National Aeronautics and Space Administration

EXOPLANET EXPLORATION PROGRAM

Program Technology Development Plan

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1 Introduction

1.1 Purpose and Scope

The purpose of this document (hereinafter called the "Plan") is to articulate NASA's Exoplanet Exploration Program (ExEP) plan for developing technology to enable the highly challenging measurements required for the scientific investigation of exoplanets. It is the intent of this Plan to maintain a long-term focus on enabling exoplanet space missions in both visible and infrared wavelengths. The Plan lays out the broad technical challenges to be addressed, specifies the programmatic approach to prioritizing the areas to be pursued in relation to the scientific strategy adopted for the Program, and describes how the technology program will be conducted.

This Plan responds directly to the ExEP Program Plan [1] and is expected to remain stable over several years. Changes, however, are expected on a shorter time scale both in technology evolution as well as scientific priorities. Therefore, an annual "Technology Plan Appendix" to this Plan will specify the details of technology tasks and needs over a rolling five-year period. Appendix C in this document contains the link to the most current version of the ExEP Technology Plan Appendix.

In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will," and descriptive material by "is."

1.2 ExEP Objectives

The ExEP responds to the requirements, strategic goals, and objectives identified in the National Space Policy of 2010[6] the 2014 NASA Strategic Plan1 and the 2014 NASA Science Plan [2]. The 2014 Update of the Astrophysics Implementation Plan [3] guides the ExEP implementation strategy within the Astrophysics Division (APD) of the Space Mission Directorate (SMD). Looking further out, the Program's future technology needs are highlighted in the APD's 30-year roadmap Enduring Quests, Daring Visions [4].

Section 1.2 of the ExEP Program Plan [3] describes how these governing documents define the purpose of the Program, specifically:

- Discovering planets around other stars
- Characterizing their properties
- Identifying candidates that could harbor life

1.3 Role of ExEP Technology Development Program

The 2010 Decadal Survey recommended the creation of a New Worlds Technology Development Program to advance the technological readiness of the three primary starlight suppression architectures: coronagraphs, starshades, and interferometers. The Survey further recommended that if the scientific groundwork and design requirements were sufficiently clear that an architecture down-select should be made and technology development investments over the latter half of the decade be focused on the selected architecture with the goal of bringing it to maturity in time for consideration by the 2020 Decadal Survey. From the outset of the decade, infrared interferometry has been prioritized lower as the basis for a New Worlds Mission than either the coronagraph or starshade architectures because of its lower degree of technical maturity and general astrophysics applicability. On the other hand, the current decade has seen sufficient advances in the technology readiness of both coronagraphs and starshades that a further downselect is no longer required, leaving the final starlight suppression decision to a future direct imaging exoplanet project. In fact, the two architectures may be complimentary, and the Program is on a trajectory to bring both to a level of technology readiness suitable for consideration by the 2020 Decadal Survey. Consequently, both architectures are being considered for large-scale mission concepts leading up to the next Survey.

Development of technologies for future exoplanet missions is primarily supported through two programs solicited annually under Appendix D of the omnibus Research Opportunities in Space and Earth Sciences (ROSES) NASA

Research Announcement (NRA): (1) the Astrophysics Research and Analysis (APRA) program; and (2) the Technology Development for Exoplanet Missions (TDEM) component of the Strategic Astrophysics Technology (SAT) program. The complimentary scope of these two programs is best described in terms of NASA's 9-level Technology Readiness Level (TRL) classification scheme, which is described in detail in Appendix E of NASA Procedural Requirements (NPR) 7123.1B [6]. In these terms, the APRA program supports low TRL technology research (TRL ~ 1 - 3), while the SAT/TDEM program supports the maturation of mid-range TRL technologies (TRL ~ 4 – 6). The SAT/TDEM program represents the implementation of the 2010 Decadal Survey's recommended *New Worlds Technology Development* Program, and is described in greater detail in Section 3.2.3 of this document.

Technology development may also be advanced when the work, approved by APD, is directed to a project. Examples are the re-programming of coronagraph TDEMs to the WFIRST Study in 2013 and starshade TDEMs re-programmed to the Starshade Technology Project in 2016.

The Program technology objectives described in this Plan are developed by identifying the technologies and performance levels needed to implement future exoplanet missions. These technology needs are captured in the form of technology gaps, which are updated annually and published as an appendix to this plan. The list of prioritized technology gaps is both peer reviewed and reviewed by the independent ExEP Technology Assessment Committee (ExoTAC) (see section 3.2.3).

2 Documentation

The table below provides the requirements, policies, processes, and procedures that flow from the source documents (most notably NPR 7120.8, NASA Research and Technology Program and Project Management Requirements [10]) through the Project plans to this document. NPR documents and NASA Policy Documents (NPD) are available at http://nodis.hq.nasa.gov.

