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HaloSat Mission

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Concept of Operations

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CM FOREWORD

This document is a HaloSat Project controlled document. Changes to this document require prior approval of the HaloSat Project Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted per HaloSat CM plan (HaloSat-PLAN-0004).

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1 Introduction

1.1 Purpose

The Concept of Operations (ConOps) document describes how the HaloSat goals and mission objectives are intended to be met. The document is used to bring a cohesive definition of the system and operations for internal development purposes in addition to final documentation. The ConOps is validated by the Mission System (Level 2) Requirements, with traceability established between the generated products to ensure consistency.

1.2 Scope

The ConOps document addresses the HaloSat mission objectives, and decomposition into project activities and operations. These include but are not limited to:

- Launch
- Commissioning
- On-orbit operations
- Disposal

1.3 Applicable Documents

Document Number	Title
HaloSat-PLAN-0001	HaloSat Project Implementation Plan
HaloSat-RQMT-0002	HaloSat Mission Requirements

1.4 Acronyms

APRA	AstroPhysics Research and Analysis Program
ACS	Attitude Control System
ATS	Absolute Time Sequence
ConOps	Concept of Operations
COTS	Commercial Off The Shelf
eV	Electron Volt
FSW	Flight Software
I&T	Integration and Test
MOC	Mission Operations Center
SAA	South Atlantic Anomaly
SOC	Science Operations Center
TBD	To Be Determined

2 Mission Overview

2.1 Mission Description and Objectives

HaloSat is an APRA-funded 6U CubeSat science mission. The goal is to search for evidence of a hot galactic halo in the Milky Way Galaxy by measuring Oxygen line emissions to trace its distribution geometry. This will be performed by measuring the X-rays emitted from the surrounding hot gas at ~10^6 K. Three identical X-ray detectors will be flown aboard a standard 6U CubeSat to take measurements around the 600 eV spectrum. The satellite will point the detectors at specific targets for observation and over the course of the mission will cover a significant portion of the sky to adequately determine the halo geometry and mass. HaloSat is planned for delivery to the launch provider during the first quarter of CY2018 for a potential launch in June 2018.

HaloSat was awarded a fixed budget to include the Instrument, Spacecraft, and Ground Operations. Launch services will be provided by NASA Headquarters at no cost to the program. To complete the mission within budget constraints, the mission has adopted a risk profile which includes:

- COTS hardware purchases, with flight heritage whenever possible.
- Hardware redundancy implemented only when required by the launch provider
- Conducting limited testing at the payload level, and full environmental at system level only.
- Designing operational solutions to compensate for hardware limitations. (e.g.: selecting the number of detectors powered at the same time.)

3 Concept of Operations

A graphical representation of the ConOps is given below:

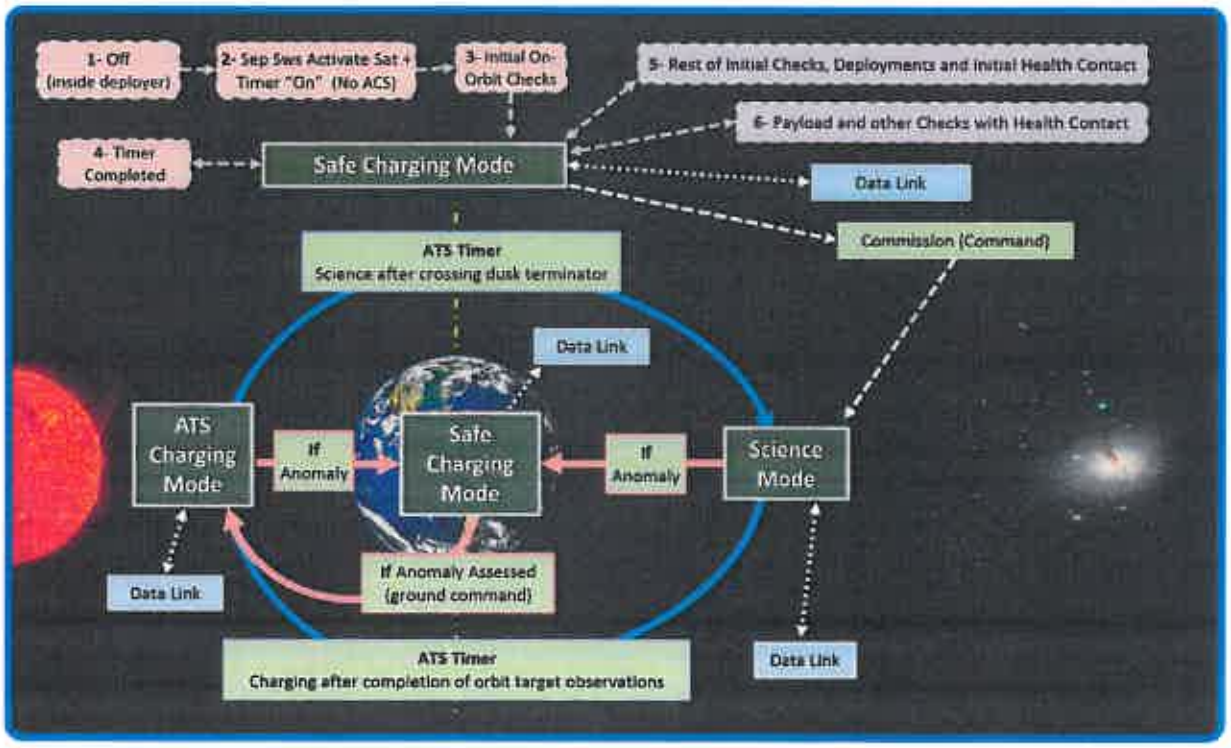

Figure 1 - ConOps Depiction

The HaloSat spacecraft will be in operation for at least 213 days, including 30 days for on-orbit checks/commissioning and 183 days of science operations once ejected from deployer at the desired orbit. The mission consists of five major phases summarized in Table 1: pre-launch operations, timer, commissioning, science operations and disposal. The spacecraft will be ready for delivery to the launch provider or delivery for storage waiting for launch during the first quarter of CY2018, with an expected launch in June 2018.

Table 1 - Mission Phases

Mission Phase	Description
Pre-launch Operations	Ground testing and verification, end-to-end system verification and pre-launch planning
Timer	Phase covering deployer ejection to end of mandatory timer including checks
Commission	Phase covering deployments, additional checks, initial contact, bus checks, instrument checks and observatory commissioning
Science Operations	Phase covering nominal operation of HaloSat **Science Mode** – Instrument target pointing ACS configuration to obtain science. **Safe Charging Mode** – Also known as Safe Mode. Solar panels Sun pointing ACS configuration and obtain no science. Used during commissioning and anomalies (anomaly trigger in / ground command trigger out). **ATS Charging Mode** – Solar panels Sun pointing ACS configuration and obtain no science. Used every orbit to charge batteries during Sun lit half orbit (ATS trigger in/out). **(Optional, not shown in diagram) Communications Mode** - Optional mode to obtain healthy link margin for downlink and uplink if necessary.
Disposal	End of mission. Disposal for this project means burn during re-entry. ODAR and demiseability analysis performed.

Pre-launch operations include Flight Readiness Review (FRR), ground testing and verification, end-to-end system verification and pre-launch planning. The time from delivery to launch provider to ejection on-orbit ranges from 3 to 9 months depending on launch opportunity and other launch provider priorities. During this time HaloSat will be powered off and battery charging will not be possible.

Timer phase includes the first 45 minutes after ejection depending on launch provider. The spacecraft power system and on board computer will turn on with deployment switches upon release from the deployer. Timer does not allow any on-board deployments or RF transmission but permits full functionality for the rest of the spacecraft. No attitude control mode will be used initially until the system performs the necessary checks to allow Sun pointing. After this step, the system will cruise while in Safe Charging Mode (Sun pointing ACS configuration) until the timer is done. Other system checks not related to deployments or RF could be performed during this period such as GPS and star trackers if so equipped.

Commissioning is the period after the timer expires until the satellite is commanded to start science operations. Initially, deployments will be activated such as antennas and solar panels if implemented. Depending on the launch provider, a smart beacon may be used to transmit housekeeping and

navigation data to be received whenever the spacecraft is within line of sight of the Wallops Ground Station. The spacecraft will undergo a series of tests to determine if the bus is operating as expected and troubleshooting may be necessary. After the bus is fully tested, the payload will be powered and testing will commence on the detectors. The satellite will be commissioned after the payload and bus teams determine proper operations of the observatory. A total of 30 days have been allocated for this activity.

