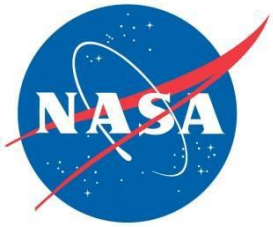

Psyche

PLRA-PMP-DI-PSYC

Planetary Missions Program Plan

Program Level Requirements Appendix for the

Psyche Project

April 2020

NASA Headquarters

Washington, DC 20546

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Reference Documents

1. Discovery Announcement of Opportunity (AO) NNH14ZDA014O, November 5, 2014
2. Discovery 2014 document "Guidelines and Criteria for the Phase A Concept Study," November 9, 2015
3. Psyche Concept Study Report (AO NNH14ZDA014O), August 15, 2016
4. NASA Memo, Discovery Program AO 2014 Selection Letter, December 22, 2016
5. NASA Memo to Discovery Program Manager, Implementation of newly selected Discovery Missions, January 26, 2017
6. NPR 7120.5, NASA Space Flight Program and Project Management Requirement.
7. NPR 8705.4, Risk Classification for NASA Payloads
8. NPR 7123.1, NASA Systems Engineering Processes and Requirements

Distribution Requests

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Program-Level Requirements Appendix
Document Change Log

Revision	Date	Description
Initial	August 2017	Developed post-selection Discovery AO 2014
Update	February 2019	Updated for PDR and KDP-C; change to Level 1 science requirement FROM: "...Al (0.3 wt%)"; TO: "...Al (1.3 wt%)"
Update	May 2019	Removed LCC TBR in Section 5.1' updated to state LCC "shall not exceed" $994.7M (RY); Updated Project Org chart in section 3.1 to align with new roles/responsibilities of DSOC/DAK
Update	March 2020	Update of personnel; update to Magnetometer instrument provider; addition of selected launch vehicle

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1.0 SCOPE

This appendix to the Planetary Missions Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on Arizona State University (ASU) and the Jet Propulsion Laboratory (JPL) for the development and operation of the Psyche project under the Discovery Program. Requirements begin in Section 4. Sections 1, 2 and 3 are intended to set the context for the requirements that follow. This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator (AA) for the Science Mission Directorate (SMD) through the Planetary Science Division (PSD) within SMD to the Discovery Program Manager in the Planetary Missions Program Office (PMPO) at Marshall Space Flight Center (MSFC). Project authority is delegated by the Program Manager to the Principal Investigator (PI), Dr. Linda Elkins-Tanton of ASU. The PI is responsible for the overall success of the Psyche mission and is accountable to the AA/SMD for the mission's scientific success and to the Discovery Program Manager for its programmatic success. The PI will also coordinate the work of co-investigators and has ultimate responsibility for the Psyche science data efforts.

The PI delegates the day-to-day programmatic and technical implementation to the Project Manager, Henry Stone, at JPL. The Project Manager is responsible for design, development, test, and mission operations and coordinates the work of all Psyche contractors.

The NASA Directorate Program Management Council (DPMC) is the governing PMC for the Psyche Mission. The JPL Director is responsible for providing institution resources to the Psyche project and for certifying Psyche's mission readiness to the AA/SMD. The Planetary Missions Program Office will participate in the Life Cycle Reviews, PMCs, and will independently certify mission readiness.

Changes to information and requirements contained in this document require approval by the same signatories that approved the original.

This project is part of the Discovery Program which is governed by the Planetary Missions Program Plan. Any extended missions will be captured as an addendum to this PLRA.

2.0 SCIENCE DEFINITION

2.1 SCIENCE OBJECTIVES

The Psyche mission is a journey to the unique metal asteroid, Psyche, orbiting the Sun between Mars and Jupiter. The asteroid Psyche provides a window into the formation of planetary cores. Metal cores formed within the solar system's first half million years and even in very small bodies. As high-energy impacts were ubiquitous in the early solar system, planetary cores likely formed and reformed repeatedly. Some impacts were accretionary, and others were destructive "hit-and-run" collisions that stripped the silicate mantles from their metal cores. This is the leading hypothesis for Psyche's formation: it is a bare planetesimal core. While it is expected that Psyche will be representative of cores everywhere, it is singular by being the only one in the solar system that can be accessed directly.