This document describes the processes for technology management to be used by the ExEP and is expected to remain relatively constant over time. Appendix C of this document, the ExEP Technology Plan Appendix, is updated annually and specifies the details of technology tasks and needs over a rolling five-year period.

2.1 Applicable Documents

NPR 7120.8	NASA Research and Technology Program and Project Management Requirements[10]
JPL ID: D-62841	Exoplanet Exploration Program Plan, JPL Doc. No: D-62841, Rev A, November 20, 2015

3 Programmatic Framework

3.1 Roles and Responsibilities

3.1.1 Exoplanet Community

The external exoplanet science and technology communities are key stakeholders for the Program technology development activities. Therefore, the ExEP seeks to have community engagement in the direction and priorities of the Technology Program. The community participates directly in the Program technology process through competitively-selected tasks (e.g. SAT/TDEM investigations), inputs into the technology gap lists, and directed activities targeting specific technology development goals (e.g. WFIRST coronagraph technology development, Starshade Technology Project). The Program also seeks input and evaluations of the process described here from the stakeholder community both formally, through the Exoplanet Program Analysis Group (ExoPAG) and informally through communication and feedback at community meetings and scientific and technical conferences.

3.1.2 ExEP Program Scientist and Program Executive

The roles of the ExEP Program Executive (PE) and Program Scientist (PS) are described in the ExEP Project Plan sections 1.5.3.3 and 1.5.3.1, respectively. In addition, the ExEP PS acts as the Program Officer for the openly-competed TDEM program.

3.1.3 Exoplanet Program Analysis Group

The Astrophysics Subcommittee (APS) of the Science Committee of the NASA Advisory Council is one of the formal channels for community input. The APS, together with NASA HQ, have chartered an Exoplanet Program Analysis Group (ExoPAG) that provides a forum for broad involvement of the scientific community in discussing and analyzing various issues of importance to exoplanet science and exoplanet space missions and the enabling technology, as tasked by the APS and NASA. The ExoPAG is governed by an Executive Council (EC).

The ExEP Technology Gap List will be presented to the EC and ExoPAG at least two times a year. The first in June opening the annual request for community inputs and the second in November presenting the conclusion of the Technology Selection and Prioritization Process (see section 3.2.2).

3.1.4 Principal Investigators

Technology efforts solicited through the competed SAT/TDEM program will have a technology Principal Investigator (PI). The PI is responsible for defining the technology development goals and approach, preparing hardware elements, defining experiments to demonstrate the technology, and, with the ExEP TDM, to ensure any promised ExEP resources are available. Examples of resources can be personnel, facilities, hardware, and modeling capabilities.

3.1.5 ExEP Technology Development Manager

The Technology Development Manager (TDM) has primary responsibility to:

- Manage and coordinate the hardware and analysis infrastructure at JPL to support technology development by competitively selected PIs and directed project technology managers;
- Support the PCT in reviewing plans and final reports of each TDEM;
- Interface with the Program Manager and the Program Business Manager to develop inputs for Program technology funding, planning, and integration or to resolve delivery issues;
- Establish and perform technical and resource management oversight of technology contracts and task orders;
- Perform independent evaluation of technology delivery metrics, schedule, cost data, management, and issues;
- Identify risks and mitigations, liens, and threats that could result in cost growth or schedule delays and identify solutions;
- Provide monthly project assessment to the Program Manager and PE;
- Conduct reviews with independent panels of experiment plans and results to validate technology readiness;
- Manage the Technology Selection and Prioritization Process (see section 3.2.2).

3.1.6 ExEP Program Chief Technologist

The responsibilities of the Program Chief Technologist (PCT) are captured in the ExEP Project Plan (section 1.5.3.8), and repeated here. The Program Chief Technologist (PCT) has primary responsibility to:

- Maintain up-to-date awareness of scientific and technology developments in the field;
- Integrate the exoplanet observing techniques and their requirements for enabling technologies with the technology development activities of ExEP by identifying requirements for future technology development;
- Prepare an annual appendix update to the ExEP Technology Development Plan, which presents a summary of current state of the art and prioritized topics for future technology development;
- Perform independent evaluation of technical metrics for Technology Readiness Level (TRL) and comparisons of technology progress;
- Support the SMD Chief Technologist and APD Technology Lead in developing integrated Directorate and Division technology plans;
- Represent the Program Office to the Space and Technology Mission Directorate (STMD) through the APD Technology Lead;
- Support the PM, PCS, ExEP Executive, and ExEP Scientist in liaison functions with the technology community;
- Provide technology overview, analysis, and support functions in support of the ExEP PM;
- Provide ExEP technology status to the SMD advisory bodies and technology communities as necessary;
- Oversee and support ExEP project technologists in their responsibility for the scientific merit and success of their individual missions;

- Serve as liaison to the ExEP PCS and JPL Engineering Divisions, and the ExEP technical staff on technology matters on behalf of the PM;
- Serve as liaison between the Program Manager and Chief Technologists at JPL and at other NASA Centers;
- Serve as Program point of contact for the ExoTAC;
- Conduct reviews with independent panels of experiment plans and results to validate technology readiness; and
- Co-chair (along with the ExoTAC Chairperson) the review board to approve Technology Development for Exoplanet Mission (TDEM) experiment plans and results to validate technology readiness.

