MAINE SPACE GRANT
CONSORTIUM
An affiliate of the National Space Grant College and Fellowship Program

Call for Proposals

FY 2021 Maine NASA EPSCoR Research Competition

Announcement Date	**September 28, 2020**
Letters of Intent Due Date to MSGC	**11:59 p.m., October 30, 2020**
Proposal Due Date to MSGC	**11:59 p.m., December 16, 2020**

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1. Summary

The Maine Space Grant Consortium (MSGC) is soliciting research proposals in anticipation of the release of the FY 2021 NASA EPSCoR (Established Program to Stimulate Competitive Research) Cooperative Agreement Notice (CAN) announcement in December 2020.

The overarching goal of Maine NASA EPSCoR over the next four years is to support the expansion and diversification of Maine's space exploration research and education capacity by increasing statewide involvement in space exploration and space technology research. Our primary strategy to achieve this goal is to use the NASA EPSCoR Research Competitions to seed the foundation for building centers of excellence in one or more of the topics areas that are critical to the development of Maine's space economy and the proposed *Maine SpacePort Complex* in a manner that also align with the priorities of NASA Mission Directorates and/or Centers. Preference will be given to multidisciplinary and multi-institutional, team-based proposals that demonstrate this alignment. An overview of the proposed vision for new space economy and the *Maine Spaceport Complex* is provided in Appendix A.

NASA Office of Education, in cooperation with NASA's Aeronautics Research Mission Directorate (ARMD), Human Exploration & Operations Mission Directorate (HEOMD), Science Mission Directorates (SMD), the Space Technology Mission Directorate (STMD), and NASA's nine Centers, plus the Jet Propulsion Laboratory (JPL), solicit proposals for the NASA EPSCoR. Each funded NASA EPSCoR proposal is expected to establish research activities that will make significant contributions to NASA's strategic research and technology development priorities and contribute to the overall research infrastructure, science and technology capabilities of higher education, and economic development of the jurisdiction receiving funding.

This solicitation provides potential applicants a head start and ample time to prepare and submit their proposals to the MSGC and its Maine NASA EPSCoR Technical Advisory Committee for review. We expect that there will be an opportunity for Maine to submit ***one*** Research proposal for potential funding under this CAN. Once the official NASA release is issued, there will be a 60-day window prior to the deadline for submission to NASA. Potential applicants will be informed when the official CAN is released and of any adjustment to the proposal requirements and due date to MSGC.

All interested research groups at Maine institutions of higher education and not-for-profit research institutions are invited to submit proposals to the Maine EPSCoR Program in anticipation of the FY 2021 CAN release. An employee of a for-profit company is not eligible to be an applicant in a NASA EPSCoR proposal but may be an active collaborator as a co-principal investigator or in another capacity. US citizenship is not an eligibility requirement.

NASA EPSCoR competitions are aimed at the emerging researcher or an established researcher who wishes to pursue new research directions, for the development of projects, contacts and collaborations that will bring Maine researchers into the mainstream of NASA related research activity, thereby increasing their chances to successfully compete in the aerospace R&D marketplace. It is anticipated (and strongly advised) that students (both graduate and undergraduate) be involved in funded NASA EPSCoR research projects.

A researcher who has received NASA EPSCoR research funding (not NASA EPSCoR Research Infrastructure Development awards) within the past five years may submit a proposal as long as the project is new and incorporates mentoring of junior faculty. Proposals that take previously funded NASA EPSCoR research projects to the next level will be considered but will require justification as to why NASA funding is required.

Until the official FY 2021 CAN is released, applicants must follow the instructions in this announcement to prepare their proposals. The FY 2020 NASA EPSCoR CAN may be used for further guidance.

2. Definitions

Throughout this document, we mention the terms Space Exploration, Space Technology and Researcher. To ensure clarity and consistency, the following is our definitions: Space Exploration includes the scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effects on the solar system, and the universe beyond. Space Technology is technology developed by space science or the aerospace industry for use in spaceflight, satellites, or space exploration, and includes spacecraft, satellites, space stations, and support infrastructure, equipment, and procedures. Researcher includes faculty and professional staff at our Affiliates that are 2-year and 4-year higher education institutions, not-for-profit research institutions, government, and aerospace businesses.

