

Opportunities for Small Satellites in NASA's Earth System Science Pathfinder (ESSP) Program

Frank Peri, Richard C. Law, James E. Wells

NASA Langley Research Center, 9 Langley Boulevard, Hampton, VA, USA 23681

ABSTRACT

NASA's Earth Venture class (EV) of missions are competitively selected, Principal Investigator (PI) led, relatively low cost and narrowly focused in scientific scope. Investigations address a full spectrum of earth science objectives, including studies of the atmosphere, oceans, land surface, polar ice regions, and solid Earth. EV has three program elements: EV-Suborbital (EVS) are suborbital/airborne investigations; EV-Mission (EVM) element comprises small complete spaceborne missions; and EV-Instrument (EVI) element develops spaceborne instruments for flight as Missions-of-Opportunity (MoO). To ensure the success of EV, frequent opportunities for selecting missions has been established in NASA's Earth Science budget. This paper will describe those opportunities and how the management approach of each element is tailored according to the specific needs of the element.

Keywords: ESSP, Earth Venture, program management, NASA Science Mission Directorate, Class-D mission, Instrument-first

1. INTRODUCTION

Following recommendations of the National Research Council Decadal Survey in 2007, NASA's Earth System Science Pathfinder Program (ESSP) introduced the Earth Venture class (EV) of mission opportunities. The ESSP is a strategic investment by NASA's Science Mission Directorate (SMD), Earth Science Division (ESD) that includes a series of relatively low-to-moderate cost, small-to-medium sized, competitively selected, PI led missions that are built, tested, and launched in a short time interval to accommodate new and emergent scientific priorities. ESSP projects support a variety of earth science objectives, including studies of the atmosphere, oceans, land surface, polar ice regions, and solid Earth. The investigations in the project complement the larger, strategic missions identified by name in the Decadal Survey and NASA's 2010 Climate Initiative and provide flexibility to accommodate scientific advances and new implementation approaches. The projects encompass the entire life cycle from definition, through design, development, integration and test, launch or deployment, operations, science data analysis and distribution. The ESSP Program Office, located at Langley Research Center (LaRC), is responsible for the management, direction, and implementation of the ESSP program elements.

2. PROGRAM GOALS AND OBJECTIVES

ESSP Program goals and objectives trace to NASA's needs, goals, and objectives. The *2011 NASA Strategic Plan* specifies six Strategic Goals for the Agency. The *2010 Science Plan: For NASA's Science Mission Directorate* (SMD Science Plan) details how SMD will turn NASA's science vision into scientific discovery. The Science Plan identifies six Earth Science Research Program Science Focus Areas: atmospheric composition, weather, carbon cycle and ecosystems, water and energy cycle, climate variability and change, and Earth surface and interior.

The goal of the ESSP Program is to stimulate new scientific understanding of the global Earth system through the development and operation of remote-sensing missions and the conduct of investigations utilizing data from these missions to address unique, specific, highly focused requirements in Earth science research.

The ESSP Program objectives to achieve this goal are to:

- provide frequent periodic opportunities for competitively selected, PI-led projects addressing NASA's high priority Earth system science outcomes, with risk posture commensurate with the classification of each project, and

- contain project and mission costs through commitment to, and control of, design, development, and operational costs within the risk and technical standards established by the Agency.

ESSP projects pursue science investigations in one or more of the six Earth Science Research Program Science Focus Areas and promote the outcomes listed above. By addressing the Science Focus Areas in innovative ways, the Earth Science community can understand variability, forcing, and response mechanisms from new perspectives. ESSP provides flexible opportunities to stimulate new scientific understanding by encouraging increased participation through smaller projects and creativity in all aspects of project development. Ideally the implementation of these lead to new strategies for acquiring and distributing datasets. ESSP projects also demonstrate measurement techniques for application on future Earth Science operational missions.

ESSP organizational objectives are designed to guide the implementation approach for the program and for the projects it contains. They are to:

- tailor the management approach of the different program elements (suborbital, orbital, instrument) consistent with the cost, schedule, technical and risk objectives of that element.
- perform assessments of ESSP projects and use lessons learned and best practices to take action to ensure success.
- promote decision making based upon clearly established cost, schedule, technical and risk parameters for each project.

3. PROGRAM ARCHITECTURE

The ESSP projects have independent science objectives and mission requirements, and yet are integrated in the program through a common funding and management structure. The projects may provide synergist coincident science measurements with other NASA projects (ESSP or non-ESSP) that enhance the overall science return.