3.1.7 Exoplanet Technical Analysis Committee

The Exoplanet Technical Analysis Committee (ExoTAC) is a group of 5-7 engineers and scientists selected by the NASA ExEP PS to be the main reviewing body for the SAT/TDEM Milestone Whitepapers and Final Reports (described in Section 3.2.4.2 of this document). They perform two primary functions:

1) provide independent assessment and approval of Milestone Whitepapers at the outset of competed technology development tasks; and
2) provide an independent assessment and approval of the Milestone Final Reports submitted upon completion of the milestone(s).

The ExoTAC can also be the reviewing body for key formulation technology milestone definitions and reviews. The ExoTAC has served in this capacity for the WFIRST coronagraph and wide-field imaging detector technology milestone reviews. They will do the same for the Starshade Technology Project. The TAC also serves in reviewing the ExEP Technology Selection and Prioritization Process ensuring there is community input and the process reflects the technology needs of the APD missions (section 3.2.2)

The Chair will be responsible for coordinating ExoTAC activities with the other board members. Members of the ExoTAC may be drawn from NASA centers as well as academia and the private sector. Their membership may be supplemented on an interim basis by subject matter experts (SMEs) as the need arises. External SMEs may be recruited directly by the ExoTAC Chair or by the PCT with concurrence of the ExoTAC Chair.

3.2 The Technology Development Process

The motivation and objectives of the ExEP technology program are to identify the technologies that will enable or enhance NASA's future exoplanet missions, and to facilitate their maturation to be ready when needed. These technologies are identified through technology gap lists and communicated through the annual Technology Plan Appendix and the ExoPAG general announcements. Some are funded through the SAT/TDEM grants program and through strategic funding approved by APD through the annual Program Planning and Budgeting Exercise (PPBE). Others are potentially funded through directed projects such as WFIRST and the Starshade Technology Project. Some technologies may be funded external to the Program, for example by industry, academia, or other NASA centers and institutions such as the STMD.

As shown in Figure 2, the top-level science goals of NASA's APD flow from the priorities of the NRC's Decadal Survey of Astronomy and Astrophysics. The APD's response to the Decadal Survey is captured in the Division's Astrophysics Implementation Plan (AIP), which guides the formulation of the ExEP Technology Plan, which itself (together with the annually-updated Technology Plan Appendix) provides the programmatic priorities that inform the selection of SAT/TDEM proposals and other ExEP technology development investments.

Other sources that will guide the formulation of the Technology Plan and its Appendix other than the AIP are missions selected both through open competitions (e.g. probe-class missions), directed missions (e.g. WFIRST, Starshade Technology Project), and future potential exoplanet missions described in the APD 30-yr Roadmap.