3. NASA EPSCoR Background

The legislative purpose of NASA EPSCoR is to strengthen the research capability of jurisdictions that have not in the past participated equably in competitive aerospace research activities. The goal of NASA EPSCoR is to provide seed funding that will enable jurisdictions to develop an academic research enterprise directed toward long-term, self-sustaining, nationally competitive capabilities in aerospace and aerospace-related research. This capability will, in turn, contribute to the jurisdiction's economic viability and expand the nation's base for aerospace research and development. Since its inception, NASA EPSCoR has been closely linked to the National Space Grant College and Fellowship Program (Space Grant). Based on the availability of funding, NASA will continue to help states achieve these goals through NASA EPSCoR. Funded jurisdictions will be selected through a merit-based, peer-review competition. The following are the specific objectives of NASA EPSCoR:

- Contribute to and promote the development of research capability in NASA EPSCoR jurisdictions in areas of strategic importance to the NASA mission;
- Improve the capabilities of the NASA EPSCoR jurisdictions to gain support from sources outside the NASA EPSCoR program;
- Develop partnerships between NASA research assets, academic institutions, and industry;
- Contribute to the overall research infrastructure, science and technology capabilities, higher education, and economic development of the jurisdiction; and
- Work in close coordination with the Space Grant consortium in the jurisdiction to improve the environment for science, technology, engineering and mathematics (STEM) education.

Connections between the NASA's EPSCoR and National Space Grant College and Fellowship Programs - Cooperative Agreements will be awarded to the institution of the NASA EPSCoR Director. Therefore, the NASA EPSCoR Director shall serve as the Principal Investigator (PI) for and manage the jurisdiction's NASA EPSCoR project (see Section 3.0, Program Management, Subsection 3.2. Jurisdiction Level for a discussion of management responsibilities). Although the EPSCoR Director and the Space Grant (SG) Director are the same person and therefore a member of the SG consortium, individuals and institutions participating in a jurisdiction's NASA EPSCoR project need not be members of the jurisdiction's SG Consortium and all institutions within the state shall be made aware of this opportunity to compete.

4. NASA EPSCoR Research Competition

The goal of the NASA EPSCoR Research Competition is to effectively utilize the resources available through NASA as incentive for faculty and students: 1) to develop research competitiveness 2) to develop new research projects or directions, and 3) to foster collaborations among the MSGC Affiliate institutions, as well as with NASA centers and/or other federal laboratories and with the business/industry community.

Each NASA EPSCoR project must perform scientific research and/or technology development in areas that support the strategic research and technology development priorities of NASA and the State of Maine. Contacts/ collaborations/ties to NASA centers and NASA researchers are required for all proposals. An emphasis should be placed on developing a core expertise capable of successfully competing for funds from NASA and non-NASA sources outside of the EPSCoR program. The programs should move progressively toward gaining support from sources outside the NASA EPSCoR program by aggressively pursuing additional funding opportunities offered by NASA, industry, other federal agencies, and other sources.

Principal Investigator and Science-PI – NASA EPSCoR requires the state NASA EPSCoR Director to be the Principal Investigator on NASA EPSCoR Research proposals. The individual submitting a proposal in response to this solicitation is the Science-PI under a subrecipient award from the Maine Space Grant Consortium.

Period of Performance - NASA EPSCoR awards will support a three-year cooperative agreement. A June 1, 2021 start date should be assumed.

Funding and Cost Sharing – Although NASA EPSCoR Research Competition awards are up to $750,000 per proposal, your budget may not exceed $743,750 over three years. The cost share requirement is 50%. Your proposal should include a minimum cost share amount of $375,000 over the three-year period. The remaining amount is required to support the Maine NASA EPSCoR Program office's cost for program management. Funds need not be spent evenly over the life of the grant. In-kind match can be used including any waived indirect should the Science-PI's institution elects to do so.

Eligibility - Faculty and researchers at Maine institutions of higher education and not-for-profit research institutions are eligible as applicants to submit proposals in response to NASA EPSCoR

Research Competition announcement. NASA EPSCoR competitions are aimed at the emerging researcher or an established researcher who wishes to pursue new research directions, for the development of projects, contacts and collaborations that will bring Maine researchers into the mainstream of NASA related research activity, thereby increasing their chances to successfully compete in the aerospace R&D marketplace. It is anticipated (and strongly advised) that students (both graduate and undergraduate) be involved in funded NASA EPSCoR research projects. An employee of a for-profit company is not eligible to be an applicant in a NASA EPSCoR proposal but may an active collaborator as a co-principal investigator or in another capacity. US citizenship is not an eligibility requirement.

