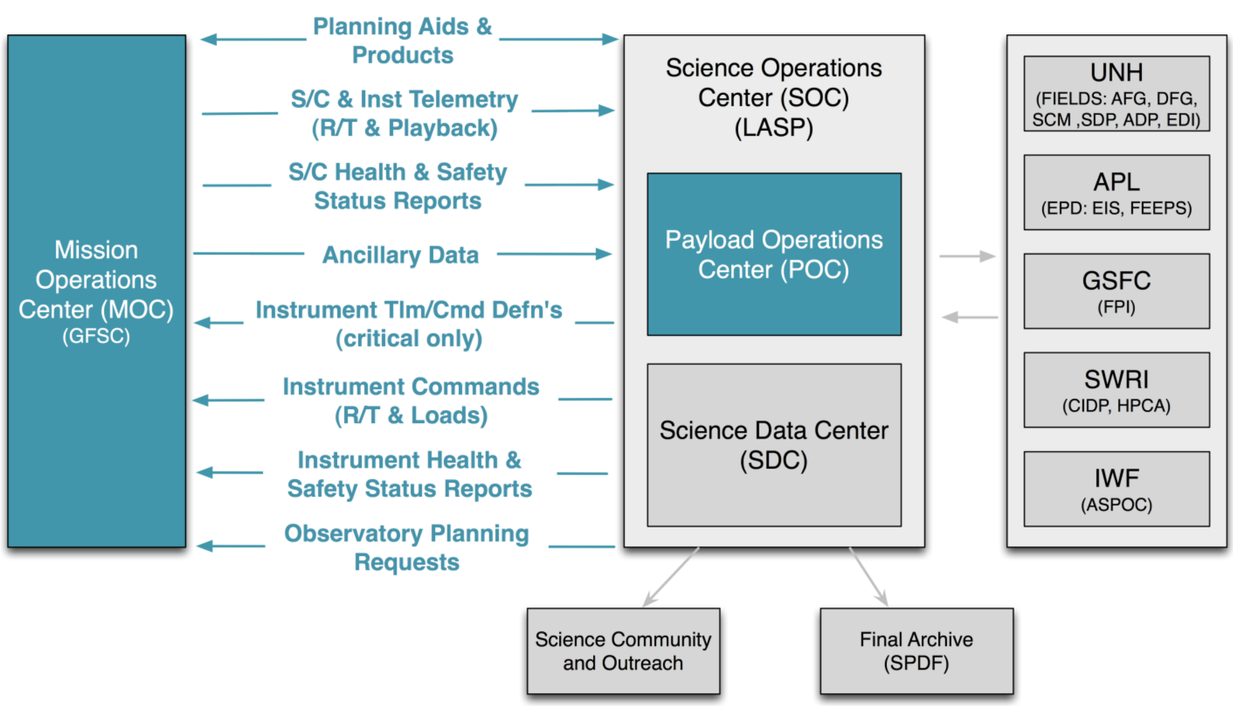

Figure 5-1: ***Key data flows between the MMS MOC and POC***

All MMS telemetry data (spacecraft and instrument housekeeping and science) are captured by the MMS MOC, and subsequently relayed or transferred to the POC. Immediately following a recorder dump pass, the MOC forwards all captured spacecraft and instrument telemetry files to the SOC/POC. Only minimal Level-0 processing and accounting is required, as the data are transferred in the reliable file mode of the CCSDS File Delivery Protocol (CFDP). All spacecraft, instrument, and ancillary data are transferred to the SOC/POC on an ongoing basis for archival and distribution; however, spacecraft data are also maintained in the MOC for the operational duration of the mission. The communications links used to support transfers between the MOC, SOC, and other ground system elements are documented in the *MMS MOC-SOC ICD*. Transfers between the SOC and other ground system sites (e.g. ITFs, science community) use the Internet.

The MOC transfers all real-time spacecraft and engineering telemetry to the SOC/POC using a private operational network, which is identified in the Project Service Level Agreement (PSLA). The MOC transfers all IS recorded telemetry files directly to the SOC/POC as it is received to allow the SOC to manage these data.

In addition to telemetry data transfers to the SOC, ancillary data are provided by the FDOA to the SOC via the MOC. The frequency and format of these data is documented in the *MOC/FDOA-SOC ICD*. These data will include:

- Predicted orbit ephemerides
- Definitive orbit ephemerides
- Definitive spin axis attitude - A definitive spin axis attitude file is computed from the downlinked spacecraft playback telemetry files and provided post-pass
- Definitive spin rate/spin phase angle
- Maneuver history

5.4. POC ⇔ Instrument Team Transfers

The POC makes available several data products to the ITFs to support operations of their instruments, including real-time telemetry data, contact schedules, planned activity summaries, and data availability notifications and quality reports. Similarly, operations support products and information are provided by ITFs to the POC, including detailed instrument state-of-health assessments, special planning requests, and any necessary special uploads (e.g. flight software updates). The principal data products transferred over this interface are indicated in Figure 5-2. The timelines for delivery of these products and formats used are documented in the *MMS SOC-ITF ICD.*