The Psyche mission addresses two of the SMD's PSD goals and ties into the Decadal Survey with an investigation that has three broad goals:

1. Understand a previously unexplored building block of planet formation: iron cores.
2. Look inside the terrestrial planets, including Earth, by directly examining the interior of a differentiated body, which otherwise could not be seen.
3. Explore a new type of world. For the first time, examine a world not made of rock or ice, but of metal.

Psyche's science objectives are to:

- Determine whether Psyche is a core, or if it is primordial unmelted material
- Determine the relative ages of regions of Psyche's surface
- Determine whether small metal bodies incorporate the same light elements into the metal phase as are expected in the Earth's high pressure core
- Determine whether Psyche was formed under conditions more oxidizing or more reducing than Earth's core
- Characterize Psyche's morphology

2.2 SCIENCE INSTRUMENT SUMMARY DESCRIPTION

The Psyche payload is comprised of three science instruments, radio science, and one technology demonstration payload:

(1) Magnetometer instrument – consists of dual vector field magnetometers (Technical University of Denmark (DTU))
(2) Imager instrument – consists of redundant multispectral imagers (ASU)
(3) Gamma-Ray and Neutron Spectrometer (Applied Physics Laboratory (APL))
(4) X-band radio science for gravity (Massachusetts Institute of Technology (MIT), JPL)
(5) Deep Space Optical Communications (DSOC; NASA Government Furnished Equipment (GFE))

The Psyche Magnetometer is designed to measure the field of a 250 km diameter Fe-Ni object with great precision, yet still accommodate the possibility of a super strong dipole with large dynamic range. The Magnetometer's role is to determine if Psyche is a core of a differentiated body. The Psyche magnetometers will be build-to-print copies of the vector field magnetometers flown on the SWARM mission.

The Psyche Imager consists of two identical 8-filter imagers which map morphology, topography, and the distribution of metal and silicate domains. The purpose of the second camera is to provide redundancy for mission critical optical navigation. Each imager includes three main components: Focal Plane Array (FPA), filter wheel, and optics assembly. This instrument is compact and low mass with heritage from Mars Science Laboratory (MSL) Mast Camera (Mastcam).

The Psyche Gamma-Ray and Neutron Spectrometer will provide elemental composition measurements at Psyche. Gamma-ray and neutron spectroscopy is a standard technique for quantifying bulk elemental compositions, having been used successfully at the Moon, Venus, Mars, Mercury, and the asteroids Eros, Vesta, and Ceres. For the Psyche mission, gamma-ray measurements will quantify the abundance of nine key elements (Fe, Ni, Si, K, S, Al, Ca, Th, U) either as compositional maps or average surface values. The Psyche Gamma-Ray and Neutron Spectrometer is an updated/modern version of the MESSENGER Gamma-Ray and Neutron Spectrometer.

The radio science investigation will map the gravity field as a means to differentiate among core-formation hypotheses. This standard technique utilizes the existing spacecraft X-band telecom subsystem, along with the Deep Space Network (DSN), to produce two-way Doppler measurements that can be used to determine the Psyche gravity field to degree and order 10 from the planned science orbits.

To accomplish the goals of the DSOC technology demonstration project, NASA will provide a Flight Laser Transceiver (FLT) as GFE to the Psyche project. The DSOC payload will be used to demonstrate optical communications technology for the first year of Psyche post-launch flight operations, out to approximately two astronomical units (2 AU). The DSOC payload operates independently from the science instruments and is not required to accomplish the scientific goals and objectives of the Psyche mission.

3.0 PROJECT DEFINITION

3.1 PROJECT ORGANIZATION & MANAGEMENT

The PI, Dr. Linda Elkins-Tanton, is responsible to NASA for meeting the scientific objectives of the Psyche mission within cost and schedule. The PI has direct accountability to the Planetary Mission Program Office for implementation of Psyche. The PI is responsible for oversight of Co-Investigators, resource-constrained tradeoffs, and deliveries into the Planetary Data System (PDS). The Psyche project organization chart is shown in Figure 1.