Restrictions - In addition to the funding guidelines and requirements in the *NASA Guidebook for Proposers, March 2018 Edition* located at http://www.hq.nasa.gov/office/procurement/nraguidebook/proposer2018.pdf. Title 2 CFR Part 1800, the following restrictions govern the use of the federally-provided and the cost-shared portion of funds for this opportunity (referred to collectively as NASA EPSCOR funds) and are applicable to this CAN:

- Funds shall not be used to fund research carried out by non-U.S. institutions. However, U.S. research award recipients may directly purchase supplies and/or services that do not constitute research from non-U.S. sources. Also, subject to export control restrictions, a foreign national may receive remuneration through a NASA award for the conduct of research while employed either full or part time by a U.S. institution. For additional guidance on foreign participation, see the *NASA Guidebook for Proposers*.
- Travel, including foreign travel, is allowed for the meaningful completion of the proposed investigation, as well as for reporting results at appropriate professional meetings. Foreign travel to meetings and conferences in support of the jurisdiction's NASA EPSCoR research project is an acceptable use of NASA EPSCoR funds, with a limit of $3,000 per trip for up to two (2) separate years of a jurisdiction's proposal (i.e., the maximum amount the jurisdiction can request for foreign travel is $3,000 total in any one year and a limit of $6,000 total for each research proposal). EPSCoR support shall be acknowledged by the EPSCoR research project number in written reports and publications. Please note that domestic travel does not have a limit. Domestic travel, which is defined as travel that does not require a passport, shall be appropriate and reasonable to conduct the proposed research.
- The construction of facilities is not an allowable cost in any of the programs solicited in this CAN. For further information on allowable costs, refer to the cost principles cited in Title 2 CFR §1800.907(a)(4), Equipment and Other Property.
- NASA EPSCoR funding shall not be used to purchase general purpose equipment, e.g., desktop workstations, office furnishings, reproduction and printing equipment, etc. as a direct charge. Special purpose equipment purchases (i.e., equipment that is used only for research, scientific, and technical activities directly related to the proposed research activities) are allowed and can be reflected as a direct charge as per Title 2 CFR §1800.907(a)(3), Equipment and Other Property.
- NASA EPSCoR funding shall not be used to support NASA civil service participation (FTE) in any research project. That funding is provided through a funding vehicle between the jurisdiction and NASA Center, such as a Space Act Agreement or other

reimbursable agreement using non-EPSCoR funds. NASA EPSCoR cannot withhold funding from an award to send to a NASA Center for FTE support (including travel).

- NASA EPSCoR funds shall be expended in NASA EPSCoR institutions. If a Co-Investigator (Sc-I/Co-I) with an NASA EPSCoR award transfers to a non-EPSCoR institution, the EPSCoR funding amount, or the part of it that remains unobligated at the time of Sc-I/Co-I transfer, cannot be transferred to the non-EPSCoR institution.
- All proposed funding requests must be for expenditures that are allowable, allocable, and reasonable. Funds may only be used for the awarded project. All activities charged under indirect costs shall be allowable under 2 CFR 200, Subpart E, Cost Principles.
- Grants and Cooperative Agreements shall not provide for the payment of fee or profit to the recipient.
- Unless otherwise directed in 2 CFR 200, for changes to the negotiated indirect cost rate that occur throughout the project period, the recipient shall apply the rate negotiated for that year, regardless of whether it is higher or lower than at the time the cooperative agreement was awarded.
- Proposals shall not include bilateral participation, collaboration, or coordination with China or any Chinese-owned company or entity, whether funded or performed under a no- exchange-of-funds arrangement.
- Any funds used for matching or cost sharing shall be allowable under 2 CFR 200.
- A non-Federal entity shall use one of the methods of procurement as prescribed in 2 CFR 200.320. As defined in 2 CFR 200.67, the micro-purchase threshold for acquisitions of supplies or services made under grant and cooperative agreement awards issued to institutions of higher education, or related or affiliated nonprofit entities, or to nonprofit research organizations or independent research institutes is $10,000; or such higher threshold as determined appropriate by the head of the relevant executive agency and consistent with audit findings under chapter 75 of Title 31, United States Code, internal institutional risk assessment, or State law.