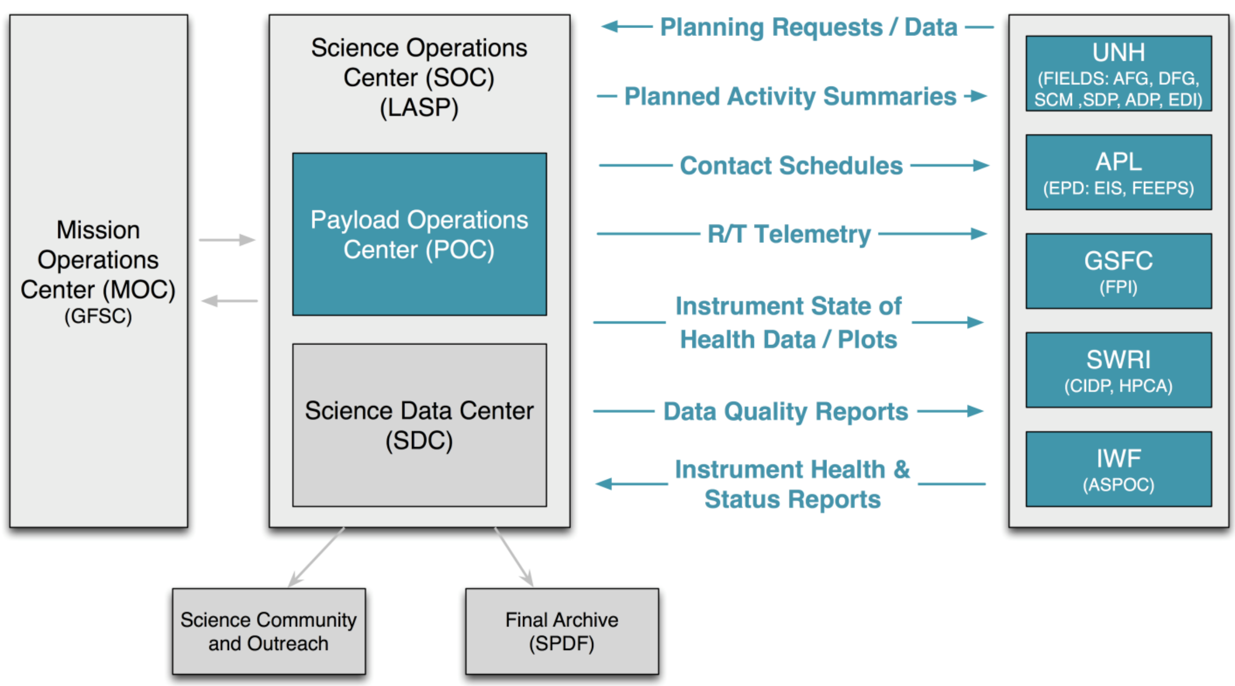

Figure 5-2: *POC-ITF Data Transfers*

5.5. SDC ⇔ Instrument Team Transfers

The interface between the SDC and the ITFs is designed to facilitate production, management, and dissemination of science data products. Low-level telemetry data, ancillary data, and Quicklook data are generated at the SOC and made available to the ITFs for generation of higher-level science products. Key data exchanges are indicated in Figure 5-3.

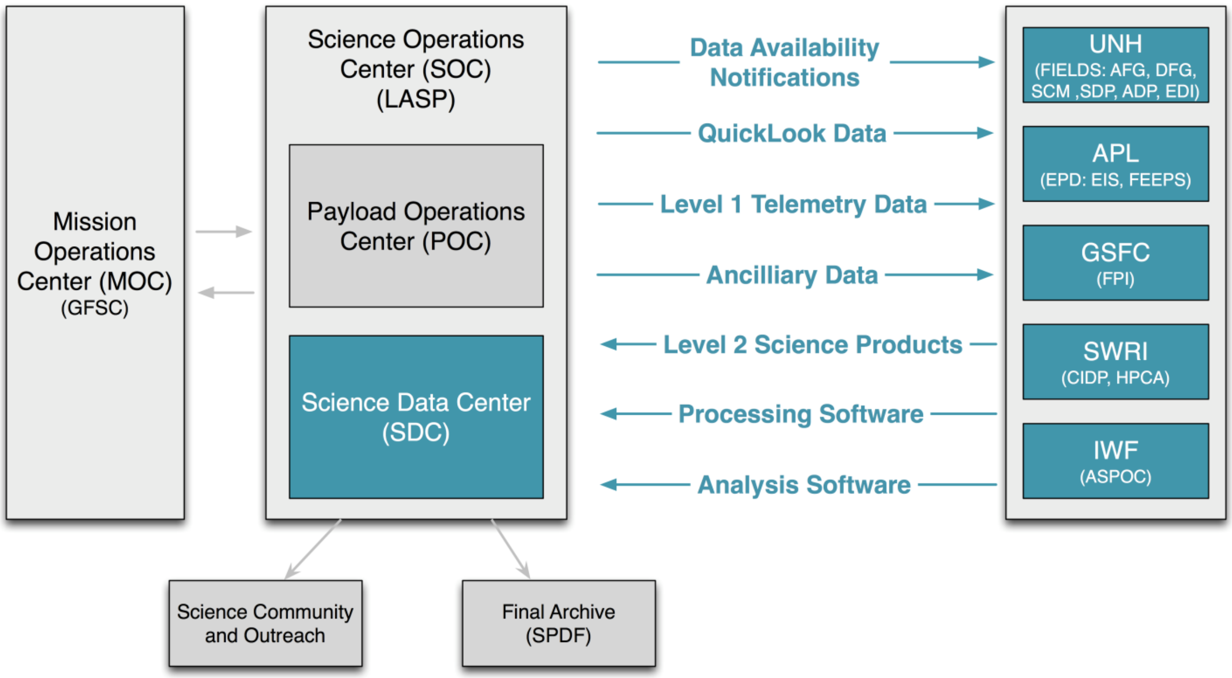

Figure 5-3: *SDC-ITF Data Transfers*

Within one day of acquisition, ITFs receive notification of the availability of Level-0 and Level-1 data. Each ITF then initiates transfer from the SDC of the telemetry and ancillary data needed for Level-2 production and data validation. Each ITF then returns Level-2 science data for their instrument to the SDC within 30 days. Level-2 data are in physical units for all appropriate quantities, based on best current calibration factors and analysis routines. Reprocessing of Level-2 data can occur throughout the operational mission as significant advances in instrument calibration and understanding warrant the production of a new data version. Version control systems are utilized by the SDC and the ITFs to ensure that changes in calibration and reprocessing of Level-2 data are tracked and are transparent to the scientific user receiving data from the SDC. Modeling data from the SMART theory efforts are also treated as Level-2 data and, after validation, can be maintained and disseminated by the SDC.

5.6. Science Data Production

In addition to raw telemetry and other ancillary data that are needed to support science processing by the ITFs, there are a number of interdependencies between instrument processing algorithms. Data products that other teams depend on (e.g. Level 2-Pre magnetometer data) are provided via programmer-level interfaces once that data is available at the SDC. For convenience, these interfaces work in much the same way as the interfaces that are used to access telemetry and ancillary data. Specific data processing needs and dependencies for each of the MMS investigations are detailed in the sections below.

5.6.1. FIELDS

Magnetometer science data from both AFG and DFG sensors are processed (to Level-2 Pre) by the SDC and provided to other ITFs for all scientific uses of the DC magnetic field. The FIELDS magnetometer team maintains and supervises this production. This Level-2 Pre Product is a preliminary version that is produced using an epoch-based set of calibration offset and matrices, with best available attitude information. These offset and matrices are refined over a period of 30 days and allow the production of a higher-fidelity Level 2 FGM product that combines AFG and DFG data into a single product that can be used for publication purposes. A Level 3 burst product, FSM (Fluxgate Search-Coil Merged), requires joint processing between AFG, DFG, and SCM to arrive at the final values.

