L’Ralph Integration and Testing

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Abstract - This paper describes the plans, flows, key facilities, components and equipment necessary to fully integrate, functionally test, qualify and calibrate the L’Ralph instrument on the Lucy observatory. Lucy is currently in the final design and fabrication phase (phase C) of mission development. It is scheduled to launch out of Cape Canaveral, Florida, in October 2021. Lucy will be the first space mission to study the Trojan asteroids associated with Jupiter, that are thought to be remnants of the primordial material that formed the outer planets. Lucy will fly by and carry out remote sensing on six different Trojan asteroids. The mission takes its name from the fossilized human ancestor (called “Lucy” by her discoverers) whose skeleton provided unique insight into humanity's evolution. Likewise, the Lucy mission will revolutionize our knowledge of planetary origins and the formation of the solar system. L’Ralph is one of the instruments on Lucy and it is provided by the NASA Goddard Space Flight Center (GSFC). L’Ralph is a combined multi-band visible imager (the Multi-spectral Visible Imaging Camera, MVIC, 0.4-0.85 microns) and wedge-filter infrared spectrometer (Linear Etalon Imaging Spectral Array, LEISA, 1-3.6 microns). LEISA will allow the team to look for the absorption lines that serve as the fingerprints for different silicates, ices and organics that likely will be on the surface of the Trojan asteroids. MVIC will take color images of the Trojan asteroid targets, and help determine how active they are. This paper will focus on the Integration and Test (I&T) activities for L’Ralph while it is at the NASA GSFC. L’Ralph has two assemblies, the telescope detector assembly (TDA) and main electronics box (MEB). The TDA is a single telescope feeding two focal planes, MVIC and LEISA. L’Ralph integration consists of assembly and alignment of the telescope, electronics box integration, thermal systems integration and the final assembly and testing. This I&T phase will be followed by the L’Ralph calibration and characterization, environmental tests which include electromagnetic interference (EMI)/electromagnetic compatibility (EMC), vibration with sine sweep, acoustics, shock, thermal balance, thermal vacuum, mass properties and center of gravity determination. This paper will briefly discuss L’Ralph shipment and delivery to the spacecraft vendor for observatory level I&T as well as some launch preparation activities.

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1. INTRODUCTION

1.1 Lucy Mission Overview

Lucy, a Discovery Class mission, will send a spacecraft to investigate six primitive asteroids near both the L4 and L5 Lagrange points with Jupiter—the so-called Jupiter Trojans (Figure 1) that lead and follow Jupiter in its orbit by 60°. The two swarms are denoted as L4 and L5. Lucy will explore both swarms, where planetesimals from the outer planetary system have been preserved since early in Solar System history. Spacecrafts have visited all of the stable populations of the Solar System, except for the Trojans. Lucy fills this gap with a mission that will fly by and extensively study all the recognized taxonomic classes of Jupiter Trojans. This comprehensive study is enabled by a fortuitous orbital alignment that is unlikely to recur in the near future.

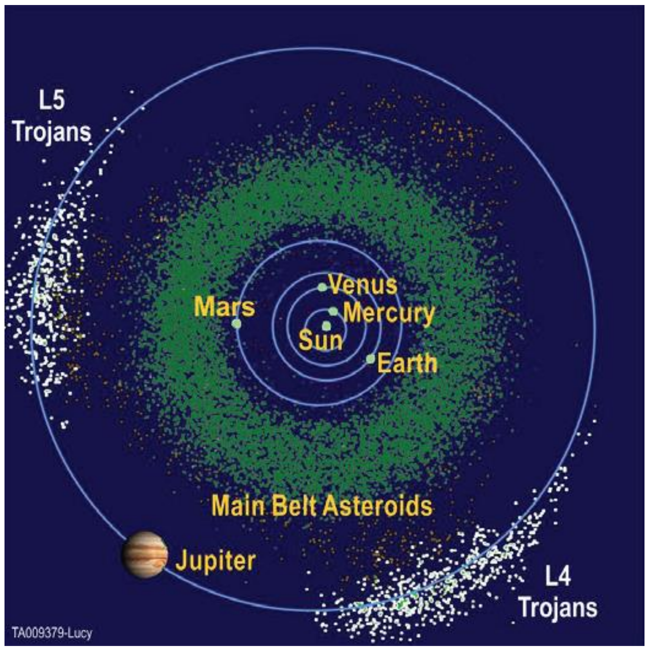

Figure 1. Jupiter's Trojan Swarms

The Lucy mission name honors the influence that the primitive Australopithecus human fossil named "Lucy" has had in advancing understanding of the history of our species, and embodies the goal that this mission will similarly advance the understanding of the formation and evolution of our Solar System. It will be ready to launch in 2021, on an Atlas V 401 rocket from Cape Canaveral, Florida, reach its first Trojan in 2027, and have its final encounter in 2033. During its lifetime, Lucy will perform five Trojan encounters closely studying six of these fascinating objects (one encounter is of a nearly equal mass binary).

Lucy's complex path [1] (shown in Figure 2) will take it to both clusters of Trojans and give us our first close-up view of all three major types of bodies in the swarms (so-called C-, P- and D-types).

The dark-red P- and D-type Trojans resemble those found in the Kuiper Belt of icy bodies that extends beyond the orbit of Neptune. The C-types are found mostly in the outer parts of the Main Belt of asteroids, between Mars and Jupiter. All of the Trojans are thought to be abundant in dark carbon compounds. Below an insulating blanket of dust, they are probably rich in water and other volatile substances.

No other space mission in history has been launched to as many different destinations in independent orbits around our sun. Lucy will show us, for the first time, the diversity of the primordial bodies that built the planets. Lucy's discoveries will open new insights into the origins of our Earth and ourselves.

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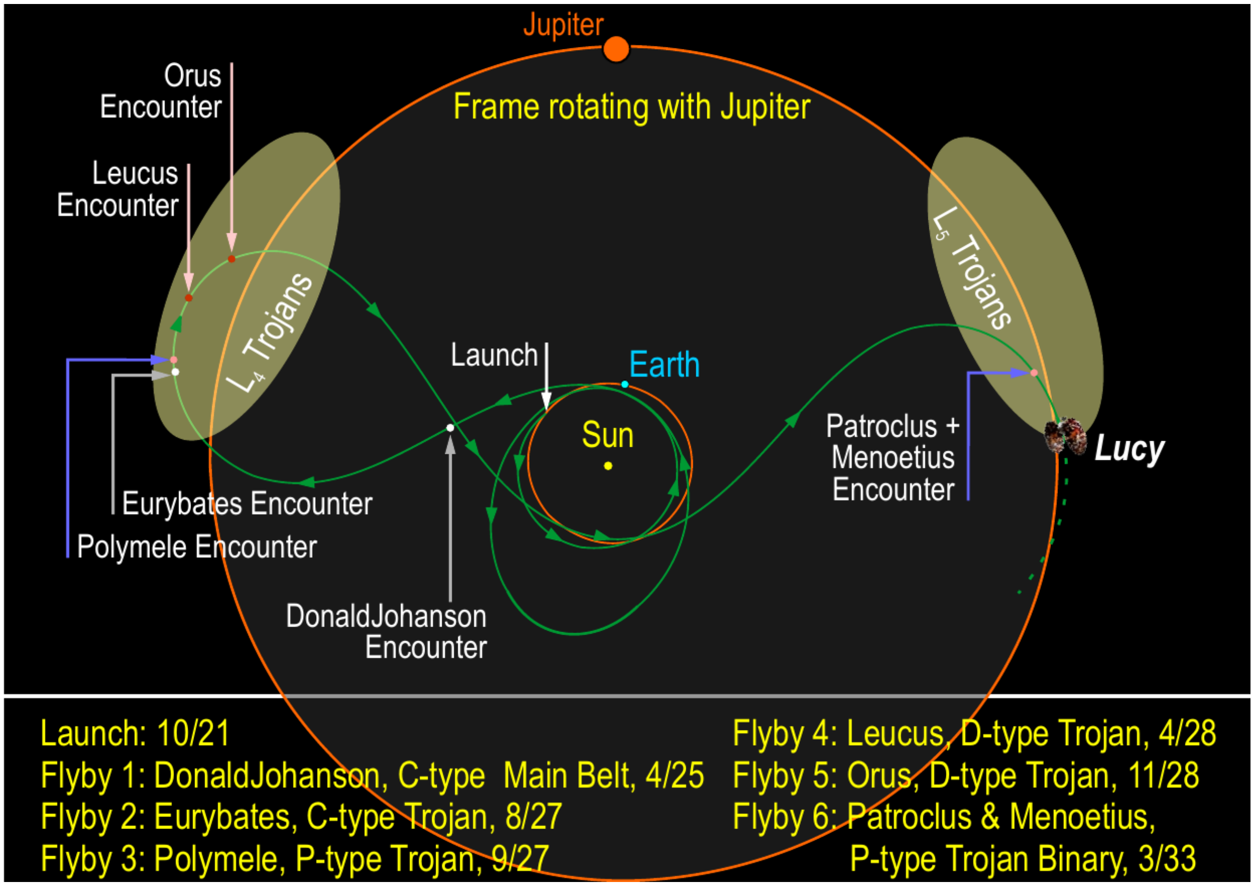

Figure 2. This diagram illustrates Lucy's orbital path. The spacecraft's path (green) is shown in a frame of reference where Jupiter remains stationary, giving the trajectory its pretzel-like shape. After launch in October 2021, Lucy has two close Earth flybys before encountering its Trojan targets. In the L4 cloud Lucy will fly by (3548) Eurybates (white) and its satellite, (15094) Polymele (pink), (11351) Leucus (red), and (21900) Orus (red) from 2027-2028. After diving past Earth again Lucy will visit the L5 cloud and encounter the (617) Patroclus-Menoetius binary (pink) in 2033. As a bonus, in 2025 on the way to the L4, Lucy flies by a small Main Belt asteroid, (52246) Donaldjohanson (white), named for the discoverer of the Lucy fossil. After flying by the Patroclus-Menoetius binary in 2033, Lucy will continue cycling between the two Trojan clouds every six years.