5. Alignment with NASA Research Areas of Interest

NASA EPSCoR research priorities are defined by the Aeronautics Research, Human Exploration & Operations, Science, and Space Technology Mission Directorates, and NASA's nine Centers plus JPL. Each Mission Directorate, Center, and JPL covers a major area of the Agency's research and technology development efforts. Information about current NASA research solicitations can be found on NSPIRES at http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations"). Research priorities for each of the Mission Directorates and Centers are summarized in Appendices B and C, respectively; also see Appendix D for detailed contact information for the NASA Point of Contact (POC) for each Center.

In a separate NASA relevance section, each proposal must demonstrate alignment with NASA Center goals and objectives, or with NASA research or technology development priorities. Background information on NASA priority research areas can be found in Appendices B and C and/or by viewing past and current solicitations at http://nspires.nasaprs.com/external.

6. Alignment with Maine's Proposed New Space Economy Vision

The overarching goal of Maine NASA EPSCoR over the next four years is to support the expansion and diversification of Maine's space exploration research and education capacity by increasing statewide involvement in space exploration and space technology research. Our primary strategy to achieve this goal is to use the NASA EPSCoR Research Competitions to seed the foundation for building centers of excellence in one or more of the topics areas that are critical to the development of Maine's space economy and the proposed *Maine SpacePort Complex* in a manner that also align with the priorities of NASA Mission Directorates and/or Centers. Preference will be given to multidisciplinary and multi-institutional, team-based proposals that demonstrate this alignment. An overview of the proposed vision for new space economy and the *Maine SpacePort Complex* is provided in Appendix A.

In a separate State of Maine relevance section, each proposal must demonstrate alignment with one or more of the foundational topic areas that align with the proposed *Maine SpacePort Complex's* business units and presented in Table 1. Specifically, applicants must demonstrate how their proposals will seed the foundation for building centers of excellence in one or more of the topics areas that also align with the priorities of NASA Mission Directorates and/or Centers. Preference will be given to multidisciplinary and multi-institutional, team-based proposals that demonstrate this alignment. Applications that do not **directly** align with one or more of the topic areas will be deemed unresponsive.

Table 1: Alignment of R&D and Education Topic Areas with NASA Mission Directorates and Centers

Maine SpacePort Complex Topic Area	Mission Directorate*	NASA Center**
Big Data & Analytics and Data Management	HEOMD	LRC, ARC, GSFC, JPL
Quantum Computing & Storage	HEOMD	GSFC, ARC
Ground Communication	HEOMD	KSC, MSFC, JSC, JPL, GSFC
CubeSat & Constellation Design	STMD	GSFC, ARC, MSFC
Vehicle and payload integration	HEOMD, STMD	KSC
Launch services	HEOMD	KSC, GRC, GSFC, SSC, MSFC, JPL
S&E Payload R&D	HEOMD, STMD, SMD	LRC, JPL, GSFC, ARC
Navigation & Tracking	HEOMD, STMD	GSFC, MSFC, GRC, JPL, MSFC
Geospatial Informatics and remote sensing	STMD	GSFC, JPL, LRC
Communications	HEOMD	JSC, GRC, JPL
Small launch vehicles, components, subsys mfg.	HEOMD, STMD	LRC, KSC, MSFC, GRC, JSC, JPL
Satellite manufacturing	STMD	MSFC, KSC, JPL, LRC

* Mission Directorates: HEOMD (Human Exploration and Operations); STMD (Space Technology); SMD (Science). ** NASA Centers: GSFC (Goddard Space Flight Center); JSC (Johnson Space Center); KSC (Kennedy Space Center); MSFC (Marshall Space Flight Center); JPL (Jet Propulsion Laboratory); SSC (Stennis Space Center); LRC (Langley Research Center); ARC (Ames Research Center); GRC (Glenn Research Center).