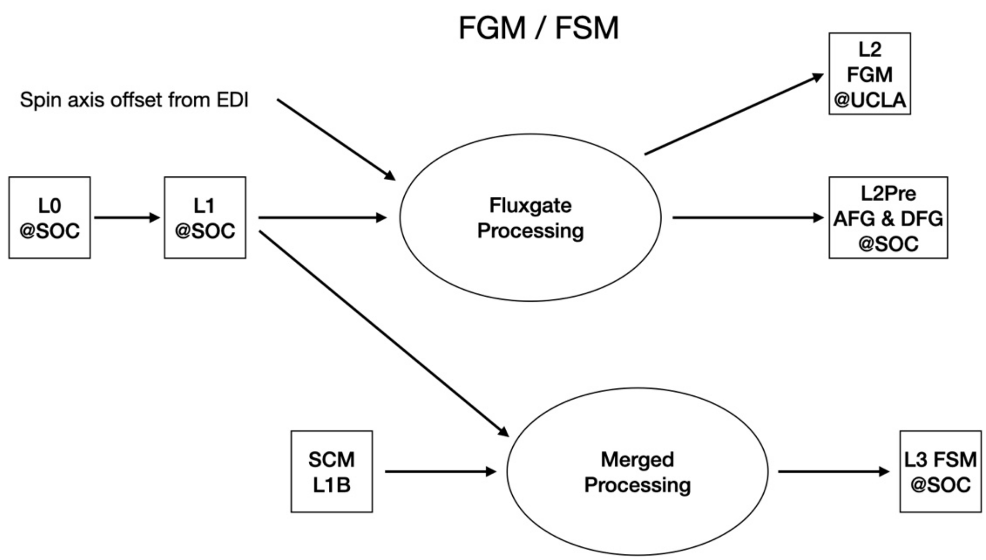

Figure 5-4: ***AFG / DFG /FGM / FSM Processing Flow***

For EDI, there is an existing software process, BESTARG, that is rather resource intensive and produces field and flow vectors for the "field" mode of EDI. Other processes, less intensive, produce time series of the electron flux, and magnetometer corrections.

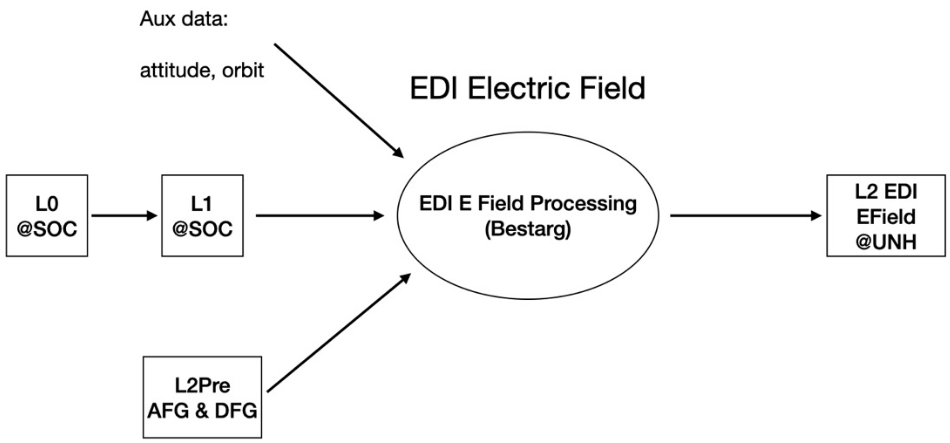

Figure 5-5: ***EDI Bestarg Processing Flow***

EDI processes "Ambient mode" electron data using the L2Pre magnetometer data sets into a time-series of electron fluxes at one selected fixed energy (250 eV, 500 eV, and 1000 eV), as diagrammed in **Error! Reference source not found.**.

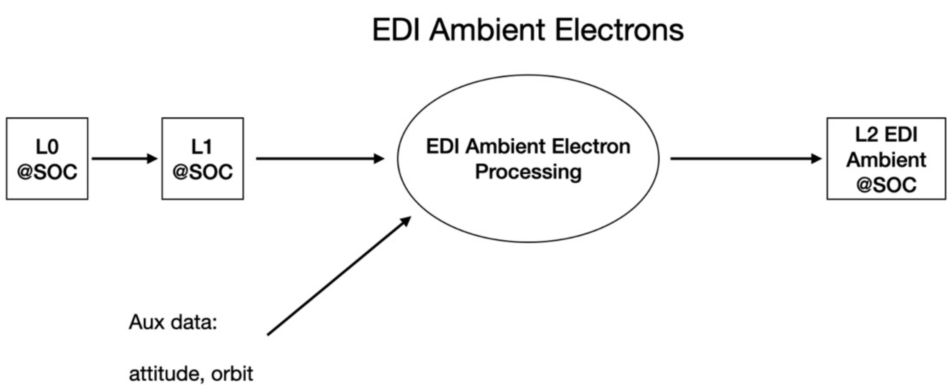

Figure 5-6: ***EDI Ambient Electron Processing Flow***

EDP Level 2 Pre processing consists of offset removals and corrections of the ADP and SDP field components, data quality and error determination, and spin-period fits. EDP Level 2 processing includes EDI electric field data and FPI L2 ion moments data for higher fidelity electric field data as diagrammed in 5.7.

In addition, wave power and auto- and cross-correlation spectra are produced for the wave data.