EV has three program elements: EV Suborbital (EVS) are suborbital/airborne investigations with 5-year duration and managed to NASA Procedural Requirement (NPR) 7120.8. The EV Mission (EVM) element comprises small complete missions launched within 5 years of initiation, managed as Class D missions per NPR 7120.5, and cost-capped at \$150M. The EV Instrument (EVI) element develops spaceborne instruments for flight as missions-of-opportunity (MoO). Instruments are managed according to Class C per NPR 7120.5, limited to 5-year development duration and cost capped at \$90M. NASA separately secures and funds the access to space for these instruments. Table 3-1 summarizes the EV mission elements.

| | Duration | Cost Cap (FY14\$) | Governing NPR | Mission Class | Call Frequency |
|---------------|-----------------------|--------------------------|----------------------|----------------------|-----------------------|
| EV Suborbital | ≤ 5 years | < 30M | 7120.8 | N/A | 4 years |
| EV Mission | ≤ 5 years to launch | < 150M | 7120.5 | Class D | 4 years |
| EV Instrument | ≤ 5 years to delivery | < 90M | 7120.5 | Class C | 15 – 18 months |

Table 3-1 Earth Venture Mission Types

Specific EV missions are designated by a three-letter abbreviation: EVS, EVM, EVI, followed by a sequential numerical identifier. The first EVS missions are designated, EVS-1. The second round of EVS missions will be designated EVS-2. The pattern continues for the other mission elements as shown in Tables 3-2 and 3-3.

Table 3-2 describes the current ESSP projects and their mission status.

| Project | Date | Category/Class | Phase | Mission Status |
|-------------------------|-------------------------|----------------|---------|---------------------|
| Orbital Missions | Launch | | | |
| GRACE | March 2002 | 3/* | Phase E | Extended Operations |
| CALIPSO | April 2006 | 3/* | Phase E | Extended Operations |
| CloudSat | April 2006 | 3/* | Phase E | Extended Operations |
| Aquarius | June 2011 | 2/C | Phase E | Operations |
| OCO-2 | July 2014 | 2/C | Phase E | Operations |
| EVM-1: CYGNSS | October 2016 | 3/D | Phase C | Implementation |
| EVI-1: TEMPO | TBD | C | Phase B | Formulation |
| Sub-Orbital | First Deployment | | | |
| EVS-1: AirMOSS | June 2012 | N/A | Phase E | Operations |
| EVS-1: ATTREX | September 2011 | N/A | Phase E | Operations |
| EVS-1: CARVE | June 2011 | N/A | Phase E | Operations |
| EVS-1: DISCOVER-AQ | June 2011 | N/A | Phase E | Operations |
| EVS-1: HS3 | August 2012 | N/A | Phase E | Operations |

* Category/class was not defined during mission implementation

Table 3-2: ESSP Project Portfolio

Table 3-3 lists the current solicitation schedule as submitted in the Agency’s 2015 budget. Note that EV Instrument solicitations specify an instrument delivery date, instead of a nominal launch date. Significant milestones for EV Suborbital solicitations are also not specified, but dependent upon the PI’s proposed science campaign. This list represents a snapshot of NASA’s plans as of the publication date of this paper.

| Mission | Mission Type | Solicitation Release | Selection | Milestone |
|---------|-----------------|----------------------|-----------|-------------------|
| EVI-2 | Instrument Only | February 2012 | Q4 FY2014 | Delivery NTL 2019 |
| EVS-2 | Suborbital | February 2013 | Q1 FY2015 | N/A |
| EVI-3 | Instrument Only | Q2 FY2015 | Q1 FY2016 | Delivery NLT 2020 |
| EVM-2 | Full Orbital | Q3 FY2015 | Q2 FY2016 | Launch ~2021 |
| EVI-4 | Instrument Only | Q3 FY2016 | Q2 FY2017 | Delivery NLT 2022 |
| EVI-5 | Instrument Only | 2017 | 2018 | Delivery NLT 2023 |
| EVS-3 | Suborbital | 2017 | 2018 | N/A |
| EVI-6 | Instrument Only | 2019 | 2019 | Delivery NLT 2024 |

Q1 (Fall) = Oct-Dec, Q2 (Winter) = Jan-Mar, Q3 (Spring) = Apr-Jun, Q4 (Summer) = Jul-Sep

Table 3-3 Future ESSP Mission Solicitations

4. MISSION ELEMENT SPECIFIC MANAGEMENT APPROACH

To ensure the success of the ESSP Program, the management approach of each EV element is tailored according to the specific characteristics of the element. The following sections define each program element.

4.1. EV-Suborbital

The EV-Suborbital (EVS) element are suborbital, competitively selected, PI led investigations to conduct innovative, integrated, hypothesis, or scientific question driven approaches to pressing earth science issues.

