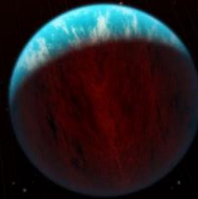
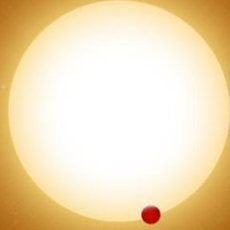




**Jet Propulsion Laboratory**  
California Institute of Technology



# EXOPLANET EXPLORATION PROGRAM

## Science Development Plan

### 2018

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JPL Document No: 1735624

Cover Art Credit: NASA/JPL-Caltech. Artist conception of the K2-138 exoplanetary system, the first multi-planet system ever discovered by citizen scientists<sup>1</sup>. K2-138 is an orangish (K1) main sequence star about 200 parsecs away, with five known planets all between the size of Earth and Neptune orbiting in a very compact architecture. The planet's orbits form an unbroken chain of 3:2 resonances, with orbital periods ranging from 2.3 and 12.8 days, orbiting the star between 0.03 and 0.10 AU. The limb of the hot sub-Neptunian world K2-138 f looms in the foreground at the bottom, with close neighbor K2-138 e visible (center) and the innermost planet K2-138 b transiting its star. The discovery study of the K2-138 system was led by Jessie Christiansen and collaborators (2018, *Astronomical Journal*, Volume 155, article 57).

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

This document has been cleared for public release (CL#19-0790).

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<sup>1</sup> <https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA22088>

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## Table of Contents

<b>1. Introduction.....</b>	<b>5</b>
1.1. Purpose and Scope .....	5
1.2. ExEP Objectives .....	5
1.3. Role of Science Investigations in the ExEP .....	6
<b>2. Documentation .....</b>	<b>6</b>
2.1. Applicable Documents .....	6
<b>3. Programmatic Framework.....</b>	<b>7</b>
3.1. Roles and Responsibilities .....	7
3.1.1. External Exoplanet Community .....	7
3.1.2. Exoplanet Program Analysis Group .....	7
3.1.3. Principal Investigators of NASA Exoplanet Science Investigations.....	8
3.1.4. NASA Exoplanet Science Institute (NExSci).....	8
3.1.5. ExEP Program Scientist and Program Executive.....	9
3.1.6. ExEP Program Chief Scientist .....	9
3.1.7. ExEP Project Scientists.....	10
3.2. Program Science Planning .....	10
3.2.1. Science Gaps.....	11
3.2.2. Science Plan Appendix .....	11
3.2.3. Science Proposal Solicitations .....	11
3.2.4. Science Gap List Calendar.....	12
<b>4. Appendix.....</b>	<b>13</b>

## 1. Introduction

### 1.1. Purpose and Scope

The purpose of this *Program Science Development Plan* (hereinafter called the “Plan”) is to articulate NASA’s Exoplanet Exploration Program (ExEP) plan for 1) obtaining the scientific information needed to define the science requirements for future exoplanet space missions; and 2) performing the precursor and follow-up investigations needed to interpret the results of current/upcoming missions in support of Program objectives. This Program Science Development Plan reviews ExEP’s objectives, the role of scientific investigations in ExEP, important documentation, and the programmatic framework for ExEP science. The Program Science Development Plan supplements two additional documents – the *ExEP Science Gap List* (SGL) and *ExEP Science Plan Appendix* (SPA). Together these three documents comprise the *ExEP Science Plan*. These three documents supporting the ExEP Science Plan respond directly to the ExEP Program Plan (Exoplanet Exploration Program, 2015).

The goal of the ExEP Science Plan is to show how the Agency can focus its science efforts on the work most needed to realize the goal of finding and characterizing habitable exoplanets, within the context of community priorities. The Science Plan Appendix lays out the scientific challenges that must be addressed and describes how the science program will be conducted. The Science Gap List summarizes the main science gaps and presents them in a concise tabulated form. Changes are expected on a shorter time scale as new scientific results refine the questions and approach need to achieve Program objectives. While the Program Science Development Plan is expected to remain stable over many years, the Science Plan Appendix will be updated as needed every two years, and the Science Gap List will be updated annually (see Sec. 3.2).