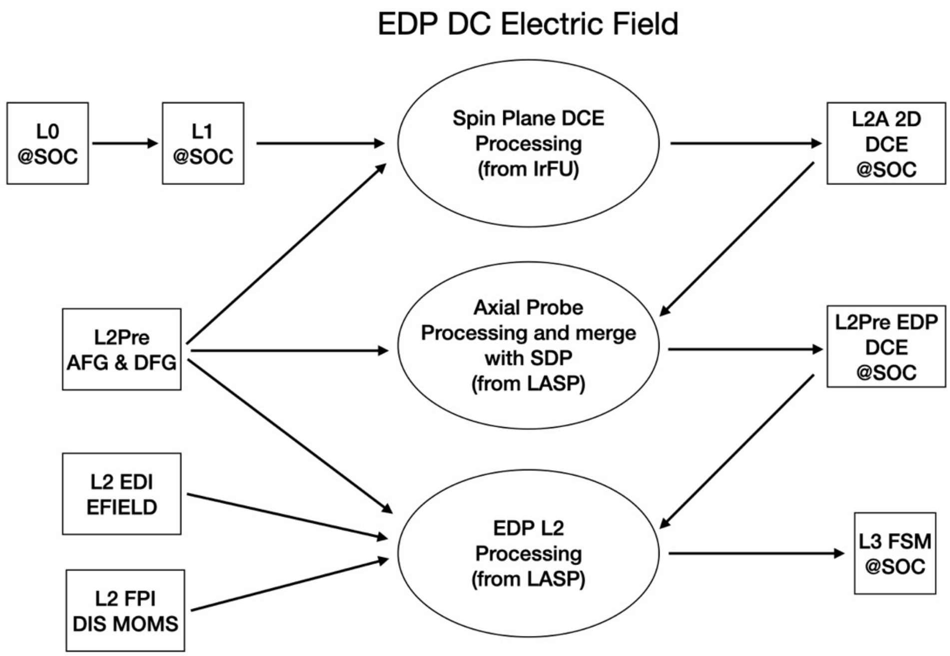

Figure 5-7: EDP / ADP / SDP Processing Flow

5.6.2. EPD

Figure 5-8 shows the flow of data and institutional responsibilities for the EPD data generation and processing functions. Primary data dependencies include accurate knowledge of the orientations of the EIS and FEEPS fields of view with respect to the local magnetic field vector and with respect to the Earth and Solar System coordinates, and accurate timing information between the EIS and FEEPS sampling (It is important that FEEPS sector "n" be accurately aligned with the very same EIS sector "n"). The EIS data are compressed on the spacecraft in two ways, and both types of compression must be inverted on the ground. Specifically, the EIS rate data are log-compressed from 16 or 24 bits to 10 bits. This compression is standard for particle detectors, but does generate loss of information. The error in intensity introduced by this process is < 2%. Secondly, a lossless compression algorithm is applied to data records. The FEEPS data is also log-compressed, but to 12 bits, for an error of < 1%. Figure 5-8 shows that the FEEPS data are validated by Aerospace (light orange box; with help from Boston University, now University of New Hampshire), and the EIS data are validated by APL, also with help from BU/University of New Hampshire (dark orange box). Standard particle detector plotting tools are generated, including intensity versus time line plots, energy versus time versus intensity color spectrograms, pitch angle versus time versus intensity spectrograms, all-sky direction (2D) versus intensity displays, energy spectrum displays and pitch angle distributions displays.

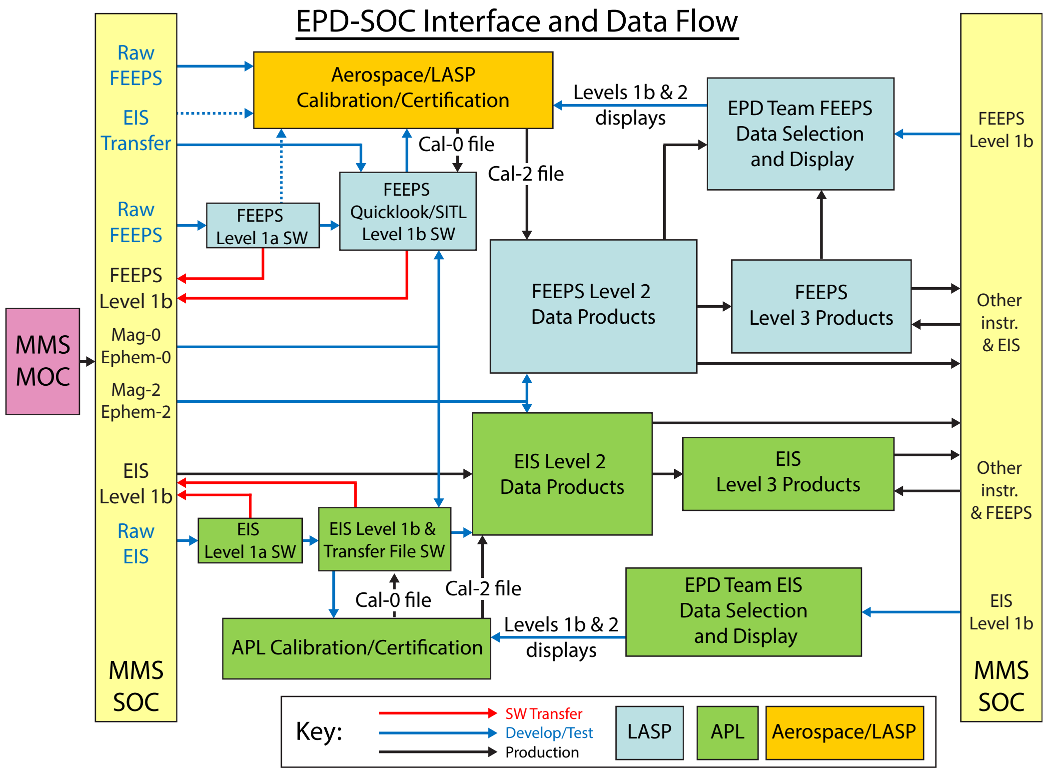

Figure 5-8: *EPD Processing Flow*

5.6.3. FPI

FPI Level-1 data products are produced using decoded and decompressed Level-0 data, plus current calibration and any ancillary data. The compression is done in hardware using a wavelet-based technique that ranges from essentially lossless to lossy, with a compression ratio varying accordingly. On orbit trades are made between burst data duration and velocity resolution, based on available telemetry allocation and experience, to assure overall data quality while maximizing the duration of telemetered high time resolution burst data. The result is fully time/energy/orientation-referenced (in spacecraft coordinates for bursts, de-spun spacecraft coordinates for survey products), associating a count (or "pixel") with the correct time, energy, and orientation (the one at which it was measured).

FPI Quicklook / Level-1B products include both the calibrated "flux skymaps" from Level-1 (all modes are available, but the results are provisional, particularly for burst-maps), and provisional moments (generated for fast-survey-mode data from the Level-1 product) which use spacecraft coordinates (albeit de-spun), and which incorporate older corrections and quality measures than those applied at Level-2.

Level-2 (and beyond) products use physical units, include all relevant (standards-compliant) metadata, and are submitted to the SOC after being certified "research grade" upon passing a set of quality tests (employing the best quality available B-field, spacecraft potential, FPI calibration data, reference densities from other instruments, etc.).

The basic set of moments consists of number density, velocity, temperature, pressure, and heat-flux parameters. Added to these moments are the associated uncertainties and some ancillary data, including spacecraft potential and "sun-sector". Differential energy fluxes for each energy are averaged over all directions as well as over various sky slices. Electron and ion distributions are phase-space-density (s/c-potential-corrected f(**v**)) representations of instrument counts and are binned in their native instrument body coordinate frame (albeit de-spun). The Level-2 products are the native-resolution moments and canonical distributions (all modes, supporting any portrayals) for both DES (electrons) and DIS (ions).

Level-3 (derived from Level-2) products follow the same content and quality standards as Level-2. These can be as simple as re-sampled FPI products, or may be the result of merging FPI products with those of other instrument-suites.