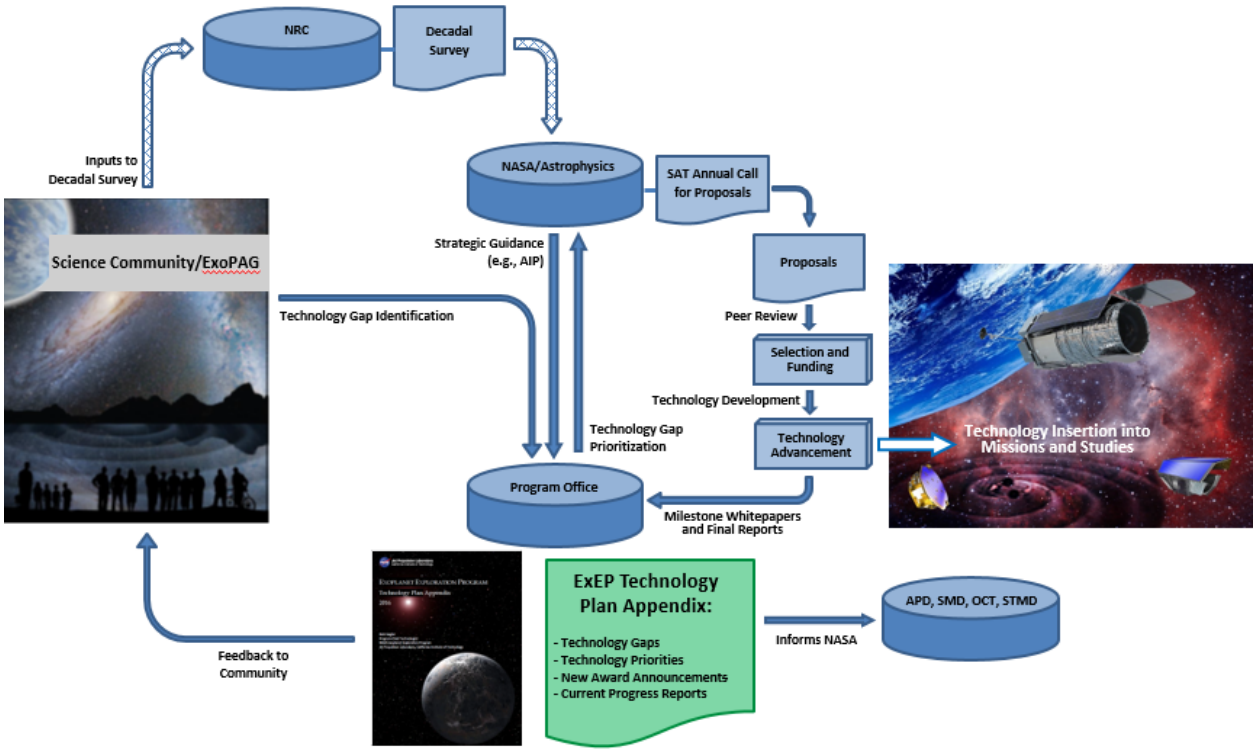

Figure 2 Technology Development Process

3.2.1 Technology Gaps

The ExEP technology needs will be captured in technology gap lists (TGLs). These lists serve to identify and signal to the broader community where technology development is needed over the next 3-5 years. They also serve in informing the PS in the annual writing of the TDEM Call and its Amendments.

A technology gap is defined as the difference between what is needed in order to enable (to make possible) a specified future mission, and the current state-of-art. In some cases, there may also be technologies that enhance (to improve), an exoplanet mission's capabilities. Both types of technologies will be considered. Not all new mission components and designs are necessarily new technology as some may be considered "standard engineering". Figure 3 illustrates the process which will be used to distinguish what is a new technology and what is challenging but standard engineering. The ExEP will use TRL levels as defined in Appendix E of NPR 7123.1B [6], NASA Systems Engineering Processes and Requirements.

3.2.2 Technology Selection and Prioritization Process

Every June, the TDM will email the website link to the updated TGLs to members of the ExoPAG, who are invited to review and submit additional technology capability needs. A Technology Capability Input Form assists the members in formulating their suggestions. This in essence opens the annual "technology input" window, which remains open until the end of August. The TGLs and the Technology Selection and Prioritization Process will be presented at the Summer ExoPAG meeting, and then will be posted to the ExEP Technology website.

The current ExEP TGLs capture and prioritize those technologies which are considered to "enable" and "enhance" the direct imaging and spectral characterization of exoplanets. *Enable* signifies those technologies without which NASA exoplanet missions would not meet their science objectives; to make possible. *Enhance* signifies those

technologies that will improve (make better) the ability to directly image and characterize these exoplanets. Examples may be those technologies that promise to improve inner working angles or reduce integration times.

During the input period, the TDM and/or his representative will interact with those who submit new technology needs to determine whether the enabling or enhancing criterion was met along with defining the state-of-art and needed capabilities. Those technology needs not falling into this category but still evaluated to advance exoplanet science will not appear on the TGL but will be captured and tracked in the annual Technology Plan Appendix. They will be evaluated annually to assess any changes in capabilities or programmatic importance.

The criteria for selecting and prioritizing the technology gaps will be peer-reviewed every September by members of the ExEP technology development team and programmatic leadership, technology and science members of the Physics of the Cosmos and Cosmic Origins programs, and the PS. This is intended to provide wider technical and programmatic inputs from within the APD. The results shall later undergo independent review by the ExoTAC. The TDM or his designate manage this process.

The purpose of prioritizing the gaps on the lists is to ensure that the highest ranked technologies receive the greatest attention. The TGLs shall be prioritized based on a clear set of criteria that include weighted impact, urgency, and trend and the criteria and their gradations shall be re-evaluated annually. The impact criterion measures the importance a technology may have towards achieving the science goals of a mission or minimizing its risk. The urgency criterion allows technology development to be prioritized to meet specific decision and review dates such as missions gate reviews and Decadal Surveys. Those studies or missions already in Formulation or Pre-Formulation will typically have the highest urgency. Trend allows consideration of outside development efforts. The trend is high when no one else is advancing a particular technology gap and low when the gap is expected to reduce or even go away due to the efforts of others. For example, if an outside non-NASA program is developing applicable segmented telescope mirrors or ultra-low noise visible detectors, then the trend could be assessed low and hence contribute to a lower prioritization.

The same membership that annually peer reviews and formally reviews (the ExoTAC) the selection and prioritization criteria described above will also review the technologies that were selected (and not selected) and prioritized by the ExEP PCT, TDM, and PCS. The final updated TGLs shall be posted onto the ExEP Technology website. It is these lists that are included in the annual Technology Plan Appendix. The final TGLs will be presented at the Winter ExoPAG meeting and shall be communicated via email to the ExoPAG members. The schedule for this annual process is captured in Figure 5.