### 1.2. ExEP Objectives

The ExEP responds to the requirements, strategic goals, and objectives identified in the National Space Policy of 2010 (National Space Policy of the United States of America, 2010), Astro2010: The Astronomy and Astrophysics Decadal Survey *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH) (Committee for a Decadal Survey of Astronomy and Astrophysics; National Research Council, 2010), the 2018 NASA Strategic Plan (National Aeronautics and Space Administration, 2018), the 2014 NASA Science Plan (National Aeronautics and Space Administration, 2014), and the 2016 mid-decadal report *New Worlds New Horizons: A Mid-Term Assessment* (NWNH:AMA) (Committee on the Review of Progress Toward the Decadal Survey Vision in New Worlds, New Horizons in Astronomy and Astrophysics; Space Studies Board; Board on Physics and Astronomy; National Academies of Science, 2016). The 2016 Update of the Astrophysics Implementation Plan (National Aeronautics and Space Administration, 2016) guides the ExEP implementation strategy within the Astrophysics Division (APD) of the Space Mission Directorate (SMD). Looking further out, the Program’s future science needs are highlighted in the APD’s 30-year roadmap *Enduring Quests, Daring Visions* (National Aeronautics and Space Administration, 2013). Section 1.2 of the ExEP Program Plan (NASA Exoplanet Exploration

Program, 2018) 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 Science Investigations in the ExEP**

NASA funds scientific research relevant to the ExEP through multiple avenues. Within ExEP, mission science teams and individual research awards are supported by individual Project elements. Current ExEP Projects support science investigations through the K2 Guest Investigator Program, Keck Guest Observer Program, LBTI Exozodi Key Science Team, and the NN-EXPLORE Program. Flight Projects outside ExEP that fund exoplanet research today through their General Observer programs include the Chandra X-Ray Observatory, Hubble Space Telescope, Spitzer Space Telescope, SOFIA, SWIFT, and TESS. The K2 mission ended in 2018. Over the three years the Spitzer mission is scheduled to conclude while the James Webb Space Telescope mission will undertake substantial new exoplanet science investigations. Finally, NASA's Astrophysics and Planetary Science Research & Analysis (R&A) Programs include several elements that support investigations of exoplanets and exoplanetary systems: The Astrophysics Data Analysis Program (ADAP), Astrophysics Theory Program (ATP), Exoplanet Research Program (XRP), Habitable Worlds Program, and NASA Astrobiology Institute (NAI). The Nexus for Exoplanet System Science (NExSS) is a NASA interdisciplinary research coordination network working toward the goal of greater integration of exoplanet research across the portfolio of the NASA R&A Programs.

## **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 (National Aeronautics and Space Administration, 2017)) 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 science management to be used by the ExEP and is expected to remain relatively constant over time. The two other supporting documents for the ExEP Science Plan will be updated regularly. The ExEP Science Plan Appendix specifies the details of needed science investigations and options for achieving them over a rolling five-year period, and will be updated every few years as changes to these topics evolve. The ExEP Science Gap List will be updated annually.

### **2.1. Applicable Documents**



NPR 7120.8A	NASA Research and Technology Program and Project Management Requirements (National Aeronautics and Space Administration, 2018)
	Exoplanet Exploration Program Charter, March 1 2018
JPL ID: D-62841	Exoplanet Exploration Program Plan, JPL Doc. No: D-62841, Rev B, in preparation (NASA Exoplanet Exploration Program, 2018)

### 3. Programmatic Framework

#### 3.1. Roles and Responsibilities

##### 3.1.1. External Exoplanet Community

The external exoplanet community is the key stakeholder for Program science activities. Therefore, the ExEP seeks to have community engagement in the direction and priorities of its science programs. The community includes: (a) scientists working at universities, government laboratories, industry, and private foundations; (b) other government agencies such as the National Science Foundation; (c) relevant Federal, State, and local officials; (d) and the interested general public. The Program seeks regular input and evaluations from this stakeholder community both formally, through the Exoplanet Program Analysis Group (ExoPAG), and informally through communication and feedback at site visits, community meetings, and scientific and technical conferences.