Research Student Support - The use of NASA EPSCoR funds for support of research students is allowable, and must be detailed in the Budget Justification and described in the narrative and evaluation sections of the proposal

Partnerships and Interactions – All institutions of higher education within an eligible jurisdiction shall be made aware of this NASA EPSCoR CAN and given the opportunity to compete. *However, all proposals shall be submitted through the jurisdiction's NASA EPSCoR*

Director's office. Applicants are strongly encouraged to submit proposals that develop partnerships or cooperative arrangements among academia, government agencies, and business and industry within Maine. Applicants are encouraged to: (a) create or strengthen existing linkages with NASA centers; (b) create or strengthen linkages with industry, private research foundations, and local and state agencies; (c) involve faculty and students from other Maine institutions of higher education; (d) include faculty and students from underrepresented and underserved groups; and (e) establish partnerships and collaborations with minority-serving institutions.

NASA-funded, in-kind services provided by NASA Centers, Mission Directorates, and/or the Office of the Chief Technologist should be identified as NASA responsibilities in the proposals and are not to be included in the 50% matching requirement.

Statements of commitment and letters of support are important components of the proposal. NASA does not, however, solicit or evaluate letters of endorsement. Review the *NASA Guidebook for Proposers* for distinctions among statements of commitment, letters of support, and letters of endorsement.

Required NASA Contact – Since a major aim of this program is the promotion of collaborative efforts between Maine researchers and NASA Field Centers, confirmation from the NASA personnel must accompany all proposals. This confirmation should comprise, at minimum, a letter (or e-mail) from the NASA researcher who is interested in the outcome of the proposed project and a statement that the proposed research is aligned with the interest of the NASA Field Center. In the absence of the required confirmation, the proposal will be returned without review.

Important Note to Applicants: Although your proposed research project aligns with NASA's research priorities and is supported by your NASA contact, this does not mean that your project aligns with the priorities of the leadership of the NASA Field Center that your NASA contact is located. This misalignment can lead to your proposal not being selected by the Review Committee even though your proposal may be reviewed highly based on scientific merit. The reason for this potential is that NASA Field Centers are represented on the Review Committee, and the perspectives of the representatives mirror the priorities of the leadership at their Centers. Therefore, it is essential that your NASA colleague makes sure that your proposed research is also a priority of the NASA Field Center leadership, if funded, when they submit their letter of support.

Diversity - It is a national priority to increase diversity in the STEM workforce at all levels. Traditionally, minority groups, women, and persons with disabilities have been underrepresented in the STEM disciplines as students and faculty as well as in the workplace after graduation. MSGC is committed, to the degree possible, to increase the diversity among its awardees by giving special consideration to women, minorities and other underrepresented groups. Proposers are encouraged to help address this diversity objective when developing their proposals.

7. Keys to Success

The focus of the FY 2021 NASA EPSCoR Research competition is to identify and fund research that NASA wants performed (see Appendix A). Excellent science or engineering is not enough. Hence, all proposals should include the strongest possible evidence that the group is developing or has active, well established ties to researchers at NASA Mission Directorates, the Office of Chief Technologist, NASA Centers, the Jet Propulsion Laboratory or Headquarters. If you have not previously collaborated with NASA personnel, you should contact the University Affairs Officer (UAO) at your NASA Center(s) of interest. NASA University Affairs Officers are listed in Appendix B of this document. The UAO at your Center of interest can direct you to specific NASA researchers in your field. Involved NASA collaborators/colleagues will be expected to be knowledgeable about the proposed research program and should be willing to act as advocates for funding of the proposal. There must be a clear and strong indication that the proposed research will fulfill a presently identified mission need at NASA.

Successful NASA EPSCoR proposals:
- Emphasize infrastructure and team building.
- Involve and nurture junior researchers and students (a mix of undergraduates, graduate students and postdocs, to the extent possible). NASA is concerned about the STEM pipeline (Its own as well as the nation's)
- Are unique. The project must not be an extension of existing work but may take an existing project to a much higher level with infrastructure building and the STEM pipeline as critical outcomes.
- Not be made up of ONLY established researchers – Nurture the STEM pipeline.
- Align with NASA's research and technology priorities and the Maine space economy topic areas – be as specific as possible.
- Include collaborations with one or more NASA scientists at one or more of the NASA research centers. NASA scientists are considered collaborators in the project and must not receive NASA EPSCoR funds.
- Include collaborations with other non-NASA institutions, to the extent possible. Although NASA EPSCoR encourages such collaborations only if it benefits your project and institution, DO NOT force collaborations for the sake of collaborations.
- Do not include outreach to K-12.
- Diversity is a critical factor with NASA. Make every effort to include members of the underrepresented community and women in your proposal. NASA encourages collaboration with predominately minority institutions or institutions with large minority student populations. Again, do not force the collaboration if it does not make sense

NASA EPSCoR Program and Project Levels - The NASA EPSCoR is a program of the NASA Office of STEM Engagement administered by the Office of Education at NASA Headquarters. NASA EPSCoR Program Management is closely coordinated with NASA Headquarters program offices (research and educational) and the Centers.