During the exoplanet community feedback period between June and August, the TDM will evaluate progress against each of the technology gaps and assesses whether alternative development paths are being advanced. The result of this assessment is captured in the annual Technology Plan Appendix.

The PCT will evaluate the opportunity to remove or retire technology gaps. Gaps can be removed because the performance goals have been demonstrated through experimentation or flight heritage, or because the technology gap has been reduced to an engineering challenge. Figure 3 captures this decision-making process (reproduced from "Technology Readiness Levels and Technology Readiness Assessment Guideline," authored by the JPL Office of the Chief Technologist [16]). Gaps are also removed due to programmatic changes in targeted missions or strategy.

Retiring a technology gap due to successful demonstrations will require a formal review. The PCT enrolls the ExoTAC to preside over the review, but can also take advantage of the results from other formal reviews performed outside the ExEP. For example, if the European Space Agency flight qualifies an ultra-low noise visible detector, the qualification documentation may serve as input into the ExoTAC review to remove this element from one of the ExEP TGLs.

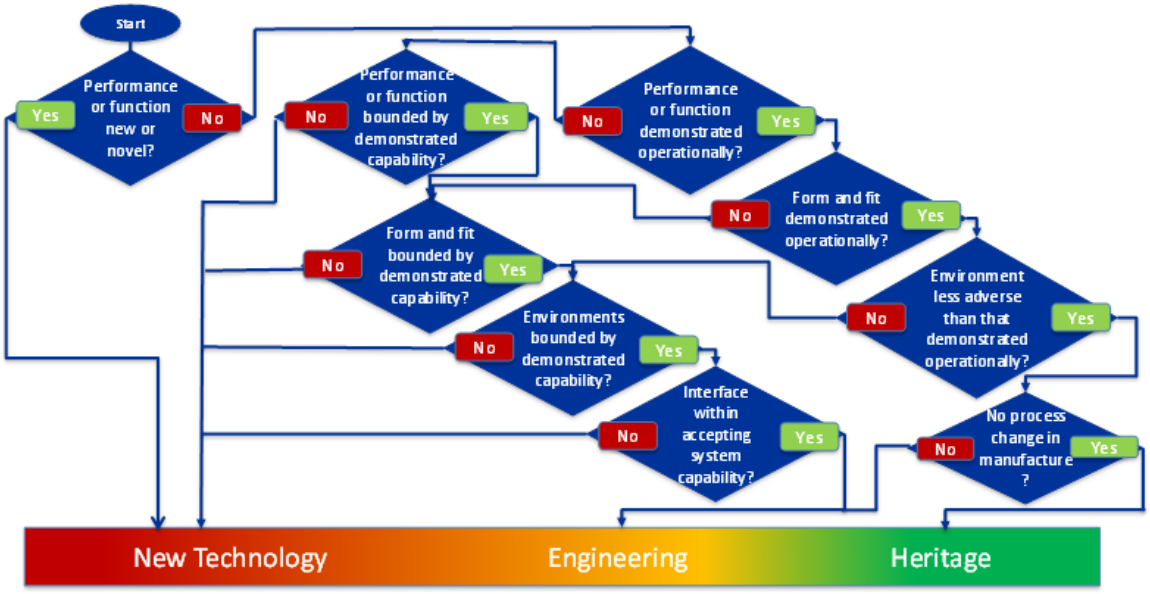

Figure 3 Flow chart to determine which of three bins - new technology, engineering, or heritage - an element is assigned to (from Frerking et al, JPL Rules, DocID 78797)

3.2.3 Technology Plan Appendix

The PCT will produce an annual appendix to the ExEP Technology Development Plan (Appendix C) based on the latest budget projections and policy direction provided by NASA APD. The Appendix will provide stakeholders with a current snapshot of ongoing ExEP technology development activities (both strategic and competed), as well as plans for the succeeding five-year period. This Appendix will capture the specific missions and mission concepts the Program aligns its technology development focus to, present the most recent technology results, and communicate the near-term technology needs and priorities of the ExEP. The Plan Appendix will contain three components:

1. The status of ongoing activities, and plans for continuing, modifying or terminating those activities based on their progress and adjusted priorities;
2. A description of latest ExEP technology development needs and priorities, which will be reflected in the next SAT/TDEM solicitation; and,
3. Longer-term guidance for future directions.

The Plan's Appendix C also publishes the TGLs presented at the summer ExoPAG meeting which communicates to the exoplanet community the desired technologies that enable/enhance the direct imaging and characterization of exoplanets in the habitable zone of their stars. Equally as important, the Appendix will also list the technologies that will also benefit exoplanet science but will not receive NASA funding. It is posted to the ExEP Technology homepage.