Science operations will begin after commissioning. Nominal operations include ATS Charging Mode (Sun pointing ACS configuration) to charge batteries during most of the Sun lit portion of the orbit while science mode takes place during half the orbit from dusk terminator to dawn terminator passing through midnight. Contact passes occur whenever the spacecraft is passing through the Wallops Ground Station. Housekeeping and science data will be obtained and absolute time sequence tables and other parameters will be uploaded as needed. ATS Charging Mode and Safe Charging mode utilize the same Sun pointing ACS configuration and the difference lies in the triggers to enter and exit the mode. Safe Charging Mode may also need a means to shed more power load. Safe Charging Mode is the default safe mode and will be used during commissioning phase and in case of science mode anomaly during nominal operations. If anomaly occurs during ATS Charging Mode, the spacecraft will enter into the Safe Charging mode. All modes and triggers are explained in Section 4. An optional Communications Mode could be allowed to meet communication requirements.

Disposal phase will commence once the mission requirements have been satisfied. It consists on orbit decay and eventual re-entry to the atmosphere. An Orbital Debris Analysis Report (ODAR) will show compliance with orbital debris regulations.

Ground communications will be through the GSFC Wallops Flight Facility 18.3 meter UHF dish. Mission operations will be run from a MOC located at the University of Iowa. Science Operations will be run from a SOC located at the University of Iowa.

3.1 Pre-launch Operations

This section will capture planned activities prior to spacecraft deployment in orbit such as ground testing and verification, end-to-end system verification and pre-launch planning.

3.2 Timer Phase

The timer phase occurs after ejection from the deployer:

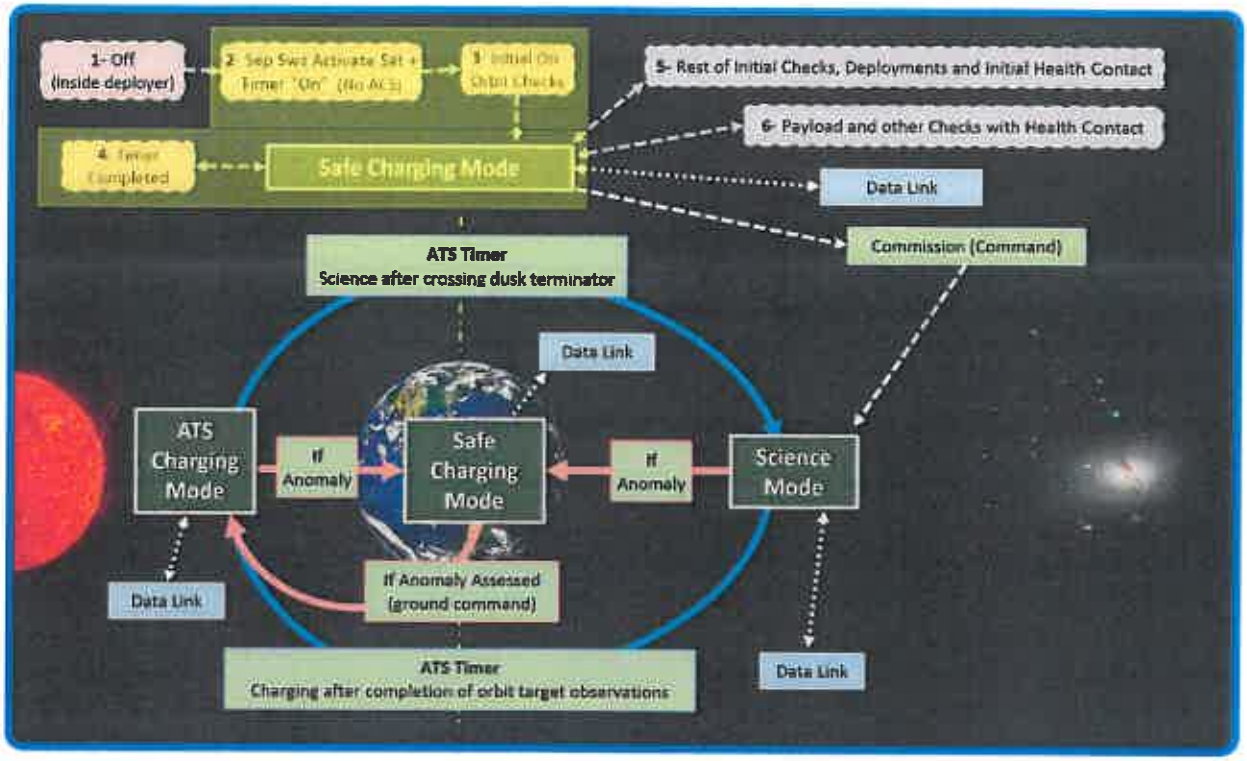

Figure 2 - Timer Phase

This phase includes the first 45 minutes after ejection depending on launch provider. The spacecraft power system and on board computer will turn on with deployment switches upon release. Deployments or RF transmission do not occur during this time but full functionality of the other systems is permitted.

The following sequence is an example of events that occur during this phase:

- Energize Power System, C&DH board, and Radio (electronics only, transmitter off)
- C&DH boot (45-minute timer starts)
- Determine if satellite is on eclipse or Sun portion of orbit
    - Use coarse Sun sensors – request Sun sensor data and determine if can be trusted
- Check items needed for Safe Charging Mode (Sun pointing ACS configuration)
    - Reaction wheels – turn "on", request data packets, analyze packets for anomaly
    - Coarse Sun sensors – request data packets, analyze packets for anomaly
    - Fine Sun sensors – request data packets, analyze packets for anomaly
- Point towards Sun as soon as Sun is available. Next steps can be performed if HaloSat is under eclipse with enough battery power. Otherwise, wait until batteries are charged to an appropriate level
    - Evaluate Solar Panel
    - Check thermistors
    - Check telemetry from Batteries and EPS
    - Check Gyros
    - Other checks or evaluations not related to deployables or RF

The primary goal of utilizing a timer is to preclude RF transmissions and mechanical deployments within an appropriate distance from the deploying vehicle (for example ISS or vehicle booster). After these

steps are performed, the system will remain in Safe Charging Mode until the timer expires. The C&DH processor will identify through flags if the FSW boot condition is an initial deployment. Subsequent satellite power cycles shall bypass timer.

3.3 Commissioning Phase

Commissioning is the period after expiration of the timer and before science operations:

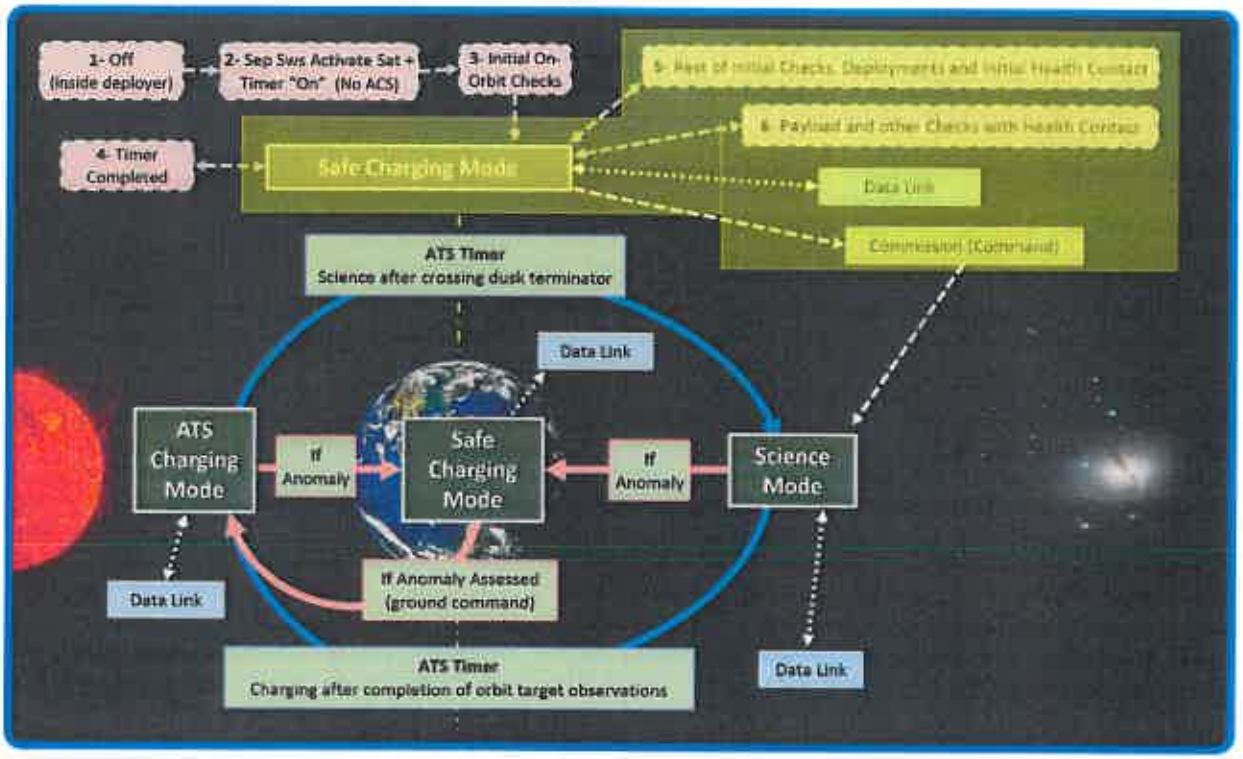

Figure 3 - Commissioning Phase

This phase occurs after timer expiration and begins with solar array and antenna deployment if so equipped. During this phase, deployments occur and the spacecraft goes through a series of checks with the instrument and supporting systems. Contact is established with the MOC and status data is downlinked. Appropriate tables and commands are uplinked.

The following sequence is an example of events that occur during this phase:

- Flag the timer expiration from previous mode in such a way that if satellite requires a hard reset, the timer does not occur again.
- Initiate deployables
  - Record release mechanisms status before deploying
  - Activate primary firing and record status
  - Activate secondary firing and record status if so equipped
- Establish contact with MOC using primary radio to report health
- Turn "on" and check the GPS and Star Trackers
- Establish downlink for GPS and trackers checks data
- Establish uplink for loading ATS commands for science instrument checkout
- Science instrument check (check instrument while on charging mode)
  - Turn instrument on

- Run initial checks script
- Read and store data while running script
- Turn instrument off

- Establish downlink with MOC to report instruments
  - Wait for uplink command to continue to science pointing check
- Science pointing check (instrument off to save power since we have not confirmed science mode power harvesting/consumption)
  - Perform 2 "fake target" pointing maneuvers during eclipse
  - Return to Sun pointing after second target as in nominal operations
- Establish downlink to report science pointing performance including pointing and power profiles
  - Wait for command from ground station
- Upload new ATS table with targets as needed for commissioning
- While on Nominal Charging Mode, wait for command from ground station for commissioning the satellite and start nominal operations

After all checks have been performed and the appropriate teams have determined proper operation, the satellite will be commissioned for science operations.

3.4 Science Operations Phase

The science phase is the primary phase for conducting the mission objectives:

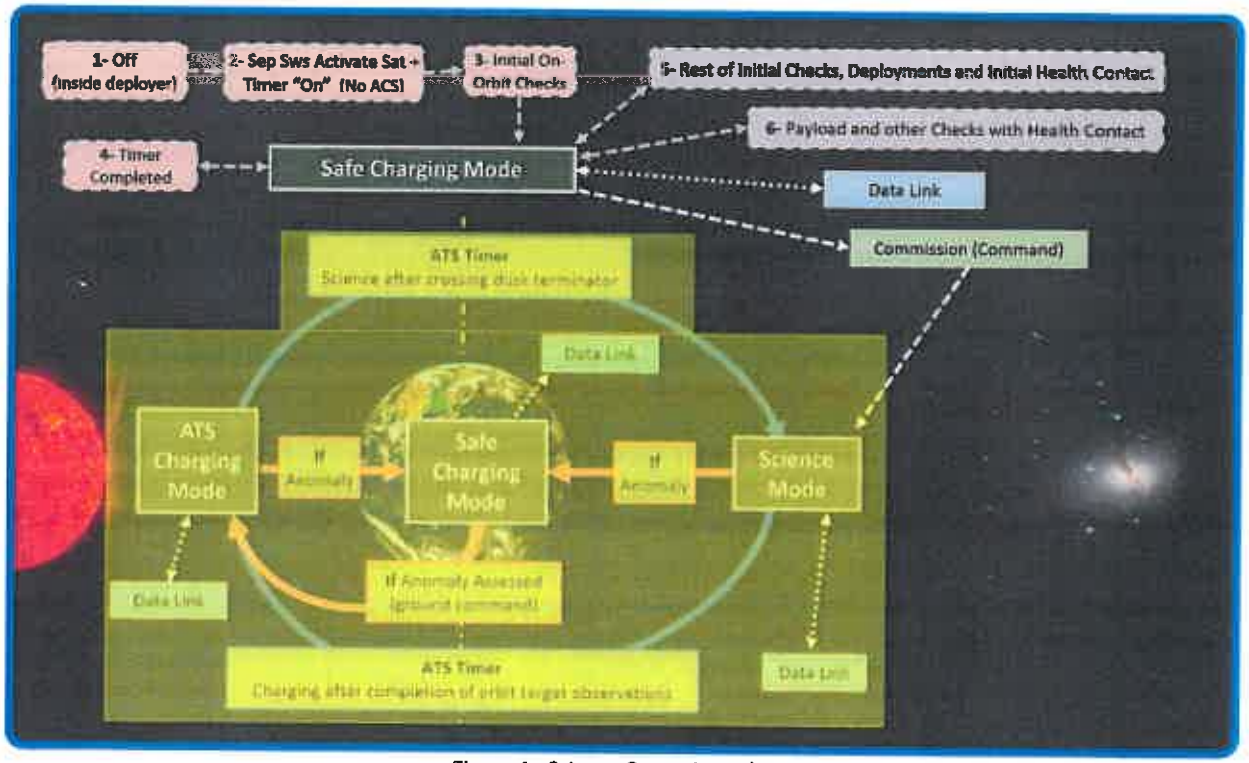

Figure 4 - Science Operations Phase

The science mission phase is entered after spacecraft commissioning, with all initial checks and ground contacts completed. This phase will nominally alternate between two modes: the nominal ATS Charging mode on the sunlit side of the orbit where the instrument is off with the observatory oriented for charging, and the Science Mode where the spacecraft points to targets for science instrument

readings. Alternating between these modes is determined by an ATS timer which is synchronized with the dawn and dusk terminators.

In case of science mode or ATS charging anomaly, the observatory will enter into a Safe Charging Mode. This is used to troubleshoot the observatory until commanded to resume science operations.

3.5 Disposal Phase

The spacecraft is intended to operate as long as it is functional. Once science mission objectives are completed, the orbit will decay and the spacecraft will disintegrate during re-entry without the need for dedicated de-orbit systems or intervention from the ground. Activities during the disposal phase may include pointing the spacecraft to ram to increase drag, deplete batteries and/or turning off most spacecraft systems including the RF transmitter.

3.6 Mapping of Mission Phases to Operational Modes

Each mission phase utilizes one or more nominal and/or anomaly modes. The following table maps the mission phases to the applicable operational modes:

Table 2 - Mission Phase to Operation Mode Mapping

Mission Phase	Nominal Modes	Anomaly Modes
Timer Phase	System Initialization Safe Charging Mode	N/A
Commissioning Phase	Safe Charging Mode	N/A
Science Phase	ATS Charging Mode Science Mode	Safe Charging Mode
Disposal Phase	Safe Charging Mode or Disposal	N/A

4 Spacecraft Software Operational Modes and Flowcharts

HaloSat operates in several modes for nominal and anomaly operations. The following sections describe the primary modes with characteristics tabulated for each.

Note: All global variables (counters and timers) are initialized to zero when the flight software boots up for the first time after dispenser deployment. During operations, these variables will change according to the specifications in the flowcharts below.