NASA EPSCoR Project Management resides at the Kennedy Space Center (KSC). NASA EPSCoR Project Management has the overall responsibility for oversight, evaluation, and reporting. Technical and scientific questions about programs in this solicitation may be directed to the NASA EPSCoR Project Manager. The primary points of contact for the Mission Directorates and the NASA Centers are listed in Appendix B.

Jurisdiction Level - The jurisdiction's NASA EPSCoR Director will serve as the managing Principal Investigator (PI) on the award, providing leadership and direction for the team from an oversight role. The submitting and awardee institution will be that of the jurisdiction's NASA EPSCoR Director. The Director is responsible for oversight and overall management of the project to assure compliance with NASA EPSCoR. The Director is responsible for ensuring the timely reporting by the team of progress and accomplishments of its work. The investigator in charge of the scientific direction of the proposed work should be listed as the Science-I (Co-I/Science-I). If the Co-I/Science-I's institution is different from the submitting institution, awards may be made to the Co-I/Science- I's institution through a subaward.

The Government's obligation to continue any award is based on satisfactory progress as detailed in the recipient's required annual progress reports. The research proposal may include a reasonable level of funding for management, administrative, and oversight function of the jurisdiction's NASA EPSCoR Director. This amount, if required, shall be included in the $750,000 cap.

The jurisdiction's NASA EPSCoR Director should provide guidance and updates to the Co-Is regarding NASA policy and direction from both an Agency technical perspective and from a NASA EPSCoR programmatic standpoint. The Director shall maintain an awareness of NASA research and technology development priorities and jurisdiction research priorities. As the primary point of contact for NASA regarding EPSCoR in the jurisdiction, the Director will identify and develop opportunities for collaboration within the jurisdiction with existing EPSCoR and EPSCoR-like programs from other federal agencies. Also, the Director will consult with appropriate jurisdiction organizations such as the economic development commission in attending to jurisdiction research priorities.

Data Management Plan - Increasing Access to the Results of Federally Funded Research - In keeping with the NASA Plan for increasing access to results of federally funded research, new terms and conditions about making manuscripts and data publically accessible may be attached to NASA EPSCoR Research awards. Almost all proposals will be required to provide a Data Management Plan (DMP) or an explanation of why one is not necessary given the nature of the work proposed. During the implementation phase of this new requirement *the DMP will be submitted by responding to the NSPIRES cover page question about the DMP (limited to 4000 characters)*. Any research project that doesn't require a DMP to be submitted shall say so explicitly in the DMP block. For example: *This is a development effort for flight technology that will not generate any data that I can release, so I can't write a DMP. The data that we will generate will be ITAR. Or, just explain why your project is not going to generate data.*

The kind of proposal that requires a data management plan is described in the NASA Plan for increasing access to results of federally funded research (see above link). In addition, one of the NASA mission directorates (SMD) has posted a FAQ site that addresses questions about DMP requirements at: http://science.nasa.gov/researchers/sara/faqs/dmp-faq-roses/. Note that although the questions pertain to the SMD ROSES NRA, the requirements given in the answers apply.

Note: Proposers that include a plan to archive data should allocate suitable time for this task. Unless otherwise stated, this requirement supersedes the data sharing plan mentioned in the *NASA Guidebook for Proposers*.

8. Review Process and Criteria

The Maine NASA EPSCoR Program uses a two-tier evaluation approach. The first tier an external evaluation of each proposal using external reviewers who do not have conflicts with the applicants. In the required letter of intent, each applicant is required to provide a list of up to five individuals who has the expertise to review their proposals. The Maine NASA EPSCoR programs contacts each reviewer to determine their availability and to confirm the absence of conflicts of interest. The external reviews are provided to an internal technical advisory committee that includes the Maine NASA EPSCoR Director (Committee Chair), the State EPSCoR Director, one representative from the state industry; one representative from state government; and one member from one of the affiliates of the state's NASA Space Grant Program. Based on the external reviews and other considerations, the Committee will provide a final recommendation to the MSGC Board of Directors.