##### 3.1.2. Exoplanet Program Analysis Group

The NASA Astrophysics Division Director (ADD) has chartered the Exoplanet Program Analysis Group (ExoPAG) which 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 NASA (Hertz, 2017). The ExoPAG is governed by a Chair and Executive Committee (EC) selected by the NASA ADD through an annual Dear Colleague letter.

The ExoPAG may form Science Analysis Groups (SAGs) and Science Interest Groups (SIGs), on its own initiative, to carry out studies on exoplanet-related topics relevant to NASA. SAGs are tasked with reporting on a specific topic, and when the analysis is complete the SAG is disbanded. SIGs are tasked with collecting input from the community over a longer term. SAGs and SIGs should address clearly-defined programmatic needs for NASA or represent an acknowledged component of the NASA ExEP. SAGs and SIGs are established with the approval of the ADD and the concurrence of the ExoPAG chair, the ExEP Program Scientist, and the ExEP Chief Scientist.

The ExoPAG provides strategic analysis for the NASA ADD but has no mandate to advocate. The Astrophysics Advisory Committee (APAC)<sup>2</sup> provides a formal channel for the community to advise the ADD. The ADD may ask the advice of the APAC before forming or closing out an ExoPAG SIG or SAG, or before accepting the analysis of a SIG or SAG. Although there is no rule to do so, the ExoPAG chair (and other PAG chairs) are members of the APAC. The ExoPAG chair may present ExoPAG analysis to the APAC in their role as chair. Note that the ExoPAG is not subordinate to the APAC.

### **3.1.3. Principal Investigators of NASA Exoplanet Science Investigations**

Research proposals and awards are led by a Principal Investigator (PI) who is responsible for defining the research goals and approach, conducting the work, presenting the results to the community through presentations at conferences and academic departments, and publications in refereed journals. ExEP will monitor the PI science investigation processes funded by its Program elements. These include the proposal submission and evaluation processes, the quality of data products provided to PIs and the community, the adequacy of data analysis funding, and the dissemination of the results to the scientific community and general public. For investigations funded outside of ExEP, the Program will maintain general awareness of the scope of ongoing activities and significant new science results in order to assess their impact on Program objectives.

### **3.1.4. NASA Exoplanet Science Institute (NExSci)**

By maintaining the heritage of past exoplanet missions and supporting active projects, NExSci provides an integrated environment and comprehensive repository for the exoplanet-related data, tools, and mission knowledge needed to carry out research programs which are beyond the scope of any one mission or project. To execute these goals NExSci carries out a core set of functions:

- Curate a comprehensive and integrated database for planetary systems and their relevant physical characteristics which must be derived from combining data from multiple wavelengths, missions and techniques.
- Provide tools to organize follow-up observing programs for space missions and to share the data needed to confirm and characterize of exoplanets.
- Inherit the critical skills, tools, and mission-specific knowledge to ensure that the heritage of individual projects is captured so that future missions can be implemented in a complete and cost effective manner.

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<sup>2</sup> The APAC formally replaced the Astrophysics Subcommittee (APS) of the Science Committee of the NASA Advisory Council in January 2017 (<https://science.nasa.gov/researchers/nac/science-advisory-committees/apac>).



- Provide comprehensive professional development activities to share and transmit expertise in exoplanet knowledge, data analysis, and observing techniques

The roles of the NASA Exoplanet Science Institute (NExSci) and the NExSci Director are described in the ExEP Program Plan (NASA Exoplanet Exploration Program, 2018) sections 1.1 and 1.5.3.14.

### **3.1.5. ExEP Program Scientist**

The ExEP Scientist at NASA HQ reports directly to the APD Director (DD). The ExEP Scientist roles and responsibilities are discussed in general in the NASA SMD Management Handbook. For ExEP, these include, but are not limited to:

- Lead overall Program science planning, including directing the activities of the ExoPAG to support this process;
- Manage the HQ's science selection process including definition and timing of NASA Research Announcements (NRAs) and Announcement of Opportunities (AOs), issuance of AOs, review of proposal evaluations, and selection of ExEP investigations;
- Serve as principal point of contact at NASA HQ for all ExEP science-related matters; and
- Provide the Program science advocacy within NASA and to the science community.