4.1 Nominal Operational Modes

4.1.1 Nominal Operation Modes

For most of the mission lifetime the spacecraft will alternate between ATS Charging and Science Modes. These two modes alternate between the sunlit half and eclipsed half of the orbit, and alternate the spacecraft between sun pointing for charging and target pointing for science. These modes are alternated automatically utilizing an ATS timer synchronized to the dawn-dusk terminators.

Table 3 - Nominal ATS Charging and Science Modes Definition

ATS Charging Mode	Science Mode
Day (sunlight) side of the orbit	Night (eclipse) side of orbit
Only essential bus components Turned ON ACS in Sun Pointing Configuration	All Bus components Turned ON ACS in Inertial Pointing Configuration
Science Payload turned OFF	Science Payload power ON During SAA crossing, payload will be turned OFF or science data will be ignored
Uplink/downlinks with ground scheduled as available	Uplink/downlinks with ground scheduled as available unless science target takes priority
Transitions into Science Mode after crossing dusk terminator. Synchronized with ATS timer	Transitions into Charging Mode after crossing dawn terminator. Synchronized with ATS timer
Transition into Safe Charging Mode autonomously if failure occurs. Examples may include: - battery voltage drops below threshold level - Thermistor temperature threshold - Insufficient charging rate Log anomaly event (through event flag or file) before transitioning to Safe Charging Mode	Transition into Safe Charging Mode autonomously if failure occurs. Examples may include: - battery voltage drops below threshold level - Thermistor temperature threshold - Insufficient charging rate Log anomaly event (through event flag or file) before transitioning to Safe Charging Mode

4.1.2 Safe Charging Mode

The Safe Charging mode points to the Sun for maximum power input similar to the ATS Charging mode. The main differences lie on the triggers to get in and out of the mode in addition to possible further power shed. Although Safe Charging mode is essentially an anomaly mode or safe mode, it is utilized nominally during the Timer Phase and Commissioning Phase hence considered also a nominal operations mode.

Table 4 - Safe Charging Mode Definition

Safe Charging Mode
Only essential bus components turned ON ACS in Sun Pointing Configuration
Science Instrument turned OFF
If timer active (Timer Phase): No communication (uplink or downlink) if timer is inactive (Commissioning, Science or Disposal Phase): Uplinks and downlinks through direct contact, location based and/or ATS commands
Transition into Science Mode or ATS Charging Mode through ground command or ground provided ATS commands. Requires instruction from the ground to transition.
Spacecraft operations will vary depending on situation and phase. This mode is usually utilized to check, test and/or troubleshoot the spacecraft.

4.1.3 System Initialization

System initialization is not considered a mode since it is part of the sequence used during initial activation of the satellite on-orbit or during on-orbit reboot. Some components are turned on sequentially including a quick set of aliveness tests to gather health telemetry. This initialization also checks for reboot status such as first system boot or number of consecutive reboots. This sequence will

activate the timer by default unless there is a flag indicating that first on-orbit boot already happened and timer is not necessary. The sequence will also identify if it is a boot during ground testing and users will have the option to bypass the timer manually.

4.1.4 Communications Mode (optional, only if needed)

Communications mode is an optional mode that can be utilized only if the mission is not feasible without it. It is used to point the spacecraft antenna towards the ground station during a communication pass to improve the data link. The attitude control system points the spacecraft toward the ground station and continue active pointing until the pass is complete. This mode can be commanded directly from the ground, configured ahead of time through ATS commands, or automatically if the spacecraft contains any form of on-board spatial knowledge to detect when the spacecraft is in the vicinity of the ground station.

Table 5 - Communications Mode

Communication Mode
Essential bus components turned ON ACS ground station pointing
Science Instrument turned OFF
Initiated through one of the following methods: 1. Command from ground station 2. Determination of proximity to ground station 3. ATS command
Transceiver receives commands and forwards telemetry to ground station
Transitions out of Communications Mode through pre-defined criteria: 1. Command from ground station 2. Determination of proximity to ground station 3. ATS command (new command or expiration of present command)

4.2 Anomaly/Safe Modes

HaloSat utilizes Safe Charging Mode as the anomaly/safe mode. This is a power-positive mode with minimal bus utilization. For more information about Safe Charging Mode, see section 4.1.2.

4.3 Spacecraft Software Flowcharts

This section is intended to capture relevant high-level software flowcharts that are derived during development.