Lucy spacecraft (shown in Figure 3) will be over 13 meters (over 45 feet) from tip to tip, but most of that is the huge solar panels (each over 6 meters (20 feet) in diameter) needed to power the spacecraft as it flies out to the orbit of Jupiter. All of the instruments, and the 2-meter (6.5 ft)-high gain antenna needed to communicate with Earth, will be located on the much smaller spacecraft body. Lucy will perform a Radio Science Investigation (RSI) using the spacecraft's telecom system to constrain the masses and bulk densities of the Trojan targets.

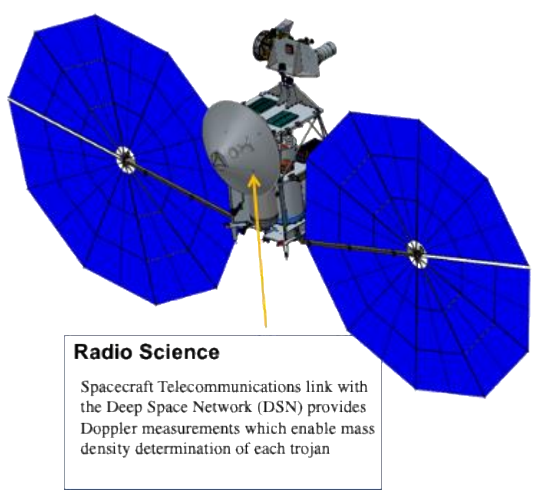

Figure 3. Lucy spacecraft

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Lucy's payload (shown in Figure 4) comprises three complementary, high-heritage imaging/mapping instruments that cover wavelengths from 0.35 to 100 µm: 1) the L'Ralph visible wavelength multicolor imaging and Infra-Red (IR) mapping spectroscopy facility; 2) the L'LORRI high-resolution visible imager, also used for optical navigation; and 3) the L'TES thermal IR spectrometer. Together this powerful remote sensing suite will provide exciting, high quality color, thermal, and panchromatic maps, and mapping spectroscopy. Lucy will also be able to use its terminal tracking camera (T2CAM) to take wide-field images of the asteroids to better constrain the asteroids shapes. Lucy's payload wavelength (microns) is shown in Figure 5.

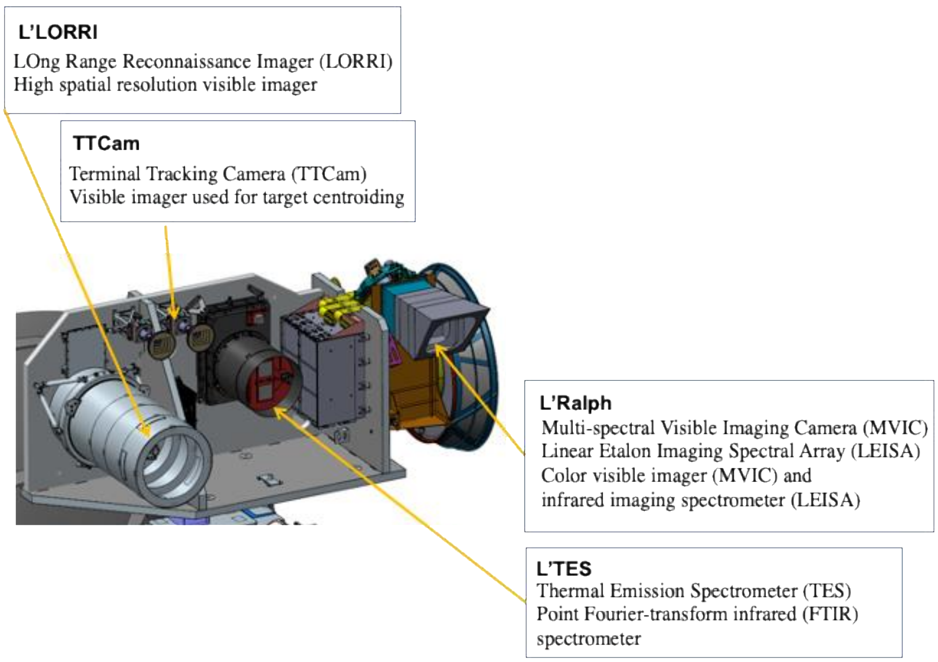

Figure 4. Lucy's Payload

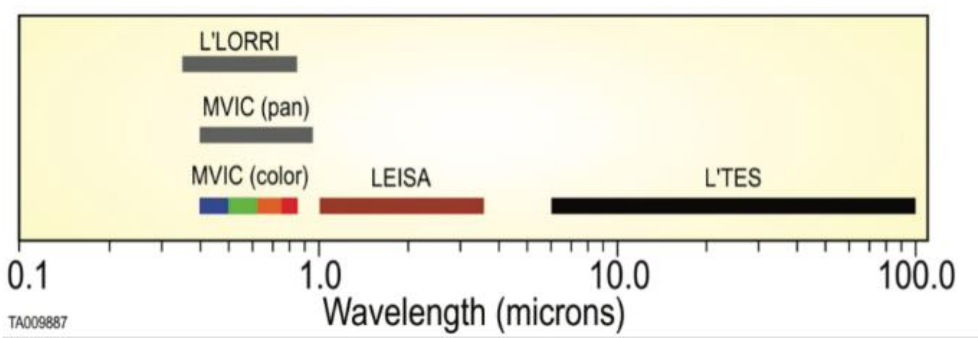

Figure 5. Lucy Payload Wavelength (microns)

Lucy is a Principal Investigator (PI)-led mission [2]. The Principal Investigator, Dr. Harold Levison, works for the Southwest Research Institute (SwRI) in Boulder, CO. SwRI will also be responsible for the management and systems engineering of instrument payload, and science operations and data. In partnership with the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) to provide the L'RALPH instrument, GSFC will also perform the project management, mission systems engineering, technical authority, and safety and mission assurance for the project. Lockheed-Martin (LM) Space Systems in

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Littleton, CO., as the prime contractor, is responsible for the mission design, spacecraft design, development, assembly and test, instrument payload integration, launch and mission operations. The Arizona State University (ASU) is providing L'TES and the Johns Hopkins's Applied Physics Lab (APL) provides L'LORRI. The KinetX Aerospace Inc. is providing the technical expertise for flight navigation in support of flight dynamics and navigation.

Scientific objectives of the *Lucy* Trojan asteroid survey mission are:

- *Lucy* must visit at least one member of each of the known Trojan taxonomic types (C-, D-, and P-type asteroids).
- *Lucy* must visit a near-equal mass binary asteroid.
- *Lucy* must visit a member of the major C-type collisional family.

The science measurement objectives that must be performed at each target are:

- *Lucy* must determine the surface composition and physical properties, including that of the regolith, of each asteroid. Spatial resolution must be such that freshly exposed surfaces can be studied.
- *Lucy* must assess the geology of the surface, including the crater record, of each asteroid.
- *Lucy* must determine the bulk properties of each asteroid including bulk density.
- *Lucy* must search for satellites and rings around each asteroid.

1.2 L'Ralph Overview

L'Ralph has two functions—a color imager, the Multi-spectral Visible Imaging Camera (MVIC), and a near infrared imaging spectrometer, Linear Etalon Imaging Spectral Array (LEISA). MVIC is used to produce Trojan large segment panchromatic and color (six bands spanning 400 - 860 nm) surface maps at a spatial resolution that exceeds science traceability matrix requirement. LEISA is a wedged filter infrared spectral imager that creates spectral maps in the compositionally important 1.0 to 3.8 μm Near Infrared (NIR) spectral region to map the composition of organics, volatiles and minerals. LEISA data is used to produce composition maps at a spatial resolution that exceeds science traceability matrix requirement.

L'Ralph operates as two instruments in one with a shared optical path. The visible wavelength multicolor imager (MVIC) acts as a multi-band push-broom camera. Five bands include color filters, and one band is panchromatic. Each of the six bands is an independent rectangular charge-coupled-device (CCD) operating in a time-delay integration (TDI) mode. The infrared mapping spectroscopy facility (LEISA) is a square Infra-Red (IR) Mercury Cadmium Telluride (HgCdTe) array with a linear wedge filter. The filter and detector are arranged so that the cross-track direction and the direction of changing wavelength are orthogonal. The resulting system operates as a push-broom spectrometer. A common set of reflective optics allow the MVIC and LEISA to share the same field of view, with a dichroic optic splitting the incoming energy between the two separate focal places. A scan mirror mechanism (SMM) attached to the first fold-flat mirror allows the scene to be mapped without having to move the entire spacecraft or integrated payload platform. A single electronics box provides power, commanding, image processing, and memory to store science data from a single pass. L'Ralph overview is shown in Figure 6.