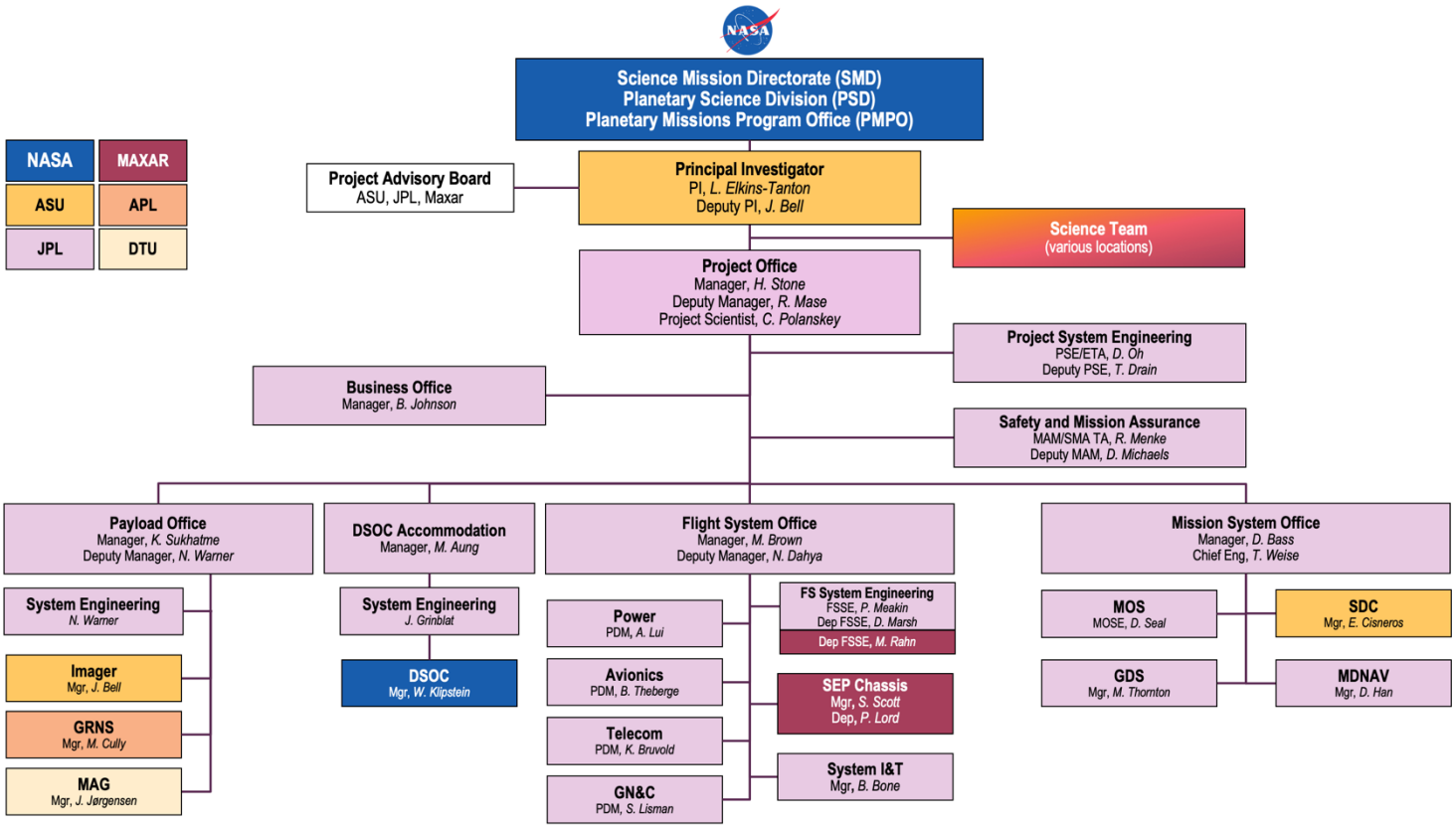

Figure 1. Project Organization Chart

3.2 PROJECT ACQUISITION STRATEGY

Psyche was selected in December 2016 under the Discovery AO 2014. Psyche does not rely on contributed hardware or NASA center contributions for mission success.

The PMPO at MSFC will hold the contract with ASU for the PI effort and the Imager development. ASU will contribute towards the efforts of the PI. Two foreign co-investigators will contribute scientific collaborations.

The PMPO will monitor the JPL task plan for their work on Psyche which includes: Project Management; Systems Engineering; Safety and Mission Assurance; Spacecraft Design, Build, Assembly, and Test; Mission Design and Navigation; Operations; and Ground Data Systems Design, Implementation, and Test.