3.2.4 Technology Development for Exoplanet Missions

3.2.4.1 The SAT/TDEM Solicitation

In response to the recommendations of Astro2010, NASA's APD has created the SAT/TDEM program to solicit investigations that undertake focused development of technologies that will enable a future strategic "*New Worlds Mission"*, capable of conducting imaging and spectroscopy of rocky planets in the habitable zones of stars in the solar neighborhood. More specifically, the SAT/TDEM program is designed to advance the mid-range TRL maturation ($3 < TRL \leq 6$) of key technologies to the point where they can be infused into a flight mission with mitigated risk.

SAT/TDEM solicitations are issued nominally each February (see Figure 6) as part of the omnibus ROSES NRA, with proposals due approximately March of the following year. Because of the lag time between the release of the solicitation and the submission of proposals, the SAT/TDEM Program Officer, in consultation with the PCT, may issue an Amendment to the original solicitation to reflect the evolving short and long term needs of the ExEP.

The selecting official for SAT/TDEM investigations is the APD Division Director. Implementation and coordination of the selected SAT/TDEM investigations is managed by the ExEP TDM following a formal process for quantifying, tracking, and documenting TRL advancement of the subject technologies. This process is described below.

3.2.4.2 TDEM Management Process

The ExEP model for TDEM advancement of technologies is founded on the following three interrelated components:

1. Demonstration of milestone performance must be stable and repeatable, thereby demonstrating that the result is not spurious or transient;
2. Modeling of the milestone demonstration must be consistent with the demonstrated result, thereby establishing that the behavior is thoroughly understood; and
3. Error budget for the milestone must be consistent with the models.

A particular technology development task may involve all of these elements or only a subset of them. All SAT/TDEM investigations are required to follow a formal process that has been developed to objectively document the readiness of a given technology and its advancement. Under this process, each SAT/TDEM PI shall deliver two key documents to the ExEP over the course of their investigation:

1. A Milestone Whitepaper (WP) that describes the test plan and quantitative milestones to be achieved; and
2. A Milestone Final Report (FR) that summarizes the results of the investigation and documents the "final" state of the associated technology.

Both the Milestone WPs and the Milestone FRs shall be reviewed by the ExoTAC and revised as necessary prior to acceptance by the ExEP. With the permission of the PI, approved WPs and FRs are posted on the ExEP Technology website.

The ExEP Technology Development Manager or his/her designate will manage the SAT/TDEM process on behalf of the ExEP PS and PCT. The process flow of a typical SAT/TDEM investigation is illustrated in Figure 4.

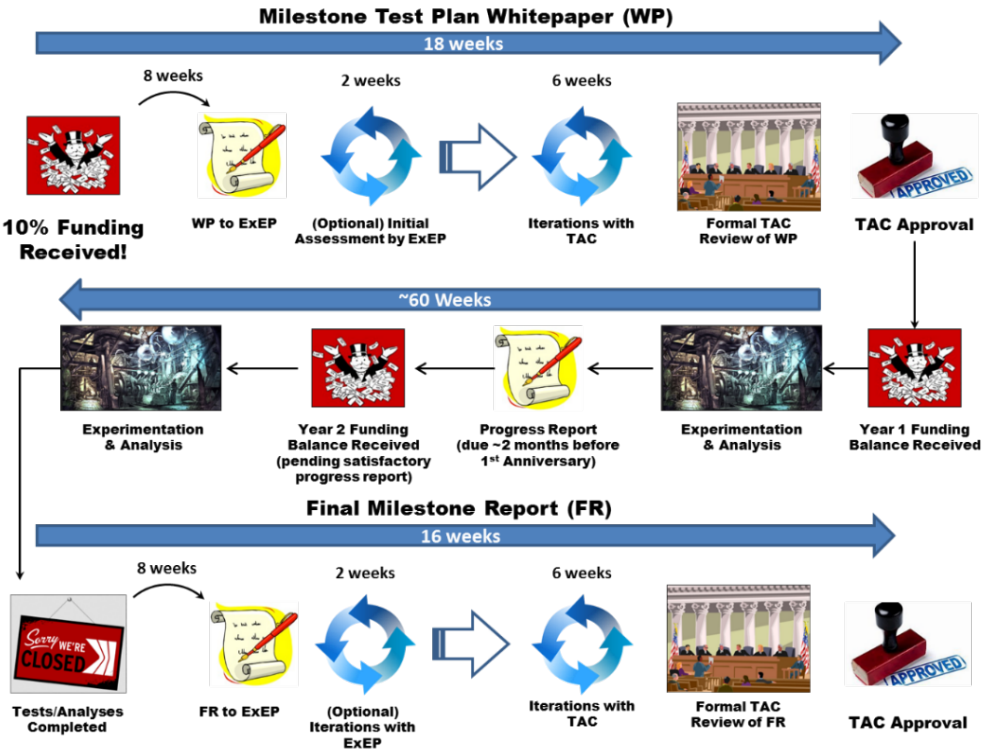

Figure 4 TDEM Process Flow

Within a few weeks following a SAT/TDEM award, the Technology Development Manager or his/her designate will coordinate a "Welcome TDEM" meeting to brief the PI on the established processes and funding schedule shown in Figure 4. The PI will receive an initial increment of funding (typically 10% of the first year award) to support the development of their Milestone WP. The WP shall fully articulate the technical parameters to be demonstrated, the measurements to be made, and analyses to be performed. It shall also identify the hardware and software needed to conduct their technology development as well as the associated schedule and risks (as well as appropriate mitigation plans).