A representation of FPI data processing flow is depicted in **Error! Reference source not found.**.

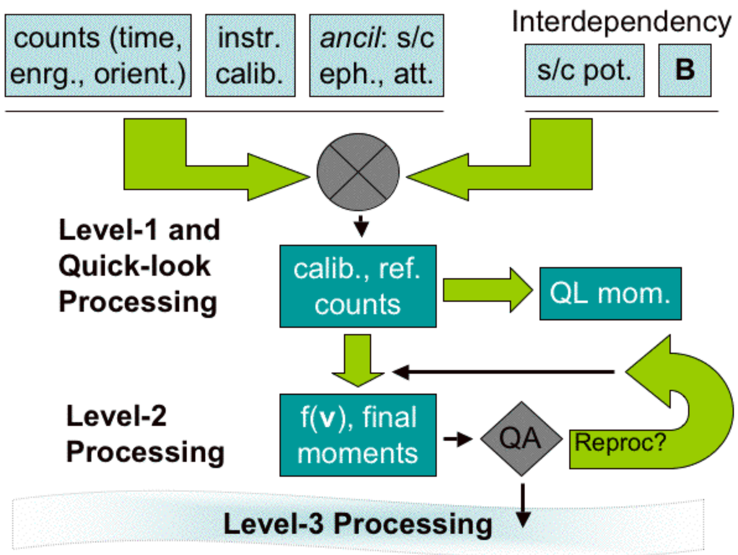

Figure 5-9: ***FPI Processing Flow***

FPI data are organized and interpreted using data on the magnetic and electric fields. FPI analysis tools are provided for both diverse plotting methods as well as ASCII text (and various other useful formats) file dumps of any specified data array. In addition, all FPI algorithms, for example those used to compute moments, are version controlled but open to inspection and comment by anyone using the FPI data set. This combination of analysis tools provides the basis for development of additional tools of arbitrary sophistication limited only by the capabilities and resources of the interested investigator.

5.6.4. HPCA

HPCA data are compressed using a combination of table driven decimation together with a lossless compression step. Reversal of the lossless compression yields Level-0 data.

Level-1 data products consist of counting rates as function of energy, elevation, azimuth, mass/charge and time-of-flight. Gain and background data are generated.

Quicklook data products consist of particle flux as a function of energy and ion species. Flux data are formatted as time vs. energy spectrograms integrated over elevation and azimuthal angles. There is one spectrogram per species for H+, He+, He++, and O+ ions.

Level-2 data products are calibrated and background–corrected and provided for four ion species (H+, He+, He++, and O+) Data products for these species consist of: energy fluxes, velocity distribution functions, pitch angle distributions, and moments (density, velocity, and temperature). Additionally, TOF raw counts are provided.

Level-3 data products are similar to level-2 but have been resampled and combined with measurements form other MMS instruments.

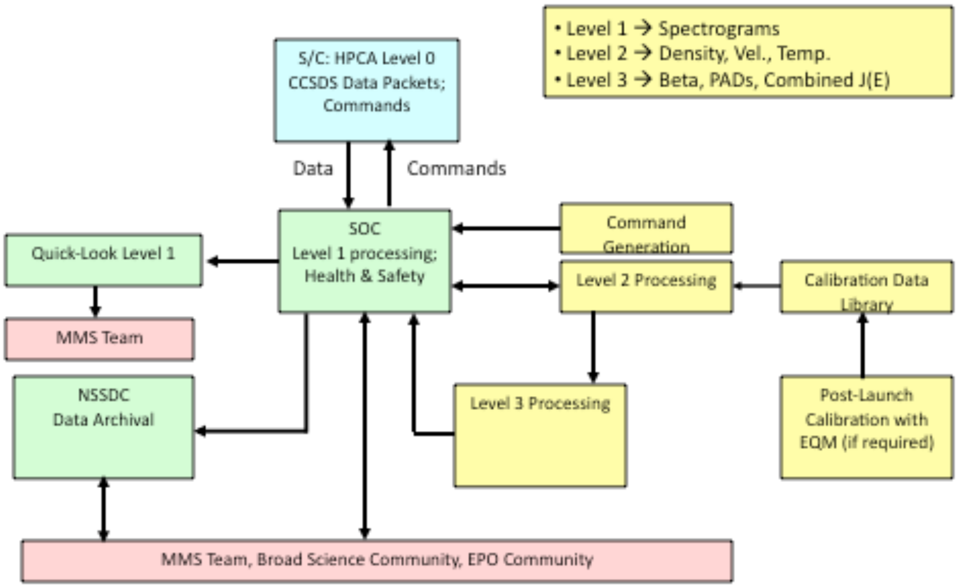

Figure 5-10: ***HPCA Processing Flow***

5.6.5. ASPOC

ASPOC data from both ASPOC instruments on each observatory are processed (to Level-2) by the SDC and provided to other ITFs for all scientific uses of the ion beam current and energy. The ASPOC team maintains and supervises this production.

Level-2 products include the current and voltage of the ion beam emitted by ASPOC using physical units. The processing consists of applying the current calibration, filtering, data quality and error determination. Data quality parameters are based on numerical analysis of the data (e.g., noise, presence of spikes). No compression is used.

As ASPOC is an active instrument, which influences the environment for other measurements, it is suggested to interpret this quality parameter (or to provide an additional quality parameter or flag) to describe the effectiveness of the control of the spacecraft potential. This parameter may be used by other ITFs together with the ASPOC L2 data to assess any cross-effect with other data.

Validation of the data are made by visual inspection of the data and by regular plausibility checks between the ASPOC L2 products on the one hand and spacecraft potential and plasma parameters on the other hand via spacecraft charging models.

Visualization software to facilitate the manual validation is provided, which delivers custom line plots of relevant parameters and support the plausibility checks mentioned before.

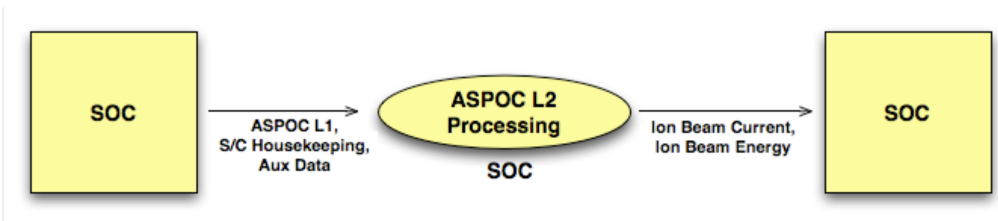

Figure 5-11: ***ASPOC Processing Flow***

5.7. Science Analysis and News Reports

The SDC reports MMS related science news and data analysis summaries on the MMS SDC website. These news items may include descriptions of solar events, magnetospheric phenomenon, and MMS data highlights (such as reconnection events) as reported by the MMS science team.