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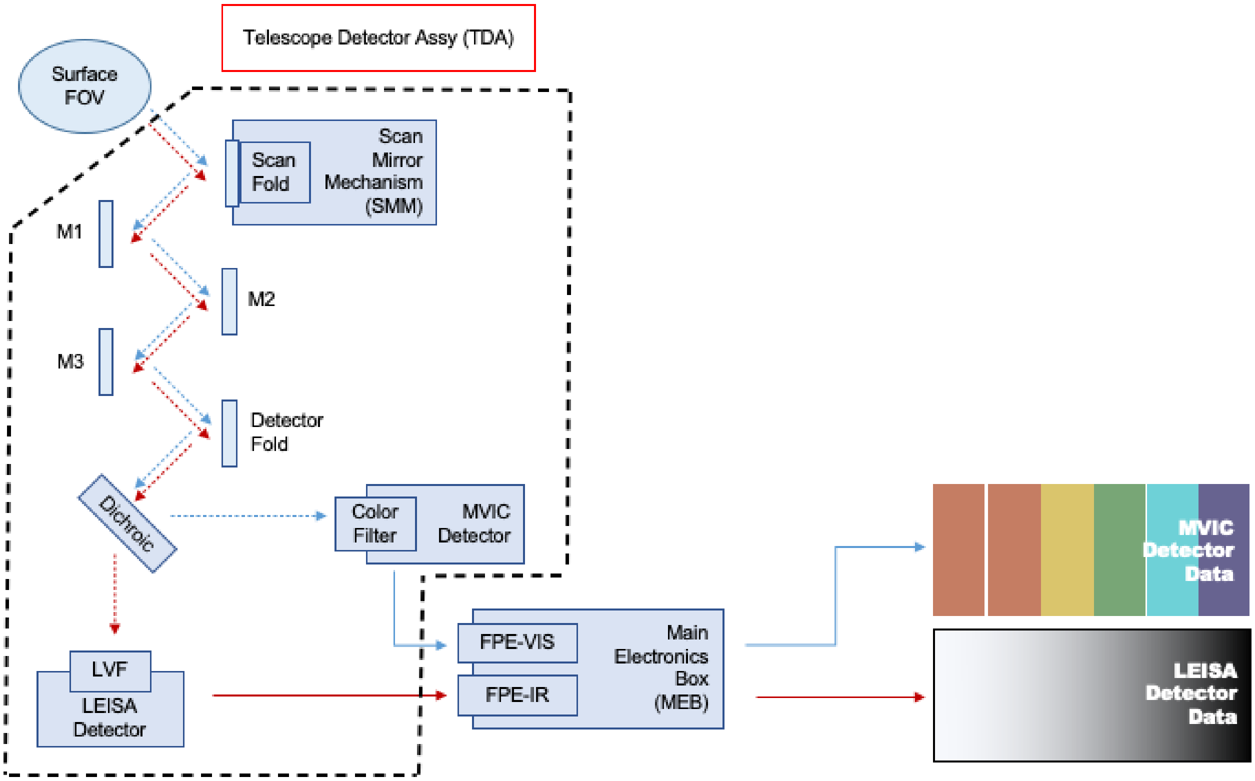

Figure 6. L'Ralph overview

The flight hardware is divided into two major components: the TDA and the Main Electronics Box (MEB). The TDA is an aluminum structure mounted on three titanium bipod flexures. The TDA holds the mechanism, optics, detectors, and in-flight calibration systems. The optics consist of Mirror 1 (M1), Mirror 2 (M2), Mirror 3 (M3), Scan Mirror and the Fold Mirror. The Linear Variable Filter (LVF) position is also shown in Figure 6. Proper alignment [3] of all aforementioned items is critical to meet L'Ralph performance requirements. The Ralph optical axes shall be coaligned with its alignment reference with knowledge of 0.84 mrad per axis (3-sigma), and accuracy of 2.0 mrad per axis. LEISA will be treated as the primary boresight for all Lucy alignment requirements.

The TDA and the MEB top level drawing are shown in Figure 7 and in Figure 8. TDA and MEB are mounted to the Instrument Pointing Platform (IPP) that keeps the instruments pointed at the target based on ephemeris updates and performs surface motion compensation. The radiator cools the Linear Etalon Imaging Spectral Array (LEISA) detector to ~ 100 K. The Multispectral Visible Imaging Camera (MVIC) and the TDA enclosure are cooled to ~ 180 K. Location of flexural plate-wave (FPW) harness is also shown in Figure 7.

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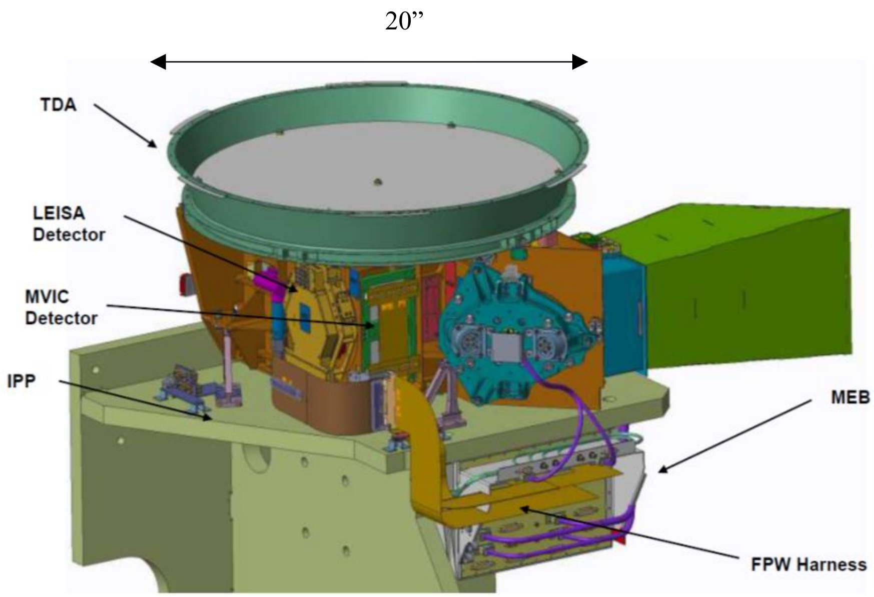

Figure 7. L’Ralph physical design

The Telescope Detector Assembly (TDA) and detector are passively cooled to maintain the detector at its operating temperature. The TDA is thermally isolated from the S/C and the MEB. The MEB provides the operational control for L’Ralph, reads out the detector, and is the electrical and communications interface to the S/C. The MEB holds the redundant L’Ralph electronics. Mechanism Control Electronics (MCE), Low Voltage Power Supply (LVPS), Command and Data Handling (C&DH), and Multi Mission Mass Memory (M4) components consist of two redundant boards each. Focal Plane Electronic-Infrared (FPE-IR) and Focal Plane Electronic-Visible (FPE-Vis) are both single cards with two redundant sides. L’Ralph parameters are shown in Table 1.

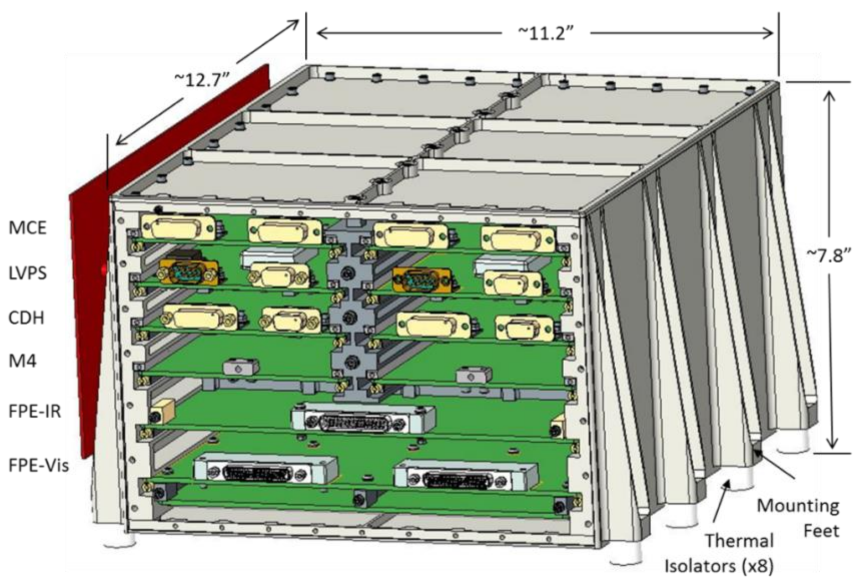

Figure 8. MEB

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Instrument Description	**L'Ralph combines a VIS/NIR multispectral and panchromatic imager (MVIC) with a SWIR spectral mapper (LEISA).**
Instrument Mass	**29.4 kg CBE (21% margin)**
Instrument Power	**24.3 W CBE (19% margin)**
Field of View	**145 mrad x 56 mrad**
Scan Angle	**140 mrad**
MVIC IFOV	**29 mrad**
LEISA IFOV	**80 mrad**
LEISA Wavelength	**0.95-3.95 µm**
MVIC Wavelength Bands	**Band 1: Panchromatic (370-905) Band 2: 375-480 nm Band 3: 480-520 nm Band 4: 520-625 nm Band 5: 625-750 nm Band 6: 750-900 nm**
Calibration	**Solar Cal, Filament and Black Body**

Table 1. L'Ralph Parameters

2. INTEGRATION AND TEST (I&T) GROUND SUPPORT EQUIPMENT (GSE)

The L'Ralph I&T team worked with all the subsystem Product Design Leads (PDLs) and systems engineering to identify any non-flight Ground Support Equipment (GSE) required to support L'Ralph I&T activities [4]. The L'Ralph unique GSE is specific to the type of instrument testing that L'Ralph requires. The following are the categories of L'Ralph unique GSE:

- Electrical GSE (EGSE)
- Mechanical GSE (MGSE)
- Optical GSE (OGSE)
- Thermal GSE (TGSE)

Example of L'Ralph unique GSE are shown in figures 9, 10, 11, 12 and 13.