The WP may be reviewed by the ExEP, but shall be reviewed by the ExoTAC, and will be iterated until agreement is reached between the PI and the ExoTAC. Upon TAC approval of the Milestone WP, the balance of year one funding will be made available to the PI, and the investigation may begin. In the case that agreement is not reached, the TDEM Program Officer shall be the final arbitrator.

Upon completion of the work the PI shall submit their Milestone FR showing that the milestone(s) success criterion has (or has not) been met. The FR may be reviewed by the ExEP, but shall be reviewed by the ExoTAC, and will be iterated until agreement is reached between the PI and the ExoTAC members. In the case that agreement is not reached, the TDEM Program Officer shall be the final arbitrator.

3.2.5 Technology Calendars

The calendar in Figure 5 shows the annual milestone dates required for key activities within the Technology Selection and Prioritization Process; the calendar in Figure 6 shows the annual milestone dates associated with the TDEM process.

Activity	Resp	J	F	M	A	M	J	J	A	S	O	N	D	J
ExEP Technology Needs and Prioritization Process														
TNPP and TGL Presented to ExoPAG EC	TDM						1st Tue							
TGL Window Opens	TDM						day after							
TGL Presented at Summer ExoPAG	TDM						mid-month							
TGL Window Closes									last Fri					
TGL Prioritization Criteria Peer Review	TDM									early				
TGL Prioritization Criteria Review	TDM									mid-month				
TGL Community Input Asessment Peer Review	TDM										early			
TGL Community Input Asessment Review	TDM										mid-month			
Present Final TGL to ExoPAG EC and PS	TDM											1st Tue		
Provide Input to TDEM Amendment	PCT, PS,											mid-month		
Update Technology Plan Appendix	TDM												mid-month	
TGL Presented at Winter ExoPAG	TDM													1st week

Figure 5 Technology Selection and Prioritization Process Calendar

		TDEM Year												TDEM Year plus 1							
Activity	Resp	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
TDEM Process																					
Solicitation Released	PS		mid-month																		
Amendment Posted	PS												mid-month								
Pre-Proposal Briefing Telecon	PS													mid-month							
Proposal Due																mid-month					
Proposals Selected	PS																				by month end

Figure 6 TDEM Calendar

3.3 Technology Leveraging

To leverage potential synergies and collaborations, the PCT and TDM of the APD's two other programs – Physics of the Cosmos and Cosmic Origins – are copied on the distribution of the TGLs and, requested to participate in the consolidation of the TGLs as well as their prioritization criteria and ranking. Correspondingly, the ExEP PCT and TDM are members of the two programs' Program Technology Management Board which clarifies and prioritizes the technology gaps relevant to those programs.

In addition, the ExEP PCT will coordinate the presentation of the Program's technology status and needs annually at a conference or workshop with the purpose of engaging a larger technology community. Possible venues may be sessions of the AAS, ExoPAG, and starlight suppression workshops.

In the case that a technology will be transferred from a development stage to a manufacturing stage, so as to be inserted into an "end-system", the PCT will request that a Technology Transition Plan be created. This plan will identify the

scope, schedule, potential costs and risks (along with appropriate risk mitigations) associated with this technology transition.

In the case that a technology will be transferred to a study or project office, a technology development plan will be required to mature that technology to a minimum of a TRL-5 level. TRL maturation from TRL-5 to TRL-6 are typically funded under a project during that project's Phase A (or Phase B).

3.4 Export Compliance

The ExEP TDEM SE will be responsible for ensuring that all TDEM processes, products, information, and information transfer comply with all requirements contained in the ExEP Export Compliance Management Plan (see section 3.18 of the ExEP Plan).