5.8. Additional Data Flows

The general science community is able to access MMS science data products (Quicklook, Level 2, and Level 3) via a publicly accessible website, which is maintained and hosted at the SDC. The SDC also makes these data products available via a programmer level interface, which enables automated processing and analysis systems at other institutions as well as the retrieval needs of Virtual Observatories. In addition, appropriate MMS data are made available through existing SPDF multi-mission data services such as CDAWeb and orbit services such as SSCWeb to further enable multi-mission science studies using MMS data and to more easily use data from other missions to establish the larger context for given MMS observations.

6. CONFIGURATION MANAGEMENT / QA

The MMS SMART team is responsible for the production, analysis, and timely delivery of high-quality science data to the MMS Project. This is a standard expectation of NASA missions; however, the complexity of the MMS mission demands additional attention to software and data quality assurance strategies by both the SDC and the ITFs. With five science investigations onboard each of its four spacecraft, MMS produces dozens of data products with many interdependencies. Data management challenges include:

- Software testing, data validation, defect tracking and data versioning is complicated by the fact that there are multiple investigations and multiple geographically dispersed teams.
- Calibration data are unique for each of the sensors. This data and its effect on Level-1, Level-2, and Level-3 (Mission Level Data) dependencies is carefully tracked.
- Changes in any of the Level-1 or Level-2 data products requires re-validating and re-releasing all affected software and data products. Affected data may include Level-1 data, Level-2 data, software products (e.g. "calibrators", analysis tools), and Mission Level Data products (Level-3).
- With dozens of data products, analysis tools, and on-the-fly data production tools (e.g. "calibrators"), staying informed of version updates may be challenging to users.

To address these challenges and ensure that the MMS project delivers correct, validated, and timely science data to the user community, a configuration management system is employed at each contributing institution for all of its science products, the data those products depend on (e.g. calibration data), and the software that is used to produce, distribute, and analyze them. Minimum configuration management includes versioning systems, release control procedures, issue/defect tracking, and documentation. Together, these configuration management systems and practices maintain a complete pedigree for each data product produced, and should also facilitate data reproducibility.

6.1. Information Preservation and Backup

As systems at the ITFs are not directly part of the Mission Archive at the SDC, adequate security and backup and recovery mechanisms are established at each ITF, if not already present. Backup and recovery mechanisms are generally documented along with contingency plans for ensuring a full recovery from catastrophic damage or failure. At a minimum this includes offline and offsite backup of all irreplaceable information, including software, calibration data, and other system dependencies.

6.2. Versioning

Each investigation has the responsibility of maintaining both an issue tracking and a version control system for its data production software, processing environment, analysis tools, data products and static calibration data. Two types of version tracking are employed in order to track revisions to both software and data products produced by software. These two types of versioning are described in the following sections.

6.2.1.Software Versioning

Teams are expected to use a source code management system for tracking code changes and other processing and data handling system dependencies (e.g. static calibration data). It is imperative that both software and calibration data are similarly revision controlled, and that the revision repository is backed up regularly and maintained off-site, as described in Section 6.1.

6.2.2.Data Versioning

MMS data users should be able to count on data of a specified version being consistent. This means that if anything changes in the processing system that produces a different data result, the version of that data product is incremented. Specifically:

- Changes to software or calibration data such that science results change for a specific time range indicates that the version number of the science data must change.
- When the version changes for a product that other products depend upon, the version must be incremented for the dependent products as well.

For clarity and consistency, version numbers included in data product file names. A consistent version numbering scheme is established and documented in each team's Data Product Guide.

6.3. Release Control

6.3.1. Validation

Ensuring the quality of the MMS science data products requires two types of validation efforts: that occurring prior to the production of data products (pre-production) and that which occurs after data products have been produced (post-production). Pre-production validation includes design reviews of algorithms and software that are used to produce and analyze data products. Production validation is best achieved through science data analysis using the archive products. All new version releases are validated by the contributing ITF and/or SDC team as appropriate, with the validation results being published and/or made available from the SDC-resident MMS data website.

6.3.2. Release Notes

Detailed release notes accompany all released software and data. At a minimum, release notes include the following information:

- Identification of the release (name, date, version number)
- Data product dependencies and corresponding versions.
- Requirements (required third-party platforms/modules/packages/etc)
- Features and changes (new features, defects corrected, etc)
- Outstanding issues (unresolved defects, work-arounds, installation issues, known issues, etc)
- Installation guide (if applicable)

6.3.3. New Release Notifications

In order to make sure that the *best* data products and tools are easily available for research and analysis, users need an easy way to be informed when new data versions and analysis tools become available. Strategies employed by the SDC include:

- Currently available version numbers are clearly indicated for all data and software products on the MMS SDC website.
- Version Release Notes for all data and software products are clearly available through the MMS SDC website.

The SDC work with applicable Virtual Observatories (e.g. Virtual Magnetospheric Observatory) to ensure that VxO users are also aware of when new releases are available.

6.4. Defect Tracking

A Defect Tracking System is established at the SDC and each ITF for tracking issues related to data products, data production software, and analysis tools. This system attaches a tracking number to all reported problems and allow for status changes (e.g. open/closed), the addition of comments, and filtered views (e.g. status, date reported, tags, etc). These systems are used for internal tracking at each ITF and need not be available for reporting by outside users.

Users from the general science community are encouraged to report any issues they might encounter through a web-based problem reporting system, which is implemented at the SDC and available through the MMS data access website, or via direct email to applicable ITF staff. The system is intended to guide users in the creation of effective problem reports, which includes user system details, activities causing problems, terminal output showing any error details, optional contact details, etc. These problem reports have a tracking number assigned to them and are communicated to the relevant instrument team(s) and the SDC manager for tracking and follow-up as needed.

7. DATA ACCESS AND AVAILABILITY

There are no proprietary periods associated with any of the MMS-SMART data products, and users have timely access to the scientifically useful products (Levels 2+). Additionally, users have access to science data analysis tools that aid in data access and analysis. To help ensure that the most recent data and software are easily available, access is centralized at the SDC. The SDC provides access to data and analysis tools via web-based interfaces and also supports data access through applicable Virtual Observatories. An overview of associated data flows is illustrated in Figure 7-1.