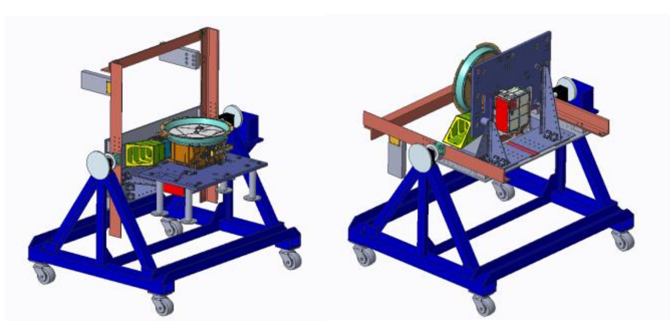

Figure 9. L'Ralph MGSE: Turnover Dolly

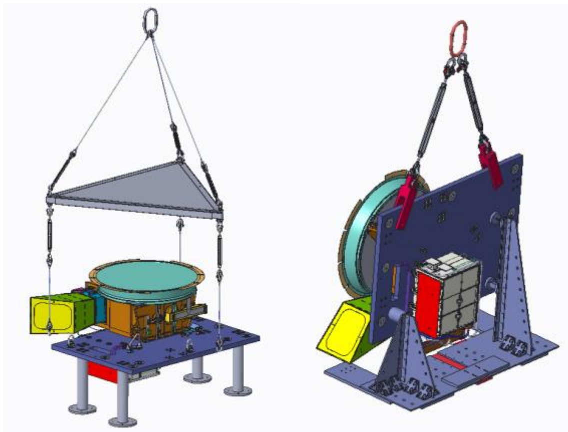

Figure 10. L'Ralph MGSE: Lift Slings

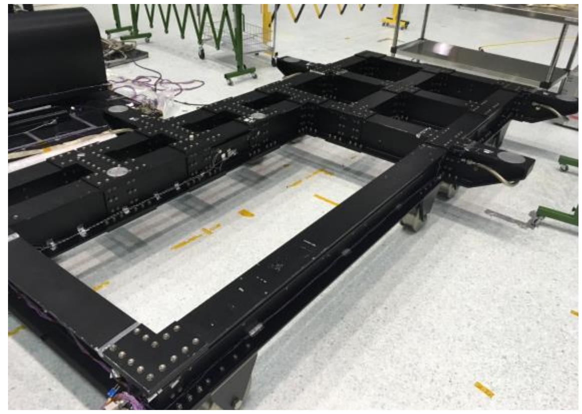

Figure 11 Payload cart

Figure 12. L'Ralph OGSE: In-chamber calibration equipment showing National Institute of Standards and Technology (NIST) traceable Infrared Source Module (IRSM) and flood sources and steering mirror

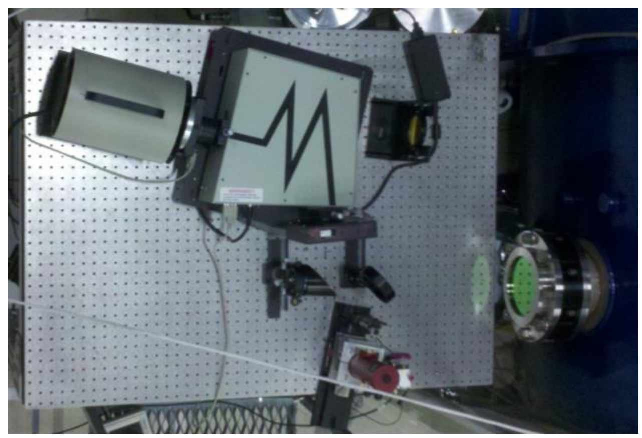

Figure 13. L'Ralph OGSE: Chopped monochromator with monitor detector (collimated beam enters chamber through window and couples to IRSM)

All L'Ralph test equipment are periodically calibrated, and have certification procedures performed prior to operation per the equipment manufacturer's instructions and GPR 8730.1I, Calibration and Metrology. When EGSE is moved and reconfigured, for example prior to start of environmental testing, an EGSE cert procedure is performed. All equipment requiring calibration have a calibration sticker that indicates that the unit is in calibration. Tracking and scheduling the calibration of this equipment is performed by the L'Ralph I&T Manager.

To avoid accidental power off of power supplies, all critical power supply On/Off switches are covered with a spring-loaded cover. To avoid accidental shorting from external objects of internal power busses, all in-house manufactured or commercial equipment have protective covers. All EGSE that interfaces directly with flight equipment has a Failure Modes and Effects Analysis (FMEA) performed to ensure that no failure of the EGSE can cause a failure or an overstressed condition of flight hardware. All EGSE connectors mating to flight hardware are flight connectors.

3. L'RALPH I&T GROUND SYSTEM

Ground Support Equipment Operating System (GSEOS) is used for testing during I&T. The software provides real-time command and control of the instrument through all mission phases. It features the Python programming language as a configuration/scripting tool and can easily be extended to accommodate custom hardware interfaces. The software is comprised of several major subsystems: database telemetry, command, and display.

The ground system consists of computer workstations and a customized system as the primary interface to the instrument through the spacecraft simulator to perform telemetry processing and command encoding. In addition, optical calibration equipment is utilized to provide stimulus to the instrument during testing, particularly during thermal-vacuum.

3.1 Test Conductor Workstation

The test conductor's workstation is a computer that hosts ground system software and provides the following functions:

- Command and Telemetry processing
- Controls System Command Authority
- Validates and screens all commands issued to the instrument
- Decodes Flight Software Events
- Forwards telemetry to other workstations

The workstation is used exclusively by I&T Test Conductors and is the primary machine used for controlling and operating the instrument and executing its test procedures.

3.2 Data Archive System

All telemetry data received through the ground system workstation are archived daily and stored in telemetry archives on a local computer. The file system is shared with other workstations so that any workstation may access and play back telemetry archives.

3.3 Science Analysis Workstation

The science analysis workstation provides the capability to receive, process and verify science data packets during I&T. The workstation receives science data files through the data archive system during I&T operations and is able to display science data in near real-time. It provides a "Quick Look" at the instrument to confirm it is performing as expected. These analyses will be the same for the science data post-processing that is performed after launch.

4. L'RALPH I&T APPROACH

L'Ralph follows a protoflight (PF) development approach, where the flight article undergoes protoflight level testing to serve as qualification of the design. However, limited Engineering Models (EM) and Engineering Test Units (ETUs) are developed to reduce the development risk. Early EMs are used to evaluate design approaches before the final flight design. ETU electronics and TDA hardware are used to mitigate the risk of performance and environmental (vibration, thermal, vacuum) problems and to avoid a change in the design much later in the schedule, which would have had a significant cost and schedule impact.

The instrument test are divided into three types:

- Complete Performance Test (CPT) that consisting of instrument functional testing that can be run in any environment without special GSE. This includes aliveness and special tests.
- Calibration consisting of instrument performance testing that requires special calibration GSE, mostly requiring flight-like temperatures performed in thermal vacuum
- Environmental testing that verifies the instrument performance against the Lucy Environmental Requirements Document (ERD) [5].

4.1 Aliveness and CPT

Aliveness

The aliveness test is an abbreviated subset of the Comprehensive Test. It provides a "quick" check of the state of the instrument. An aliveness test can be performed for an individual subsystem or the entire instrument. The aliveness test typically lasts less than an hour. It includes receiving housekeeping data and checking the power draw of the subsystem or instrument which provides verification that each electrical component is properly connected and in the proper configuration to produce telemetry and receive and execute commands. It is usually performed in one or

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more of the following scenarios: as a pre-test check, after a move, between vibration test axes, or to verify functionality of EGSE. MVIC will be able to take data but it will have increased noise. LEISA will be saturated

CPT

The CPT is used as a detailed verification test that shows the instrument meets performance requirements in all operational modes and is performed on the entire integrated instrument. The test will be based on planned operational and contingency configurations and mission scenarios to ensure it is tested in the modes it is intended to be operated in on-orbit. The CPT will be repeated throughout I&T and is the primary means of by which the instrument's performance is trended during I&T.

4.2 Calibration tests

Geometric Calibration and Verification Test

Geometric characteristics for both MVIC and LEISA will be verified by measuring detector responses to collimated inputs at the solar calibration port in the stray light stay-out zone around the instrument field of view. This will measure the extent of the field of view, the stray light suppression built into the instrument, and the response to various sun angles at the solar calibration port. Since LEISA only functions within specifications while at cold temperatures, most testing will be performed in a thermal vacuum environment. Some MVIC and solar calibration port testing may be performed at ambient temperatures, if necessary.

Spatial Calibration and Verification Test

Spatial response for both MVIC and LEISA will be verified by measuring detector responses to full-aperture collimated inputs within the instrument field of view. This will measure the Encircled Energy (EE) at points across the focal plane, as well as focus. Since LEISA only functions within specifications while at cold temperatures, this testing will be performed in a thermal vacuum environment. Some MVIC testing may be performed at ambient temperatures, if necessary.