APPENDIX A: REFERENCES

1. Astrophysics Implementation Plan (update) - December 2014, http://science.nasa.gov/media/medialibrary/2015/01/16/ImpPlan_Rev2_15Apr2013_LL_150107TAGGED.pdf
2. 2010 Astrophysics Decadal Survey, New Worlds, New Horizons in Astronomy and Astrophysics, http://science.nasa.gov/astrophysics/special-events/astro2010-astronomy-and-astrophysics-decadal-survey/
3. Exoplanet Exploration Program Plan, JPL Doc. No: D-62841, Rev A, November 20, 2015. https://alpha-lib.jpl.nasa.gov/docushare/dsweb/Get/Document-1544763/ExEP%20Plan%20with%20signatures%202016-05-06.pdf
4. Enduring Quests, Daring Visions; NASA Astrophysics in the Next Three Decades, http://science.nasa.gov/media/medialibrary/2013/12/20/secure-Astrophysics_Roadmap_2013.pdf
5. NASA 2014 Science Plan, http://science.nasa.gov/media/medialibrary/2015/06/29/2014_Science_Plan_PDF_Update_508_TAGGED.pdf
6. NPR 7123.1B, NASA Systems Engineering Processes and Requirements, April 2013, http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001B_/N_PR_7123_001B_.pdf
7. NASA, Science Mission Directorate Management Handbook, October 31, 2013.
8. NPD 7500.1D, Program and Project Life-Cycle Logistics Support Policy, March 2, 2015, http://nodis3.gsfc.nasa.gov/npg_img/N_PD_7500_001D_/N_PD_7500_001D__main.pdf.
9. Research Opportunities in Space and Earth Sciences (ROSES) – 2015, http://solicitation.nasaprs.com/ROSES2015
10. NPR 7120.8, NASA Research and Technology Program and Project Management Requirements, April 18, 2013, http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_0008_/N_PR_7120_0008_.pdf
11. NPR 7500.2, NASA Technology Transfer Requirements, December 19, 2014, http://nodis3.gsfc.nasa.gov/npg_img/N_PR_7500_0002_/N_PR_7500_0002_.pdf
12. NPR 2200.2, Requirements for Documentation, Approval and Dissemination of NASA Scientific and Technical Information, December 9, 2014, https://standards.nasa.gov/documents/viewdoc/3315379/3315379
13. NPR 1080.1, Requirements for the Conduct of NASA Research and Technology (R&T), May 2008, http://nodis3.gsfc.nasa.gov/npg_img/N_PR_1080_001A_/N_PR_1080_001A_.pdf
14. NPD 2200.1C, Management of NASA Scientific and Technical Information, December 9, 2014, http://nodis3.gsfc.nasa.gov/npg_img/N_PD_2200_001C_/N_PD_2200_001C__main.pdf
15. 2014 NASA Strategic Plan, https://www.nasa.gov/sites/default/files/files/FY2014_NASA_SP_508c.pdf
16. Frerking et al, "JPL Institutional Technology Readiness Levels and Technology Readiness Assessment Guideline", JPL DocID 78797, April 4, 2016. http://rules.jpl.nasa.gov/cgi/doc-gw.pl?docid=78797
17. National Research Council. *New Worlds, New Horizons in Astronomy and Astrophysics*. Washington, DC: The National Academies Press, 2010.

APPENDIX B: ACRONYM LIST

AAS	American Astronomical Society
AFTA	Astrophysics-Focused Telescope Assets
AIP	Astrophysics Implementation Plan
APD	Astrophysics Division (NASA HQ)
APRA	Astrophysics Research & Analysis
APS	Astrophysics Subcommittee
DARPA	Defense Advanced Research Projects Agency
EC	Executive Committee
ECMP	Export Compliance Management Plan
ExEP	Exoplanet Exploration Program
Exo-C	Exo-Coronagraph
Exo-S	Exo-Starshade
ExoPAG	Exoplanet Program Analysis Group
ExoTAC	Exoplanet Technical Analysis Committee
FR	Milestone Final Report
HEA	Headquarters Export Administrator
HQ	NASA Headquarters
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NRA	NASA Research Announcement
NRC	National Research Council
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
NWNH	New Worlds, New Horizons
PCS	Program Chief Scientist
PCT	Program Chief Technologist
PDLM	NASA Product Data and Life-Cycle Management
PDR	Preliminary Design Review
PE	NASA Program Executive
PI	Principal Investigator
PM	Program Manager
PPBE	Program Planning and Budgeting Exercise
ROSES	Research Opportunities in Space and Earth Sciences
SAT/TDEM	Strategic Astrophysics Technology/ Technology Development for Exoplanet Mission
SBIR	Small Business Innovation Research
SMD	Science Mission Directorate
SME	Subject Matter Expert
SPIE	Society of Photo-Optical Instrumentation Engineers
STMD	Science and Technology Mission Directorate
STTR	Small Business Technology Transfer
TAC	Technical Assessment Committee
TBS	to be supplied
TDEM	Technology Development for Exoplanet Mission
TDM	Technology Development Project Manager
TGL	Technology Gap List
TRL	Technology Readiness Level
WFIRST	Wide-Field Infrared Survey Telescope
WP	Milestone Whitepaper

APPENDIX C: EXEP TECHNOLOGY PLAN APPENDIX

The annual Technology Plan Appendix to this Plan will specify the details of technology tasks and needs for a rolling five-year period. It is updated annually. More details can be found in Section 3.2.2 of this document.

The most recent Technology Plan Appendix will be found at https://exoplanets.nasa.gov/exep/technology/