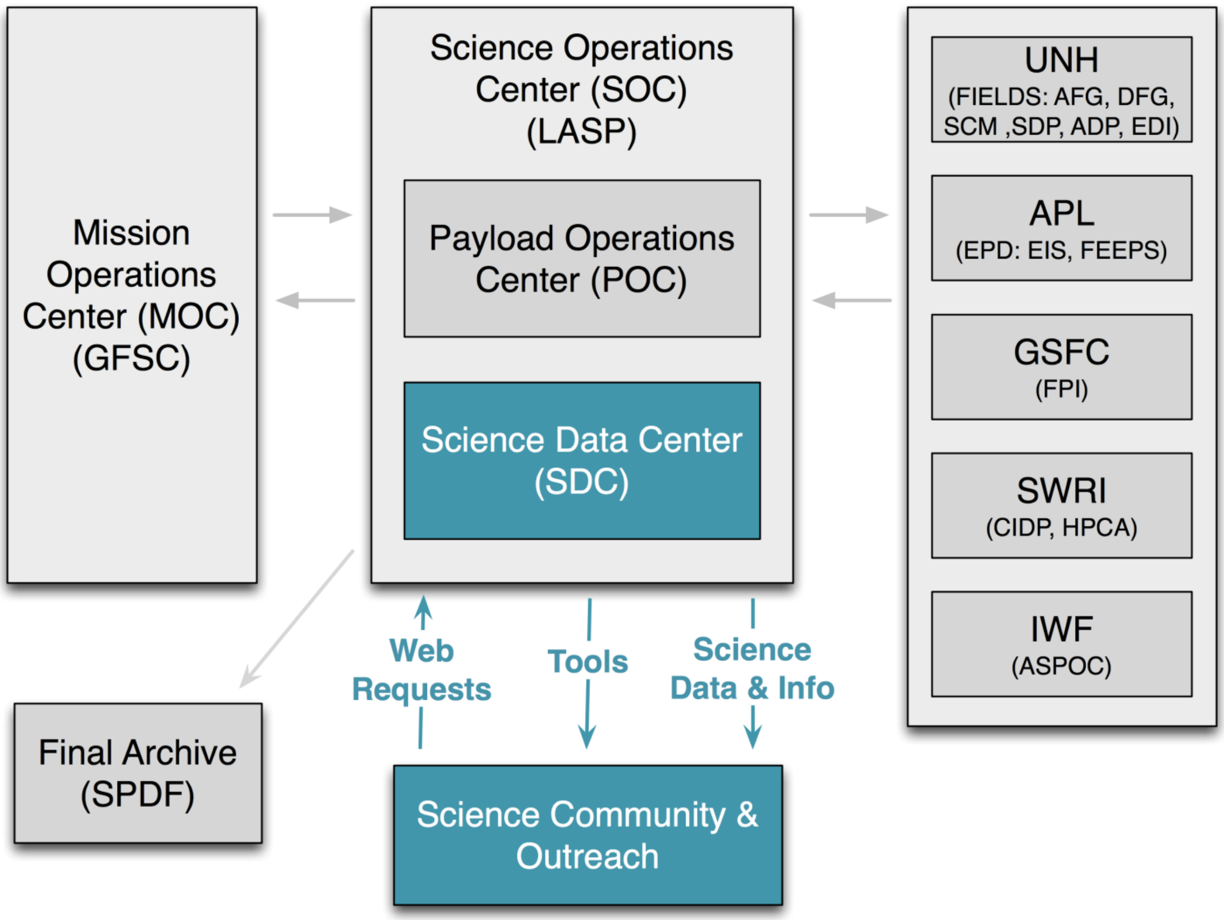

Figure 7-1: ***MMS-SMART Public Data Access***

The MMS science data system is designed to fully exploit the simultaneous measurements from all four MMS spacecraft. In close coordination with the MMS science groups, display tools are developed and provided at the SOC that are tailored for close association with modeling efforts and the broader science community. A timeline for MMS data availability is given in Table 5-1

7.1. Science Data

The SDC makes available Quicklook, Level-2, and Level-3 science data to the science community and general public. Instrument teams provide the SDC with software to produce Quicklook data products and Level-2 data files for archival and distribution and, in some cases, software 'calibrators' that allow users to produce Level-2 data on the fly.

In order to most effectively index, store, and distribute the MMS-SMART data, instrument teams are expected to provide the SDC with detailed documentation and metadata for each of their products. Specific metadata and documentation requirements are defined in the *MMS SDC-ITF ICD*. In part, these documentation and metadata requirements support the Space Physics Archive Search and Exchange (SPASE) data model so that the SDC can readily provide access to the data through Virtual Observatories. The SDC is responsible for identifying and collaborating with applicable Virtual Observatories to ensure that MMS data are accessible through these channels.

Additionally, the SDC is expected to maintain a record of spacecraft locations, instrument operating parameters, and version history notes for each data product and provide access to these data via its data access website.

7.2. Engineering Data

Spacecraft and instrument suite housekeeping/engineering data are provided to MMS team members and other designated individuals or organizations on a restricted basis.

7.3. Data Analysis Software

In coordination with the MMS science team, the SDC provides access to software tools to allow display, manipulation, and analysis of MMS data. Analysis tools that are unique to a specific dataset are developed by appropriate science team members and delivered to the SDC along with documentation for using the tools. These tools are made available to the science community via the SDC's data access website.

8. DATA ARCHIVAL

The SOC serves as the Mission Archive during the MMS mission, having responsibility for archiving all MMS mission data, and helps plan and provide for subsequent archive phases prior to mission termination. Resources archived at the SOC will include:

- Data – raw instrument and spacecraft telemetry (housekeeping and science); calibration data; ephemerides; attitude and other ancillary data needed to support scientific use and interpretation of MMS data; all levels of science data products.
- Metadata and Documentation describing data products (e.g. in SPASE terms), algorithms, instrument calibrations, validation, and data quality; also, command and telemetry definition information, descriptions of spacecraft and instrument design and operations, status reports, and other information needed for use of MMS data.
- Software and analysis tools, including software used for generation of scientific data products and corresponding metadata, as well as tools used for accessing, visualizing, and interpreting MMS science data.

Beginning with the observatory Integration and Test (I&T) phase and extending through launch, the SOC will collect and archive MMS data, principally telemetry data generated during ground testing and calibration activities. Following launch, as instruments are commissioned and begin routine science data collection, the SOC becomes actively responsible for data production and distribution activities and the archival function associated with management of science data sets. Throughout the mission, the SOC ensures that adequate security and backup/recovery mechanisms are established and documented, thereby maintaining the integrity of all data managed in the SOC repository and safeguarding them against loss. As responsibility for data processing and analysis activities is a distributed function on the MMS mission, each MMS-SMART instrument team also shares responsibility for maintaining the integrity of the MMS data during the active mission. The SOC and all Instrument Team Facilities (ITFs) establish backup/recovery mechanisms and document contingency plans for achieving a full recovery from catastrophic damage or failure. At a minimum, this includes offsite backup of raw telemetry, documentation/metadata, analysis software, and any software that would be needed to reprocess, index, store, and distribute MMS data and analysis tools.