Scan Calibration and Verification Test

The accuracy of the instrument scanning function will be verified by using a full-aperture collimated input into the instrument, then using the scan mirror to move it along-track across the focal planes. This will allow a calibration between the commanded scan rate, the scan rate measured throughout the scan with the position sensors, and the scan rate observed on the focal planes. It will also allow a direct observation of any cross-track scan errors that may cause blurring. Since LEISA only functions within specifications while at cold temperatures, this testing will be performed in a thermal vacuum environment.

Spectral Calibration and Verification Test

Spectral response, including wavelength calibration and linewidths/shapes, of both MVIC and LEISA will be verified by measuring detector responses to specific wavelengths using external sources, coupled to the calibration equipment in the chamber. These sources include laser, arc lamps and a monochromator. Since LEISA only functions within specifications while at cold temperatures, this testing will be performed in a thermal vacuum environment.

Radiometric Calibration and Verification Test

Radiometric response of both MVIC and LEISA will be verified by measuring detector responses to GSE calibrated full-aperture sources. The radiometric response to the on-board calibration sources, and solar port, if possible, will also be measured and checked for stability, including blackbody burn-in. In order to improve post-calibration radiometric accuracy, this testing will be repeated at multiple voltages and temperatures. Since LEISA only functions within specifications while at cold temperatures, this testing will be performed in a thermal vacuum environment. Some solar calibration port testing may be performed at ambient temperatures, if necessary

The individual activities that comprise the calibration tests are detailed in the calibration plan [6].

The environmental tests are described in paragraph 6.

5. L'RALPH PRE-ENVIRONMENTAL I&T

L'Ralph pre-environmental integration and test activities are performed at GSFC in tent 150 of building 7 (shown in Figure 14) and are reported in Figure 15. Major activities are: TDA/MEB integration, metrology measurements, blankets installation and post environmental checkout.

Figure 14. Building 7 tent 150. Class 10,000 clean area

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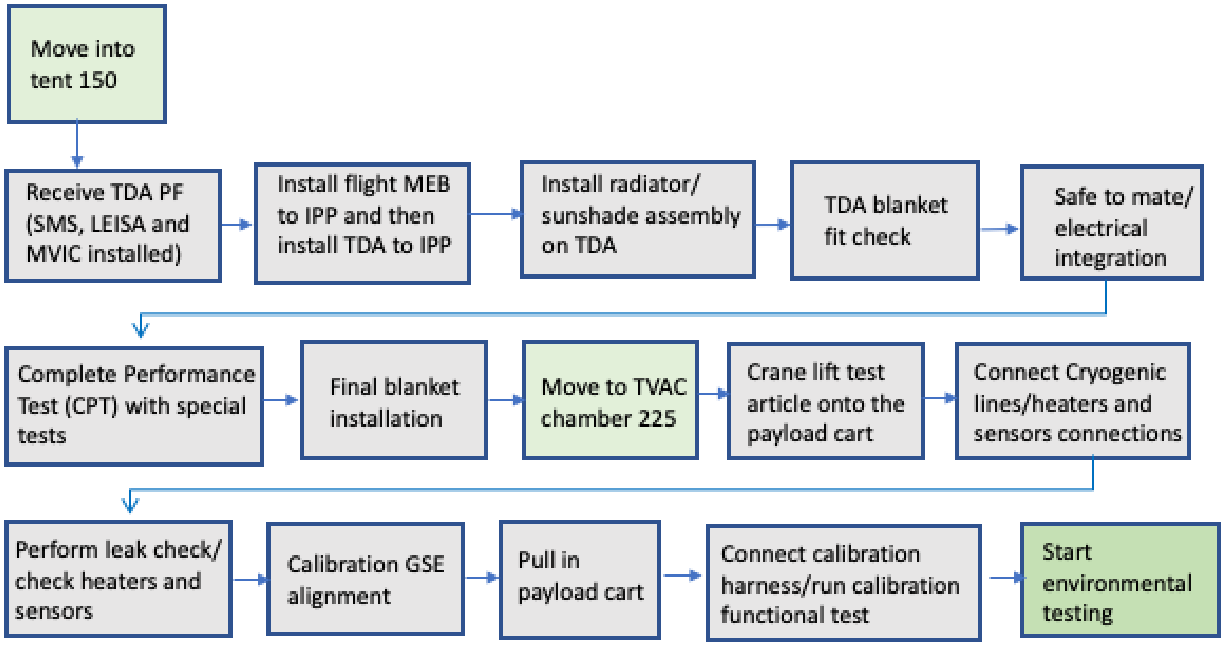

Figure 15. L'Ralph pre-environmental integration and test activities

6. L'RALPH ENVIRONMENTAL TESTS AND FACILITIES

The L'Ralph Environmental Testing phase starts after the successful completion of the L'Ralph Pre-Environmental Review (PER). The Environmental Tests performed in building 7 and 10 at GSFC are the following:

- Thermal Balance / Thermal Vacuum (TVAC Focus) that includes at-temperature focus measurement
- Thermal Balance / Thermal Vacuum (TVAC1) that includes 2 of the 4 required thermal cycles, the baseline CPTs at temperature and the baseline calibration results, with assessment of EE and Signal to Noise Ratio (SNR) performance
- TDA Vibration that includes protoflight-level vibration of flight hardware (the MEB went through vibration test before delivery to I&T)
- EMI/EMC (radiated emission and susceptibility)
- Thermal Balance /Thermal Vacuum (TVAC2) that includes 2 of the 4 required thermal cycles, CPTs and calibration to measure any changes due to environmental testing

In general, prior to each environmental test, an Aliveness Test is performed on the instrument, that is then configured and readied for the next scheduled environmental test.

TVAC Focus Test is required to verify LEISA and MVIC Encircled Energy (EE) performance in flight-like conditions. Baseline plan is to measure focus at cold temperatures, then to break chamber configuration for shim adjustments before executing TVAC1.

The primary reason for performing two TVAC tests, TVAC-1 and TVAC-2, is that since the LEISA detector needs to operate cold at around 100 K, cold TVAC operations is required in order to achieve a baseline prior to the rest of the environmental test program. EMI and Vibe happen between TVAC-1 and TVAC-2. The environmental test flow is shown in Figure 16.

TDA is de-integrated for TDA vibration testing, then re-integrated afterwards. The TDA is much more sensitive to changes in the EE due to shifts of its internal optics in vibration test than it is to bulk changes in the instrument alignment due to integration and de-integration of its elements. The flow shown in Figure 16 is the same basic flow that every infra-red instrument recently built at GSFC has followed.

After the environmental tests, the mass is measured and the center of gravity (CG) is calculated by analysis.

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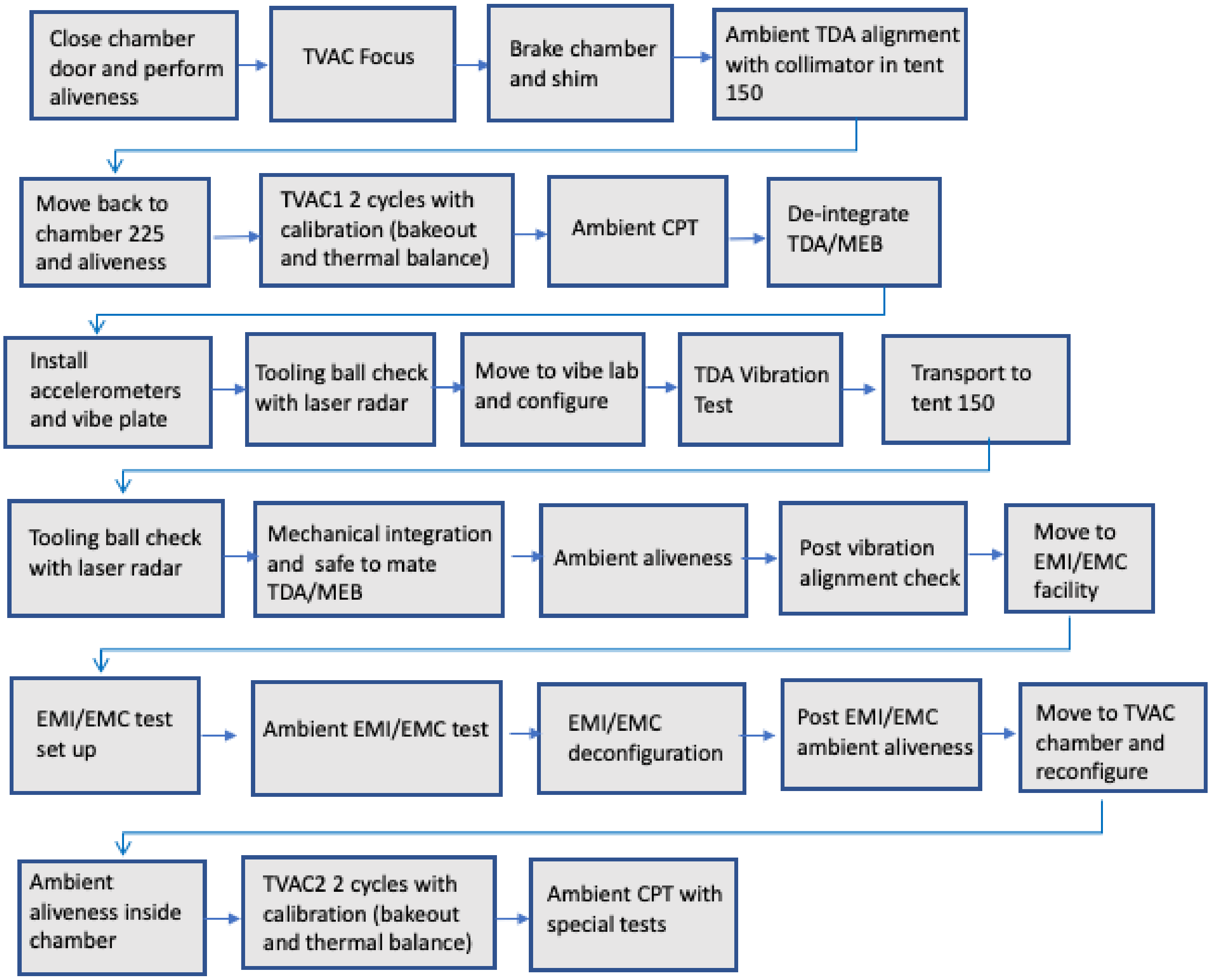