The Gamma-Ray and Neutron Spectrometer will be developed and delivered by Applied Physics Lab (APL), the Imager by ASU, and the Magnetometer by DTU. DSOC is GFE that is not required to meet science requirements.

JPL will procure a commercial Solar Electric Propulsion (SEP) chassis from SSL (Palo Alto) using a firm fixed price contract. The SEP chassis will include the composite bus structure, power subsystem including solar arrays, electric and cold-gas propulsion systems, thermal subsystems, attitude-control actuators and sensors, and harnesses. JPL will provide spacecraft command and data handling, low voltage power distribution, flight software, and telecommunications.

The launch vehicle will be supplied through the commercial launch services contract managed by NASA Kennedy Space Center (KSC). The vehicle chosen to launch Psyche is the Falcon Heavy provided by SpaceX.

Psyche will leverage NASA’s Advanced Multi-Mission Operations System (AMMOS) tools and services as the backbone of the ground data system. Psyche flight operations teams will be co-located at JPL and instrument operations teams will be located at science data centers at ASU (Imager), at MIT (Magnetometer, radio science), and at APL (Gamma-Ray and Neutron Spectrometer).

4.0 PROGRAMMATIC REQUIREMENTS

4.1 SCIENCE REQUIREMENTS

The five primary science requirements map directly to the five major science goals for the Psyche mission.

1. The Psyche project shall determine whether Psyche is a core.
    a. Determine whether Psyche's dipole moment exceeds $2x10^{14}$ Am^2.

    b. Determine whether there are contiguous silicate regions on scales larger than 1 km^2, where silicates are defined as having > 14% Si by mole.

    c. Determine whether Psyche has surface density variations of ≥ 25% with spatial resolution better than 50 km x 50 km.

    d. Discriminate between achondritic and chondritic silicates in Psyche's surface by measuring Fe (detection limit 4 wt%), Si (2.5 wt%), K (0.02 wt%), (on a surface spatial dimension of 200 km^2 or less) and either Ca (0.3 wt%) or Al (1.3 wt%) (as a global average), all with 20% precision.

    e. Determine whether Psyche's surface has a global average of less than 4 wt% nickel (indicating reducing conditions), or > 12 wt% (indicating highly oxidizing conditions), by measuring Ni with 20% precision.

2. The Psyche project shall determine the relative ages of regions of the surface of Psyche by counting craters with diameters larger than 1 km over at least 50% of the surface.

3. The Psyche project shall determine the average abundances of light elements S (detection limit 3 wt%), K (0.02 wt%), and Si (2.5 wt%) to 20% precision in portions of Psyche's surface that appear to be a metal phase, to compare to models of their abundances in Earth's core.

4. The Psyche project shall determine whether Psyche was formed under conditions more oxidizing or more reducing than Earth’s core.

    a. Determine whether Psyche’s surface has a global average of > 10±5 wt% oldhamite, indicating highly reducing conditions.

    b. Determine whether Psyche's surface has a global average of less than 4 wt% nickel (indicating reducing conditions), or > 12 wt% (indicating highly oxidizing conditions), by measuring Ni with 20% precision.

5. The Psyche project shall characterize Psyche's morphology over 50% of the surface at 200 m/pixel horizontal and 50-m vertical resolution.

4.2 THRESHOLD SCIENCE REQUIREMENTS FOR MISSION

For this mission, there are no threshold science requirements. Determination for science mission success is outlined in section 4.8 and encompasses a subset of the science requirements.

4.3 SCIENCE INSTRUMENT REQUIREMENTS

All science instruments shall provide data with sufficient sensitivity and accuracy to achieve the science objectives defined in 2.1 and the science requirements in 4.1.

4.4 MISSION AND SPACECRAFT PERFORMANCE

Psyche shall be Category 2 per NPR 7120.5 and risk classification B per NPR 8705.4, Risk Classification for NASA Payloads.

The spacecraft shall provide the required subsystem support to satisfy the science and instrument requirements in section 4.1 for the duration of the nominal mission.

The spacecraft shall be designed to operate for a baseline of at least five years after on-orbit checkout.

4.5 LAUNCH REQUIREMENTS

The Psyche project shall utilize the selected Falcon Heavy launch vehicle, and shall launch in a 20-day period that opens as early as mid-July 2022.