Earth Venture Suborbital investigations have the following characteristics:

- Sustained, science-based data acquisition – Investigations advance earth science objectives through temporally sustained regional- or larger-scale measurements sufficient and necessary to prove/disprove a scientific hypothesis or address scientific questions.
- Mature technology – Investigations must use mature system technology where, at a minimum, there has been a system/subsystem model or prototype demonstration in a relevant environment.
- Cost and schedule constraints – Each suborbital Venture-class investigation must have a life cycle duration of less than or equal to five years with total investigation cost not to exceed \$30 million.

4.1.1 Principal Investigator Responsibility

An EVS PI is wholly responsible to accomplish the investigation objectives using his/her own management processes, procedures, and methods. The PI is responsible for all planning and documentation for the investigation, including science goals and objectives, baseline and threshold science requirements and investigation implementation approach.

4.1.2 Risk Management

For EVS investigations the PI identifies potential risks to successful achievement of investigation objectives within resource and schedule constraints. The PI specifies risk mitigation plans, including descopes and changes in the instrument complement, if appropriate. Generally, the nature of suborbital investigations allows for an aggressive risk posture compared to spaceflight missions. For example, investigations occur during deployments of equipment to a field location with a schedule established for taking measurements that has some margin, i.e. extra days built in. If any equipment exhibits anomalous operations or failure, the PI's team can, in some cases, perform repairs on the equipment without impacting the deployment schedule. As such, subsystem redundancy is not required, for example.

4.1.3 NASA Oversight

The PI has a large degree of freedom and responsibility to accomplish the science objectives. NASA's oversight ensures that the investigation is responsive to requirements and the constraints of NPR 7120.8 for the risk that is acceptable for suborbital investigations.

4.1.4 Reviews

EVS investigations have a minimal, streamlined review structure that includes the following events:

Investigation Confirmation Review (ICR)

The ICR generally occurs within one year of investigation selection after the PI and ESD agree upon investigation requirements, the PI matures the investigation implementation approach, and the major risks to completion of the proposed investigation have been addressed. The original proposal forms the baseline for the assessment. Following the assessment, the PI presents their investigation and responses to the assessment to ESD. The ICR will be complete when the ESD approves the investigation to continue with implementation.

Flight Readiness Review (FRR) / Operations Readiness Review (ORR)

The FRR/ORR is conducted according to NASA policies and procedures to ensure the instrumentation and aircraft are ready and safe for flight. This review does not generally assess the performance of the instrumentation.

Project Status Review (PSR)

PSRs are conducted quarterly by the investigation team and ESSP to examine the progress to date against the approved cost, schedule, and performance of the investigation.

Science Review

The purpose of the Science Review is to measure progress toward meeting the baseline and threshold requirements listed in the PLRA. This review is conducted at least annually.

4.2. EV-Mission

The Earth Venture Missions (EVM) are spaceflight missions defined to conduct innovative integrated, hypothesis or scientific question-driven approaches to pressing earth science issues. They are PI led and encompass all measurements required to achieve the scientific objectives. The Associate Administrator of the SMD is the Decision Authority and is supported by the Directorate Program Management Council that recommends approval or disapproval to the Decision Authority for entry to the next phase at Key Decision Points (KDP).

4.2.1 Principal Investigator Responsibility

An EVM PI is responsible for accomplishing the proposed mission objectives. The PI defines the technical implementation and the project management approach that drives the risk posture. The PI can exercise decisions to accomplish requirements within a trade space that includes performance margins, quality assurance, and reliability. The PI is responsible for defining and describing in the formulation agreement (Phase A/B) or project plan (Phase C/D/E/F) the standards, processes and practices for mission assurance, the mission implementation (approach & execution), the approach for performance/cost/schedule/risk management and the approach for peer reviews.

4.2.2 Risk Management

Because EVM projects can be classified as Class D, the risk tolerance is typically higher than other earth science missions (most of which are Class C). The PI implements a rigorous and accountable risk management process that identifies all mission risks and defines acceptable residual risk posture for the mission overall.

4.2.3 NASA Oversight

The PI has a large degree of freedom and responsibility to accomplish the proposed science objectives and implement the mission. NASA's oversight ensures that the project is performing to applicable standards. While Class D missions are required to comply with the requirements of NPR 7120.5, NPR 7123, the PI may propose to tailor NASA processes or use their institution's processes as long as they meet the intent of governing NASA policies. NASA exercises only essential oversight to ensure implementation is responsive to requirements and constraints of NPR 7120.5 for the risk that are acceptable for Class D implementations.

4.2.4 EVM Life Cycle Reviews

EVM reviews will be conducted as specified in NPR 7120.5 and NPR 7123.1. As a Category 3 activity with LCC < \$250M, an independent review team is established to conduct the design reviews that precede KDP events. EVM mission reviews (except KDP's) are led by a NASA Center. For missions selected that are not led by a NASA Center, LaRC will serve as the host NASA center with responsibility to satisfy Agency Technical Authority requirements.