### **3.1.6. ExEP Program Chief Scientist**

The ExEP Program Chief Scientist is resident in the Program Office at JPL. ExEP is organized around a well-focused set of science objectives; therefore the Program Chief Scientist has an important function to develop connections to the science community, and to articulate and integrate the diverse approaches to exoplanet science. This includes maintaining currency with developments in theory, discoveries through ground observations or using other space assets, and focusing the scientific objectives of exoplanet flight projects in APD.

The Program Chief Scientist (PCS) has primary responsibility to:

- Support the ExEP Scientist in the initiation and preparation of ExEP-related AOs and NRAs;
- Support the ExEP Scientist in refining the Program content and direction;
- Support the ExEP Scientist in liaison functions with the science community;
- Provide science overview, analysis, and support functions in support of the PM;
- Report ExEP status to the APD science advisory bodies and science communities as necessary;

- Serve as liaison to the ExEP Project Scientists and JPL Science Division, and to the ExEP technical staff on science matters on behalf of the PM;
- Serve as liaison to the NExSci scientists on behalf of the PM;
- Oversee and support the ExEP project scientists in their responsibility for the scientific integrity and success of their individual projects/activities;
- Serve as liaison to the Chief Scientists at JPL and other NASA Centers;
- Carry out a program of exoplanet research related to the ExEP goals and provide scientific expertise and leadership within the broader community; and
- Maintain a current science plan and science gap list for purposes of capturing and maintaining priorities for program investments.

The Deputy Program Chief Scientist (DPCS) at JPL will temporarily replace and act for the Program Chief Scientist as needed or directed. When acting for the Program Chief Scientist, the Deputy will fulfill the roles and responsibilities of the Program Chief Scientist. The Deputy Program Chief Scientist will perform delegated functions of the Program Chief Scientist on a continuing basis. The DPCS is expected to devote a fraction of his/her program-funded time towards independent research and publication.

### **3.1.7. ExEP Program Scientist for each Project/Activity**

The roles of the Project Scientists for ExEP projects are described in the ExEP Program Plan Section 1.6.4.4 (NASA Exoplanet Exploration Program, 2018). Currently there are Project Scientists for K2, LBTI, and NN-EXPLORE.

## **3.2. Program Science Planning**

The motivation and objectives of ExEP strategic science planning are to identify the investigations that will enable or enhance the definition of and performance assessment for NASA's future exoplanet missions, and to identify the follow-up investigations that would maximize the scientific impact of current/upcoming missions on Program objectives. The planning is structured around an annually updated Science Gap List and communicated through the Science Plan Appendix and the ExoPAG general announcements. As detailed in Section 1.3, a large fraction of the science investigations that address the gaps are funded outside the Program.

The top-level science goals of NASA's APD flow from the priorities of the NRC's Decadal Survey of Astronomy and Astrophysics (National Space Policy of the United States of America, 2010). The APD's response to the Decadal Survey is captured in the Division's Astrophysics Implementation Plan (AIP) (National Aeronautics and Space Administration, 2016), which guides the formulation of the ExEP science direction that is used to identify Program science gaps. The needs of current and upcoming missions in the NASA Astrophysics Program are foremost in the

program science plan. The relevant missions include those directed by NASA HQ (e.g. WFIRST), selected through open competitions (e.g. Explorer missions), mission studies selected by NASA HQ (e.g. probes and flagships for consideration by the Decadal Survey (Committee for a Decadal Survey of Astronomy and Astrophysics; National Research Council, 2010)), strategic NASA participation in foreign-led missions, and other potential future exoplanet missions described in the APD 30-yr Roadmap (National Aeronautics and Space Administration, 2013).

### **3.2.1. Science Gaps**

The ExEP science needs will be captured in a Science Gap List (SGL). This list serves to identify and signal to the broader community where focused science investigations are needed over the next 3-5 years in support of ExEP goals. A *science gap* is defined as the difference between what is needed to define requirements for specified future exoplanet missions and the state of the art, or which is needed to enhance the science return of current and future exoplanet missions.

The ExEP SGL represents activities and investigations that will advance the goals of NASA's Exoplanet Exploration Program. By making the SGL widely available, funding sources both inside and outside the Program can make their own judgements as to whether or not to align the work they support with NASA's Exoplanet Exploration goals. All of these gaps are deemed important for program goals, so each funding organ remains free to assign their own relative priorities between the ExEP science gaps when allocating their resources. The SGL will be revised annually through discussions with the ExoPAG.