Figure 16. L'Ralph environmental test flow

6.1 Thermal Vacuum and Thermal Balance

TDA and MEB is mounted vertically onto the IPP mockup. The tests are conducted in Chamber 225 at the NASA GSFC in building 7 (shown in Figure 17). Chamber 225 is a 9' x 14' horizontal loading, cylindrical, thermal vacuum chamber used for thermal vacuum and thermal balance testing, and baking out large test items. It is capable of operating from -140ºC to +150ºC in GN2 mode, and can reach as cold as -190ºC in LN2 mode. Chamber evacuation down to 10-7 Torr is provided by 2 cryopumps and a turbomolecular pump, while roughing is provided by a blower and rotary vane mechanical pump. The standard electrical feedthroughs include 37 pin, 7-pin, 4-pin and RF, and the feedthrough penetrations are available on the front, sides, and rear of the chamber. It is equipped to monitor up to 320 thermocouples. Standard contamination equipment includes two thermoelectric quartz crystal microbalances (TQCMs), cold finger, and residual gas analyzer (RGA). A clean tent is located at the opening of the chamber, providing a Class 10,000 clean area for hardware integration prior to testing. The chamber is also equipped with a test item load cart that rolls in and out along a rail system to facilitate with hardware integration and provide better accessibility. The load cart can support payloads weighing up to 2,269 kg (5,000 lb).

Figure 17. Chamber 225 (GSFC/building 7)

As described in chapter 6, TVAC Focus Test is required to verify LEISA and MVIC Encircled Energy (EE) performance in flight-like conditions. TVAC Focus test profile is shown in Figure 18. Baseline plan is to measure focus at cold temperatures, then to break chamber configuration for shim adjustments before executing TVAC1.

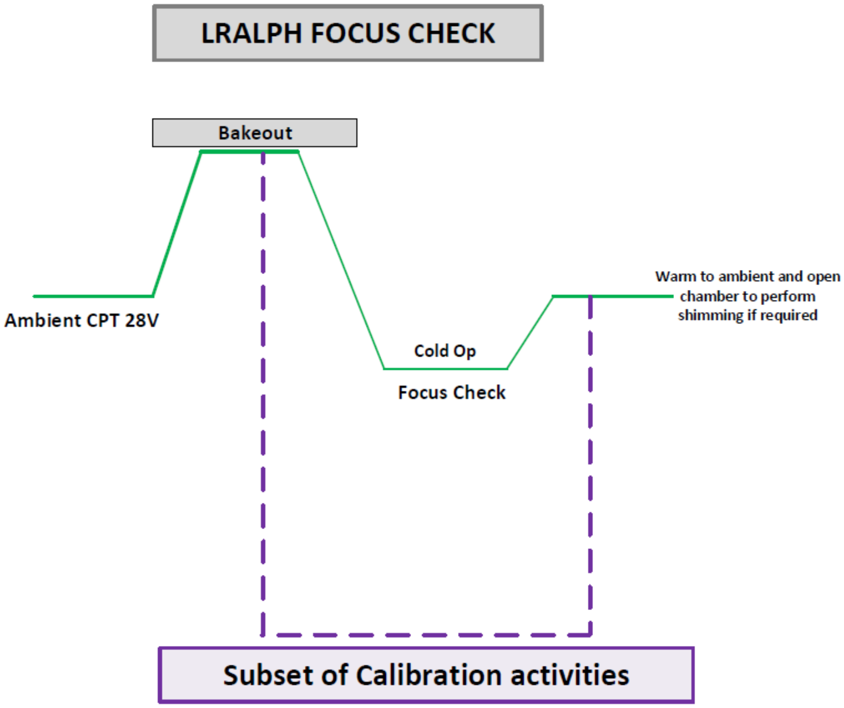

Figure 18. TVAC Focus test profile

The primary reason for performing two TVAC tests, TVAC-1 and TVAC-2, is that since the LEISA detector needs to operate cold at around 100 K, cold TVAC operations is required in order to achieve a baseline prior to the rest of the environmental test program. EMI and Vibe will happen between TVAC-1 and TVAC-2.

TVAC-1 test profile is shown in Figure 19. TVAC-2 test profile is shown in Figure 20.

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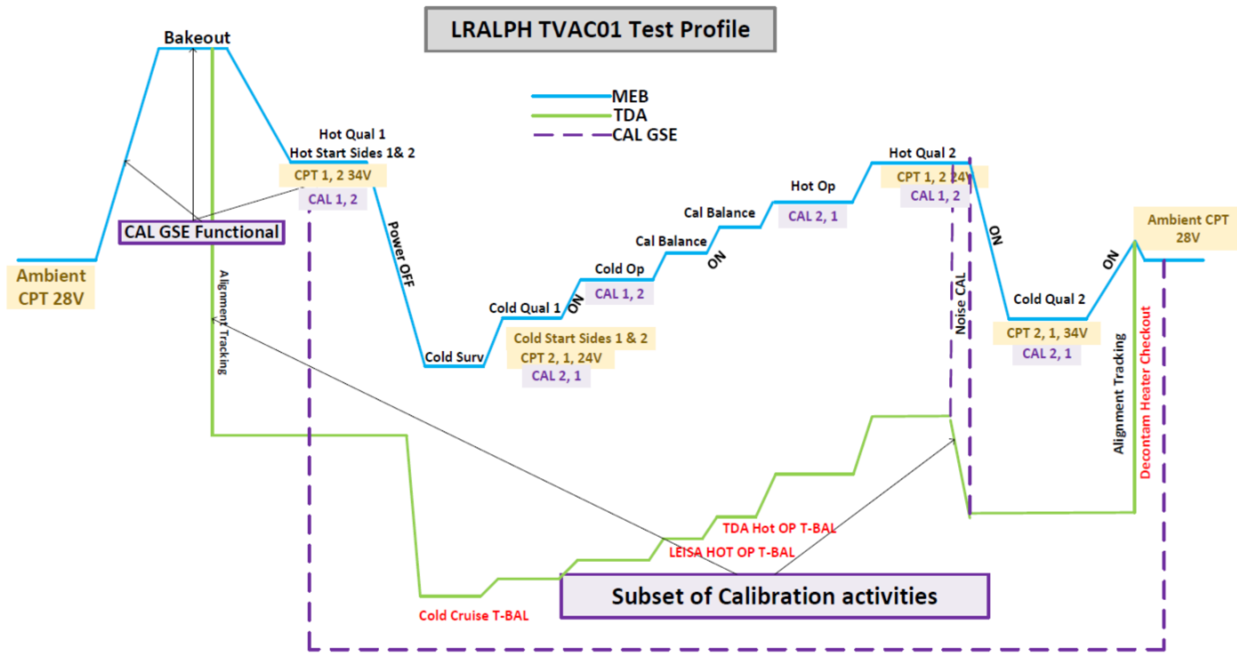

Figure 19. TVAC-1 test profile

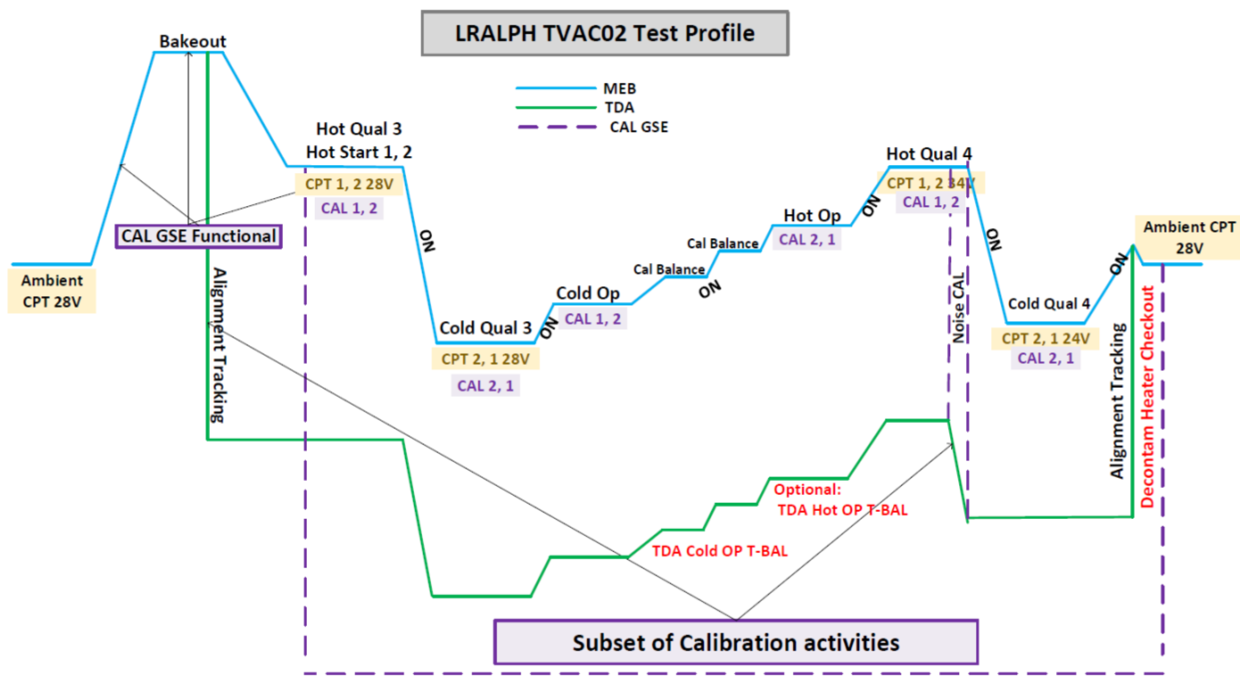

Figure 20. TVAC-2 test profile

The individual activities that comprise the TVAC tests are detailed in the L'Ralph Thermal Vacuum/Thermal Balance Test Plan [7].