4.6 GROUND SYSTEM REQUIREMENTS

None to be included for this mission.

4.7 SCIENCE DATA REQUIREMENTS

The Psyche PI shall be responsible for initial analysis of the data, its subsequent delivery to NASA's PDS, the publication of scientific findings, and communication of results to the public. Additionally, the Psyche PI shall be responsible for collecting engineering data, and ancillary information necessary to validate and calibrate the scientific data prior to archiving it. The Psyche science data shall be made available to the science community without restrictions or proprietary data rights of any kind.

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

4.8 MISSION SUCCESS CRITERIA (SC)

For science mission success, the following criteria must be met:

SC-1 Determine whether Psyche is a core by (1) measuring a dipole moment greater than $2x10^{14}$ Am^2, or (2) measuring global average Ni content less than 4 wt% or more than 12 wt%, or (3) achieving at least three of the five science requirements listed in section 4.1-1.

SC-2 Determine whether Psyche was formed under conditions more oxidizing or more reducing than Earth's core by determining at least one of the two science requirements listed in section 4.1-4.

SC-3 Characterize Psyche's morphology over 50% of the surface at 200 m/pixel horizontal resolution.

SC-4 Process and release data in a timely manner, including the archival of acquired data and standard data products into the PDS within six months after the approach phase, then every three months following.

4.9 FINAL MISSION REPORTS

The Psyche Project shall develop two final mission reports. These reports are required at the conclusion of the Primary Mission and each Extended Mission.

A spacecraft report shall be provided to the PMPO, no later than 90 days after the completion of mission operations, summarizing the technical performance of the spacecraft and science instruments and an assessment on the fulfillment of the Level 1 requirements defined in sections 4.3, 4.4, and 4.5.

A science requirements report shall be provided to the PMPO and the Program Scientist at the end of the data analysis period, at least 90 days prior to the termination of the project, summarizing the scientific accomplishments of the mission and an assessment on the fulfillment of the Level 1 science requirements in Section 4.1 and 47.

Upon acceptance of the science requirements report, the Program Scientist will provide a memo to the PMPO and project stating concurrence on the accomplishment of Level 1 science requirements.

4.10 SCHEDULE REQUIREMENTS

The Psyche project shall meet the following set of (no later than) milestones:

4.8.1	Preliminary Design Review (PDR)	March 2019
4.8.2	Critical Design Review (CDR)	May 2020
4.8.3	Systems Integration Review (SIR)	December 2021
4.8.4	Launch	August 2022
4.8.5	Orbit Psyche	2026
4.8.6	End of Mission	2028

5.0 NASA MISSION COST REQUIREMENT

5.1 LIFE CYCLE COST

The Life Cycle Cost (LCC) for the 2022 launch shall not exceed $996.4 M (RY). This cost includes the cost for launch vehicle and HQ Unallocated Future Expenses (UFE).

5.2 COST MANAGEMENT AND SCOPE REDUCTION

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the Psyche project shall pursue scope reduction and risk management as a means to control cost. Because the project has no threshold mission requirements, as documented in Section 4.2, no descopes have been identified that will not affect the accomplishment of the science objectives. Any reduction in scientific capability, shall be implemented only after consultation with and approval by the Program Scientist.

6.0 MULTI-MISSION NASA FACILITIES

Multi-mission NASA facilities required by the Psyche Mission include launch services and launch site payload processing facilities at KSC and the DSN.

7.0 EXTERNAL AGREEMENTS

The Psyche mission does not have any external or international agreements upon which mission success depends.

8.0 COMMUNICATIONS

The Psyche project shall develop and execute communications activities as defined in the Psyche Communications Plan.

9.0 SPECIAL INDEPENDENT EVALUATION

Independent reviews, such as Life Cycle Reviews (LCRs) and Key Decision Point (KDP) reviews, are required by existing directives and do not constitute special independent evaluation. There are no special independent evaluations required by the Discovery Program. However, the governing and/or technical authorities may convene special reviews as determined necessary per NPR 7120.5, section 2.2.9.

10.0 WAIVERS

The 7120.5 Compliance Matrix for the Psyche project documents requirement compliance. Waivers, if any, are documented in the Table 2 below.

Title	Description	NPR 7120.5 Requirement	Justification
None			

Table 2. Psyche Waivers to NPR 7120.5