A *Mission Archive Plan* (MAP) is drafted by the SOC prior to the first Senior Review that guides the preparation of the final MMS archive. After the mission ends, MMS data, analysis tools, and the expertise to use them remains accessible through the SOC, as long as the SOC remains funded for its tailored dissemination of MMS data to the community. This ensures continuity of MMS data access mechanisms and tools to the scientific community. At some point after mission termination, once maintaining the SOC is no longer considered cost effective, full responsibility for maintaining and disseminating data will pass to a long-term archival facility determined in collaboration between the MMS program and the SPDF.

9. DATA RIGHTS AND RULES FOR DATA USE

The terms for distribution and use of the MMS data products are specified in the *NASA Heliophysics Science Data Management Policy* document, and are summarized here in terms of the MMS mission. These guidelines govern both the production and distribution of scientific data sets by the MMS program, and also use of the MMS data by the science community and general public, and are summarized below:

- MMS-SMART data products are open to all scientists and the public (Users).
- There are no proprietary periods associated with any of the MMS-SMART data products.
- Users shall have timely access to the scientifically useful data and analysis tools that are equivalent to the level that the MMS-SMART science team uses.
- Users should contact the MMS-SMART Principal Investigator (PI) or a designated lead investigator of an instrument or modeling group early in an analysis project to discuss the appropriate use of instrument data or model results. This applies to MMS-SMART team members, guest investigators, other members of the scientific community, and general public.
- Users that wish to publish the results derived from MMS data should normally offer co-authorship to the MMS-SMART PI and/or instrument PIs and science team members. Co-authorship may be declined.
- Users should heed the caveats of investigators as to the interpretation and limitations of data or model results. Investigators supplying data or models may insist that such caveats be published, even if co-authorship is declined. Data and model version numbers should also be specified.
- Users should acknowledge the sources of data used in all publications, presentations, and reports. Appropriate acknowledgement to institutions, personnel, and funding agencies should be given.
- Users are encouraged to provide the MMS-SMART PI and/or instrument PIs a copy of each manuscript that uses MMS-SMART data upon submission of that manuscript for consideration of publication. On publication the citation should be transmitted to the PI and any other providers of data.
- Pre-prints of publications and conference abstracts should be widely distributed to interested parties within the mission and related projects.
- Users are encouraged to make tools of general utility and/or value-added data products widely available to the community. Users are encouraged to notify the MMS-SMART PI of such utilities or products. The User should also clearly label the product as being different from the original MMS-SMART produced data product.

APPENDIX A - TABLE OF ACRONYMS

Acronym	Description
ADP	Axial Double Probe electric field instrument, part of FIELDS investigation
AFG	Analog Flux Gate Magnetometer, part of FIELDS investigation
APL	Applied Physics Laboratory
ARB	Anomaly Review Board
ASPOC	Active Spacecraft Potential Control
ATS	Absolute Time Sequence command
BADCO	Burst Algorithm Definition and Concept of Operations
CCSDS	Consultative Committee on Space Data Systems
CDF	Common Data Format
CDQ	Cycle Data Quality (burst buffer quality indicator calculated onboard each s/c)
CDR	Critical Design Review
CFDP	CCSDS File Delivery Protocol
CIDP	Central Instrument Data Processor
CMAD	Calibration and Measurement Algorithm Document
DES	Dual Electron Spectrometer, part of FPI investigation
DFG	Digital Flux Gate Magnetometer, part of FIELDS investigation
DIS	Dual Ion Spectrometer, part of FPI investigation
DSN	Deep Space Network
EDI	Electron Drift Instrument, part of FIELDS investigation
EDP	Electric Double Probe electric field instrument, combination of SDP and ADP
EIS	Energetic Ion Spectrometer, part of EPD investigation
EPD	Energetic Particle Detector System
EPO	Educational and Public Outreach
FDOA	Flight Dynamics Operations Area
FEEPS	Fly's Eye Energetic Particle Sensor, part of EPD investigation
FGM	Flux Gate Magnetometer, combination of AFG and DFG
FPI	Fast Plasma Instrument
FSM	Fluxgate Search Coil Merged, combination of AFG, DFG, and SCM
GSFC	Goddard Spaceflight Center
HPCA	Hot Plasma Composition Analyzer
HSD	Heliospheric Science Division
ICD	Interface Control Document
IDPU	Instrument Data Processor Unit (FPI)

IDS	Interdisciplinary Scientists
IS	Instrument Suite
ITF	Instrument Team Facility
IWF	Institut für Weltraumforschung (Space Research Institute of the Austrian Academy of Sciences)
JHU	Johns Hopkins University
L2	Level 2 Science (used to refer to data products and/or the software used to create Level 2 science products)
L3	Level 3 Science (used to refer to data products and/or the software used to create Level 3 science products)
LASP	Laboratory for Atmospheric and Space Physics
LF	Low Frequency
MAP	Mission Archive Plan
MF	Medium Frequency
MLD	Mission Level Data (Level 3)
MMS	Magnetospheric Multiscale
MOC	Mission Operations Center
MRD	Mission Requirements Document
NAV	Navigation
PDMP	Project Data Management Plan
PDR	Preliminary Design Review
PLSA	Project Level Service Agreement
POC	Payload Operations Center (located at the SOC)
QA	Quality Assurance
RA	Resident Archive
R_E	Unit of measure: 1 Earth Radius
ROI	Region of (science) Interest, defined as geocentric apogee distances > 9 R_E for Phase 1, and > 15 R_E for Phase 2.
RTS	Relative Time Sequence commands
SCM	Search Coil Magnetometer, part of FIELDS investigation
SDC	Science Data Center (located at the SOC)
SDP	Spin-plane Double Probe (part of FIELDS investigation)
SMART	Solving Magnetospheric Acceleration Reconnection and Turbulence
SOC	Science Operations Center
SPASE	Space Physics Archive Search and Exchange
SPDF	Space Physics Data Facility
STP	Solar Terrestrial Probes
SWG	Science Working Group
SwRI	Southwest Research Institute

TBC	To be Confirmed
TBD	To be Determined
TDRSS	Tracking and Data Relay Satellite System
TOF	Time of Flight
UNH	University of New Hampshire
USN	Universal Space Network
VMO	Virtual Magnetospheric Observatory
VxO	Virtual Observatory