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6.2 Vibration Test

L'Ralph uses the GSFC building 7 Vibration Test Facilities to conduct a 3-axis sine and random vibration test. The test campaign utilizes the T4000 shaker systems shown in Figure 21. The Vibration Test Cell is a class 100,000 clean room. Digital control systems provide sinusoidal, random, and transient waveform control to four separate electro-dynamic exciters. All exciters are rigidly mounted to very large reaction masses that are isolated from the building. Digital data acquisition systems condition and record accelerometer, force, and strain gage signals. During vibration, the instrument is unpowered and configured in its launch configuration [8].

Figure 21. GSFC T4000 Shaker

The L'Ralph Main Electronics Box (MEB) and harnessing is not included in this test. The integrated MEB went through sine, sine burst, and random vibration testing before delivery to instrument I&T. The Differential Position Sensor Electronics (DPSE) were not installed for the MEB vibration test, but they were vibrated separately at the vendor site. l'Ralph will go through vibration test during the Lucy observatory environmental test campaign at LM.

MVIC, LEISA, and the SMM have previously undergone vibration test campaigns. The TDA structure has undergone a sine burst test. The purpose of this test is to perform protoflight level sine and random vibration testing for the TDA Flight Unit in order to verify the frequency and that the TDA, including all components, is capable of withstanding the required vibration levels without degradation. Protoflight level testing is necessary to qualify the structural integrity of the TDA. The pre/post vibration electrical functional testing is done outside of the vibration test facility; therefore, no GSE is required in the vibration laboratory during the vibration testing.

The purge GSE is used throughout vibration testing. It is located outside of the vibration cell.

Flight Configuration Proto-flight Testing is performed in each of the three coordinate axes of the test article with the unit mounted on the flight flexures and with the thermal radiator installed to the top of the box. Low-level (signature) sine sweeps is performed as a method of identifying structural changes resulting from testing.

TDA functional tests and visual inspection take place before vibration testing to establish a performance baseline and at the completion of testing to ensure that this baseline is maintained. The TDA (bagged or tent-like contamination covered) is powered OFF. The TDA protoflight sine levels are shown in Figure 22.

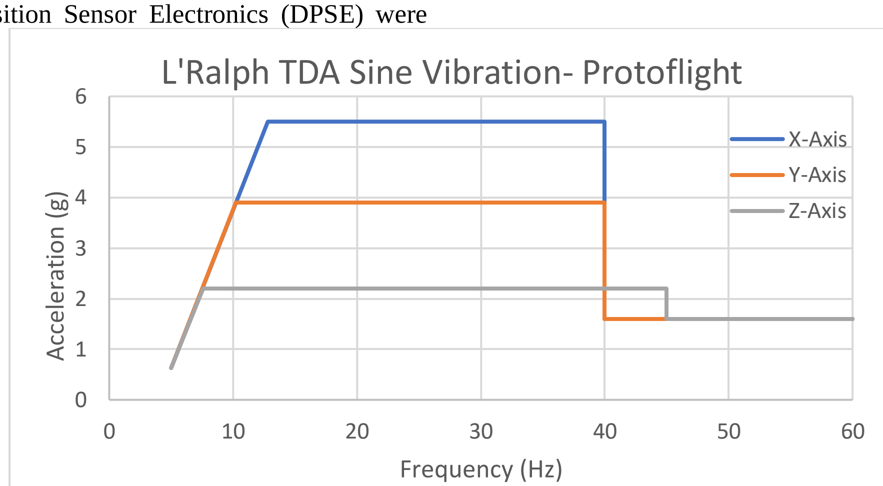

Figure 22 TDA Sine Vibration Protoflight

Random vibration levels for the L'Ralph TDA are described in Table 2. These levels are based on the ERD [5] and are modified by the Instrument Environments Update from Coupled Loads Analysis.

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Zone 5d1 - IPP: Ralph TDA	Random Vibration Spectrum G^2/Hz		
Description	**Freq (Hz)**	**Protoflight**	**Acceptance**
IPP Mounted - Ralph TDA	20	0.01	0.01
	80	0.04	0.04
	500	0.04	0.04
	2000	0.01	0.01
	Overall G_{rms}	6.78	6.78

Table 2. TDA Random Vibration Levels, All Axes

6.3 EMI/EMC

TDA and MEB are installed on the IPP mockup, shown in Figure 23, that is mounted to transport dolly. An EMI-compatible soft cover is on the entrance aperture. The MEB goes through EMI box level testing at the Southwest Research Institute (SwRI). The instrument level tests are performed in the large GSFC building 7 EMI/EMC test facility with a Class 10K test enclosure shown in Figure 24. L'Ralph personnel and GSE are located just outside the facility in the connected staging area.

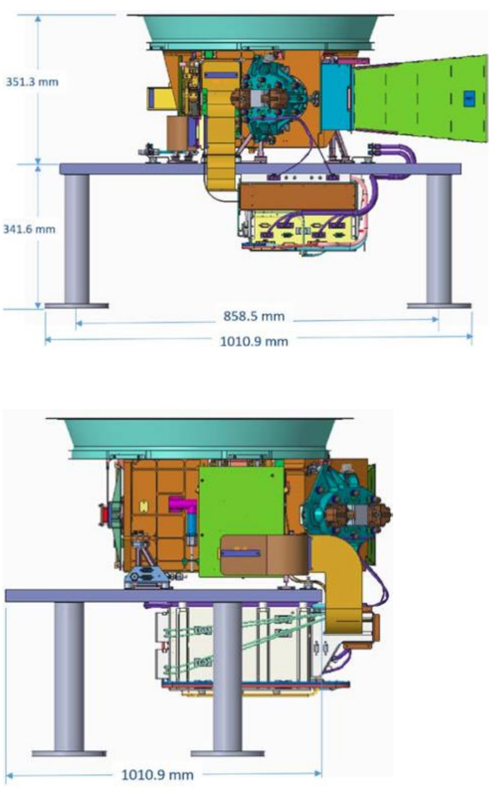

Figure 23. L'Ralph Instrument on the I&T Instrument Pointing Platform (IPP) mockup

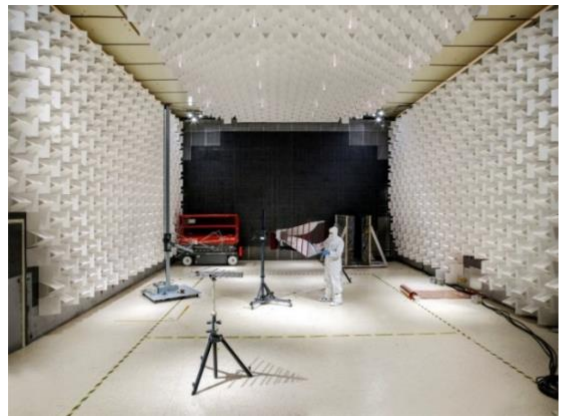

Figure 24. GSFC Large EMC/EMI Facility

The instrument EMI/EMC campaign consists of the following tests at ambient temperature [9]:

- Inrush Current during turn on and Average Current
- Conducted Emissions Common Mode, Tailored to 150kHz – 200MHz
- Radiated Emissions, Electric Field, 200MHz – 18GHz
- Radiated Susceptibility, Antenna Spurious and Harmonic Outputs, Tailored to 2MHz – 18GHz

LEISA is saturated at room temperature operations. LEISA is held in permanent reset mode and the susceptibility test looks for changes in the noise rather than for an absolute noise level.

7. INSTRUMENT SHIPPING AND POST SHIP ACTIVITIES

After the successful completion of the environmental test campaign and of the Pre Ship Review, L'Ralph is shipped by road from GSFC to Lockheed Martin, Denver using dedicated environment control truck. TDA and MEB are installed on the IPP simulator. The shipping container is the same that has been used for the Thermal

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Infrared Sensor (TIRS)/TIRS2. The instrument is monitored by L'Ralph personnel.

Upon delivery to Lockheed Martin, Denver, L'Ralph is moved to an appropriate class cleanroom, unpacked, inspected and configured for the Bench Acceptance Testing (BAT) which includes executing of ambient functional. Following the successful completion of the BAT (including the data review by the instrument project), the flight instrument is prepared for its mechanical and electrical integration on the observatory for the Lucy observatory I&T campaign. The ground processing activities at Lockheed Martin, Denver are shown in Figure 25.