4.2.5 Expectations to achieve a successful Class D Mission

The successful implementation of a Class D mission acknowledges a greater acceptance of known risks as long as the scientific or programmatic return is sufficiently high. The PI and the NASA authorities define and agree early in the development the risk management approach for the mission, and the PI is delegated flexibility and authority to manage the implementation, while staying within a strictly enforced budget cap. To ensure success in this environment, all stakeholders share ownership of the implementation to ensure the Class D characteristics are applied to all elements of the project. The following are some key ways NASA and the PI contribute to success:

NASA Management (Science Mission Directorate) and ESSP Program Office

- Maintain Class D risk posture through launch while verifying compliance with NASA guidelines and Directives
- Encourage innovative implementations
- Maintain vigilance against requirements creep and risk suppression

Principal Investigator

- Keep open communications on implications of Class D risk management process and mission implementation
- Manage the project execution while balancing science requirements vs. implementation cost and risk.

4.3. EV-Instrument

The Earth Venture Instrument (EVI) element develops instruments for participation on a NASA-arranged spaceflight mission of opportunity to conduct innovative, integrated, hypothesis or scientific question-driven approaches to pressing earth science issues. The NASA funded PI retains a central role on the instrument or instrument package development, integration and testing, calibration, and science operations. The Associate Administrator of the SMD is the Decision Authority and is supported by the Directorate Program Management Council that recommends approval/disapproval to the Decision Authority regarding entry to next phase at Key Decision Points.

4.3.1 Principal Investigator Responsibility

An EVI PI is responsible for accomplishing the proposed mission objectives. The PI defines the technical implementation and the project management approach that drives the risk posture. The PI can exercise decisions to accomplish requirements within a trade space that includes performance margins, quality assurance, and reliability. The PI is responsible for defining and describing in the formulation agreement (Phase A/B) or project plan (Phase C/D/E/F) the standards, processes and practices for mission assurance, the mission implementation (approach & execution), the approach for performance/cost/schedule/risk management and the approach for peer reviews.

Costs that are within the PI Managed responsibility:

- Instrument development
- Functional algorithms and ground processing system
- Science team
- Calibration/validation activities
- Operations, product generation, data analysis
- Key management and engineering staff during Phase D

Costs that are outside the PI Managed responsibility:

- Integration to NASA selected platform
- Required funding to cover the gap between instrument delivery and start of platform I&T
- Access to space

4.3.2 Risk Management

For EVI projects the risk tolerance is consistent with typical earth science projects that are either Class C or Class D, depending on the project. The PI will implement a rigorous and accountable risk management process that identifies any consequences of risk that are accepted. The PI identifies the risks and the mitigations while NASA examines consistency with the risk tolerance appropriate for the mission classification Class C or Class D.

4.3.3 NASA Oversight

The PI has a large degree of freedom and responsibility to accomplish the proposed science objectives. NASA's oversight ensures that the project is performing to applicable standards. NASA uses its standard policy and processes to evaluate the PI established management processes to ensure the rigor required for success. NASA exercises only essential oversight to ensure project implementation is responsive to requirements and constraints of NPR 7120.5 for the risk that are acceptable for the mission.

4.3.4 EV-I Life Cycle Reviews

EV-I reviews will be conducted as specified in NPR 7120.5 and NPR 7123.1. As a Category 3 activity with LCC less than \$250M, an independent review team is established in place of an IPAO SRB. EV-I reviews (except KDP's) will be

led by a NASA Center. For missions selected that are not led by a NASA Center, the LaRC will serve as the host NASA center with responsibility to satisfy Agency Technical Authority requirements.

The PI can propose tailored technical reviews subject to approval by ESD. An independent review team is established by the lead NASA Center. The chair of the review team reports findings to the PI, lead NASA Center, Program Office, and HQ. The Independent review team is involved in major reviews and not day-to-day implementation.

4.3.5 Expectations to achieve a successful “Instrument-First” Mission

The success of the EVI element hinges on the ability to mitigate the most critical instrument development risks identified during the early stages of development and prior to selecting a spacecraft and launch, and prior to making an external commitment with stakeholders on the life-cycle cost and launch date. In doing so, NASA hopes to maintain the EVI projects’ cost and schedule commitments.

5. SUMMARY

With diverse mission approaches, acute risk awareness and a steady tempo of new mission selections, NASA’s Earth Venture missions are positioned to continue NASA’s preeminence in world-class earth system science. Program management approaches tailored to the specific risk posture, implementation approach and science objectives will enable cost effectiveness and science performance to drive NASA’s decisions.