### **3.2.2. Science Plan Appendix**

The ExEP Science Plan (Appendix B) provides context for the SGL. It is based on the latest scientific results and policy direction provided by NASA APD. The Appendix will provide stakeholders with a current snapshot of science activities needed (both strategic and competed), as well as options for making progress over the next several years. This Appendix will capture the specific missions and mission concepts the Program aligns its science support with, review the most significant resnet results in exoplanet science, and communicate the near-term science needs and priorities of the ExEP. The Plan Appendix will be updated every two years.

### **3.2.3. Science Proposal Solicitations**

Individual Program elements will solicit science proposals with a cadence and scope determined by their Project schedules and requirements. The Program itself will not normally issue its own calls for science proposals. However, ExEP Projects in their pre-formulation phase may wish to receive scientific inputs that require competitively-selected work by the outside community. Depending on the funding source, ExEP will work with NASA HQ to develop such proposal calls. Past examples of this are the TPF Foundation Science Program, WFIRST Preparatory Science Program, and WFIRST coronagraph "quick studies."

### 3.2.4. Science Gap List Calendar

The calendar in Figure 1 shows the annual milestones required for updating the Science Gap List. The schedule is designed so that an updated science gap list is available for science proposers at the annual ROSES omnibus proposal call (currently each February) and for Program planning in the annual PPBE budget cycle (usually February through April). Development of an updated gap list begins each year with a call for inputs from the ExoPAG during the summer. These will be incorporated into a draft updated to the SGL during the fall, which will then be discussed and confirmed with NASA HQ late in the year. The updated science gap list will then be presented to community for feedback at the winter ExoPAG meeting.

Activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>ExEP Science Needs Process</b>												
Request input on SGL from ExoPAG						ExoPAG meeting						
SGL Window Opens						day after						
SGL Window Closes								end of month				
ExEPO updates SGL									mid			
ExEPO reviews SGL w/ ExEP HQ Prog Scientists										late		
SG Presented to Winter ExoPAG	ExoPAG meeting											
Update Science Plan Appendix		mid-month										

*Figure 1: The Science Gap List and Science Plan Appendix update annual calendar.*

#### 4. Appendices

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- [11] P. Hertz, "Exoplanet Exploration Program Analysis Group (ExoPAG) Terms of Reference," 6 Mar 2017. [Online]. Available: [https://exoplanets.nasa.gov/exep/resources/documents/exopagFoundingDocuments/553\\_ExoPAG-TOR\\_2017.pdf](https://exoplanets.nasa.gov/exep/resources/documents/exopagFoundingDocuments/553_ExoPAG-TOR_2017.pdf). [Accessed 30 Jul 2017].

## Appendix 2 : Acronyms

AO	Announcement of Opportunity
ADAP	Astrophysics Data Analysis Program
AIP	Astrophysics Implementation Plan
APD	Astrophysics Division, NASA Headquarters
APRA	Astrophysics Research & Analysis
ATP	Astrophysics Theory Program
APAC	Astrophysics Advisory Committee
ExEP	Exoplanet Exploration Program
ExoPAG	Exoplanet Program Analysis Group
JPL	Jet Propulsion Laboratory
LBTI	Large Binocular Telescope Interferometer
NAI	NASA Astrobiology Institute
NExSci	NASA Exoplanet Science Institute
NExSS	Nexus for Exoplanet System Science
NRA	NASA Research Announcement
NWNH	New Worlds New Horizons Decadal Survey
PCS	Program Chief Scientist
PM	Program Manager, sometimes Project Manager
PPBE	Planning, Programming, Budgeting and Execution
ROSES	Research Opportunities in Space and Earth Sciences
SAG	Science Analysis Group
SIG	Science Interest Group
SGL	Science Gap List
SMD	Science Mission Directorate
SPA	Science Plan Appendix
XRP	Exoplanet Research Program



## Appendix X: Decision Memoranda

If the ExEP Office of the Chief Scientists receives periodic important directions from SMD, APD, and/or ExEP, this is a good way to document them. If not, then you don't need this section.

In the ExEP Plan, we said "Copies of the decision memoranda will be added as they are signed." ". . . as they are received." may be a better way to say it in this document.