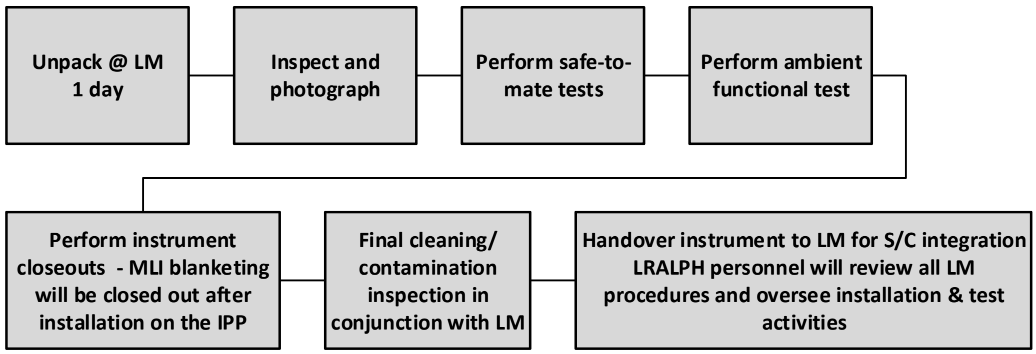

Figure 25. Ground Processing Activities at Lockheed Martin, Denver

At the conclusion of Observatory I&T, the L'Ralph team work closely with the Lucy I&T team to ensure that L'Ralph is properly configured and readied for shipment to the launch site. All required GSE is also configured, packed, and readied for shipment to the launch site.

8. L'RALPH LAUNCH SITE ACTIVITIES

The Lucy Observatory I&T activities at the Launch Site are primarily the responsibility of the Spacecraft Vendor. The L'Ralph team work closely with the Lucy Observatory I&T Manager planning launch site activities that include:

- Support L'Ralph GSE unpacking, inspection, setup and checkout
- Perform an instrument CPT and support any required Mission Simulation, Mission Readiness Tests (MRTs), and/or any End-to-End tests
- Support closeout including MLI of L'Ralph Instrument, including Red Tag/Green Tag closeouts, and final cleaning/inspection
- Support Launch Readiness Review (LRR) and launch operations as required
- Support packing and the return of L'Ralph Instrument GSE back to the GSFC

9. CONCLUSIONS

Plans, resources and facilities are in place to assure a successful L'Ralph I&T campaign. The I&T plan and the verification matrix are in compliance with the requirements documents. Major deliverables are well understood. The baseline plan is to test as L'Ralph will fly.

Available resources are sufficient to execute the plan. It takes time and effort to integrate members of a team from different disciplines or subsystems. The L'Ralph I&T Manager will also integrate people through planning and coordination of I&T activities, which will result in increased team dynamics, maximized system testing performances, on-time delivery and reduced budget over-runs.

Key Considerations for L'Ralph Flight Hardware Safety are: Electrostatic Discharge Protection [10], Contamination Control [11] and Laser Safety [12]. L'Ralph personnel will receive the proper training.

All L'Ralph Assembly, Integration and Test Activities will be performed at the GSFC facilities. The GSFC facilities provide environmental test capability that ensures flight systems will withstand the launch and will operate properly in space environment. The GSFC Environmental Test and Integration Facilities are one of the most complete and comprehensive complexes within the United States Government.

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APPENDICES

A. ACRONYMS AND ABBREVIATIONS

APL	Applied Physics Lab
ASU	Arizona State University
BAT	Bench Acceptance Testing
C	Celsius
CCD	Charge Coupled Device
C&DH	Command and Data Handling
CG	Center of Gravity
CPT	Comprehensive Performance Test
CO	Colorado
DPS	Deep Space Network
DPSE	Differential Position Sensor Electronics
EGSE	Electrical Ground Support Equipment
EE	Encircled Energy
EM	Engineering Model
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
ERD	Environmental Requirements Document
ETE	End to End Test
ETU	Engineering Test Unit
FMEA	Failure Modes and Effects Analysis
FOV	Field Of View
FPE-IR	Focal Plane Electronic-Infrared
FPE-Vis	Focal Plane Electronic-Visible
FPW	Flexural Plate-Wave
FTIR	Fourier-transform infrared spectroscopy
GN2	Gaseous Nitrogen
GSE	Ground Support Equipment
GSEOS	Ground Support Equipment Operating System
GSFC	Goddard Space Flight Center
Grms	root-mean-square acceleration
HgCdTe	Mercury Cadmium Telluride
IPP	Instrument Pointing Platform
IR	Infra-Red
IRSM	Infrared Source Module
I&T	Integration and Test
K	Kelvin
LEISA	Linear Etalon Imaging Spectral Array
LM	Lockheed-Martin
LN2	Liquid nitrogen
LORRI	LOng Range Reconnaissance Imager
LRR	Launch Readiness Review
LVF	Linear Variable Filter
LVPS	Low Voltage Power Supply
M	Mirror
M4	Multi Mission Mass Memory
MCE	Mechanism Control Electronics
MEB	Main Electronics Box
MGSE	Mechanical Ground Support Equipment
MLI	Multilayer Insulation
mrad	milliradian
MRT	Mission Readiness Tests
µm	micrometer
MVIC	Multi-spectral Visible Imaging Camera
NASA	National Aeronautics and Space Administration
NIR	Near Infrared
NIST	National Institute of Standards and Technology
nm	nanometer
OGSE	Optical GSE
PAN	Panchromatic
PDL	Product Design Lead
PER	Pre Environmental Review
PF	Protoflight
PI	Principal Investigator
OGSE	Optics Ground Support Equipment
PER	Pre Environmental Review
PSR	Pre Ship Review
RF	Radio Frequency
RGA	Residual Gas Analyzer
RSA	Radio Science Investigation
S/C	Spacecraft
SMM	Scan Mirror Mechanism
SNR	Signal to Noise Ratio
SWIR	Short Wave Infrared
SwRI	Southwest Research Institute
TDA	Telescope Detector Assembly
TDI	Time Delay Integration
TES	Thermal Emission Spectrometer
TGSE	Thermal GSE
TIRS	Thermal Infrared Sensor
TQCMs	Thermoelectric Quartz Crystal Microbalances
TTCam	Terminal Tracking Camera
TVAC	Thermal Balance / Thermal Vacuum

REFERENCES

[1] LRALPH-SYS-PLAN-0001, L'Ralph Systems Engineering Management Plan (SEMP), NASA Goddard Space Flight Center

[2] LRALPH-MGMT-PLAN-0005, L'Ralph Instrument Implementation Plan, NASA Goddard Space Flight Center

[3] LRALPH-OPT-PLAN-0019, Optical Alignment and Test Plan, NASA Goddard Space Flight Center

[4] LRALPH-INT-PLAN-0010, Instrument Integration & Test Plan, NASA Goddard Space Flight Center

[5] Lucy-MGMT-REQ-0002, Lucy Environmental Requirements Document (ERD), NASA Goddard Space Flight Center

[6] LRALPH-INT-PLAN-0021, L'Ralph Calibration Plan, NASA Goddard Space Flight Center

[7] LRALPH-THRM-PLAN-0038, L'Ralph Thermal Vacuum/Thermal Balance Test Plan, NASA Goddard Space Flight Center

[8] LRALPH-MECH-PLAN-0045 L'Ralph Telescope Detector Assembly (TDA) Flight Vibration Test Plan, NASA Goddard Space Flight Center

[9] LRALPH-ELEC-PLAN-0039, L'Ralph Instrument-Level and L'Ralph Main Electronics Box-Level (MEB) Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) Test Plan, NASA Goddard Space Flight Center

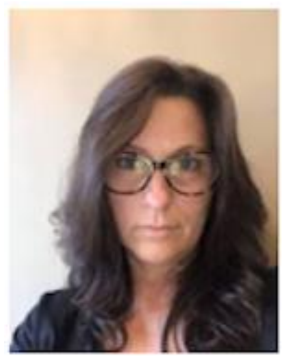
[10] LRALPH-SYS-PLAN-0020, L'Ralph ESD Control Plan, NASA Goddard Space Flight Center

[11] LRALPH-SMA-PLAN-0011, L'Ralph Contamination Control Plan, NASA Goddard Space Flight Center

[12] LRALPH-SMA-PLAN-0088, Laser Safety Plan Goddard Laser for Absolute Measurement of Radiance (GLAMR) Laboratory For Characterizing L'Ralph Instrumentation , NASA Goddard Space Flight Center

BIOGRAPHY

***Susanna Petro** has 30 years of experience in spacecraft and instrument systems design, test, and launch. She currently works as Staff Engineer in the Flight Systems Integration and Test Branch at the Goddard Spaceflight Center. She previously worked at the GOES-R Project supporting the Space Environment In-Situ Suite instruments for technical design, calibration and testing. Before that, she worked at the Johnson Space Center with the Electromagnetic Interference/Compatibility Test & Analysis Group. She obtained a doctor's degree in Experimental Nuclear Physics from the University of Rome, Italy La Sapienza.*



***Teresa Null** has 35 years of experience in aerospace. She began working at the Goddard Spaceflight Center in 1985 as a high school senior in the technician apprenticeship program, through which she earned a journeymen's license in electronics. She has served as a battery laboratory manager, Integration and Test Manager of the Submillimeter Wave Astronomy Satellite (SWAS), Integration and Test Manager of the Thermal Infrared Sensor (TIRS) instrument, Integration and Test manager of the Micro Shutter Subsystem for the Near Infrared Spectrometer on the James Webb Telescope and now Senior Integration and Test Manager of the Lucy L'Ralph instrument.*

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