Applicants are advised that their proposals must be responsive to the evaluation criteria outlined in the FY 2020 NASA EPSCoR CAN (the evaluation criteria in the FY 2021 CAN should not be different) which are part of NASA's external and internal evaluation processes for selecting proposals for funding. In addition, applicants are advised that their proposals must be responsive to the following evaluation criteria of the Maine NASA EPSCoR Program in order to select and submit the most responsive proposal to NASA for national review:

a. The quality of the science and it's applicability to NASA and MSGC/Maine priorities should be the paramount consideration - who has the strongest case to make with regard to the urgency of the need, the validity and integration of their research agenda (appropriate objectives linked to strong hypotheses), and the relevance to Maine. Additional credit would be given to any proposal with innovative, more cutting-edge objectives (vs. more traditional basic research).

b. The breadth, depth, and strength of the personnel involved: PI, academic and industry collaborators, students, NASA collaborators, etc. - this also includes the strength of the integrated education component. Layers of mentoring are important - if there is a more experienced PI, then have junior Co-PIs, postdocs, grads, undergrads on the teams being mentored for next generation of researchers in this area.

c. Sustainability and future plans. What will be the impact of this research on Maine's infrastructure/competitiveness/capacity, and what can/will happen after the support ends. Consider the development of solid infrastructure for the state vs. the PI because faculty tends to leave Maine.

9. Deadline and Important Date

Letter of Intent Due	11:59 p.m., October 30, 2020
Proposals Due	11:59 p.m., December 16, 2020

NOTE: The proposal due date may change depending on the release date of the official NASA announcement for the FY2021 NASA EPSCoR Research Program solicitation. Usually after the office release there is a 60-day window prior to the deadline for submission to NASA. Potential applicants will be informed when the official CAN is released and of any adjustment to the proposal due date to MSGC.

10. Letters of Intent

Letters of Intent (LOIs) are due at the Maine Space Grant Consortium by 11:59 p.m., October 30, 2020. Please e-mail LOIs to Jana Hall at jana.hall@msgc.org. The information provided in this notice will be used to (a) assess alignment with NASA's research interests and (b) determine the expertise required of merit reviewers. The LOI must include:

1. Name, title, mail and e-mail addresses, and telephone number of the applicant.
2. Title of the planned research.
3. Summary of the project. Provide sufficient information to allow determination of discipline and subdisciplines. Summary must also indicate the NASA Mission Directorate, the NASA research center, and the Maine Spaceport Complex topic area(s) the proposed research topic falls under.
4. Name, title, mail, and e-mail addresses of five (5) out-of-state merit reviewers. The reviewers must not be associated with, have any involvement in the development of your proposal or in the execution of the project, if funded by NASA EPSCoR, and is not involved in a current or pending research project with you. Please do not contact the reviewers.

11. Proposal Format and Instructions

Applicants must follow the format described in this section especially for the Scientific/ Technical/Management section. The instructions provide more detailed description of the subsections, which are not outlined in the NASA EPSCoR Research Program CANs.

A. Cover Page (one page, limit responses to one or two lines)

1. Tentative title of research:

2. Science-I and Co-PIs (name, title, institution, contact information):

3. Other in-state or out-of-state collaborators (names, titles, institutions) and their role in project (note: Maine NASA EPSCoR funds may not be used for direct support of out-of-state collaborators): *(Though not required, collaborations among individuals and institutions are strongly encouraged; the goal of EPSCoR is not to fund individual investigators, but rather to*

develop research teams and programs that will improve the capability of the state to compete for NASA and other funds.)

4. NASA research contact, if known (name, title, organization) and their role in project. Identify the level of existing collaboration, as well as planned. Be as specific as possible. *(It is the responsibility of the proposer to identify a NASA contact. Colleagues who are familiar with your research may be able to suggest a researcher at a NASA Center, or you may contact the University Affairs Officers at NASA's ten Research Centers. These are listed in Appendix B of this announcement.)*

5. Total federal amount requested, total cost share and major equipment purchases (with cost), if any.

B. Summary Page (separate page, 4,000 characters maximum)

C. Table of Contents (1 page)

D. Scientific/Technical/Management (**limit 15 pages,** single space, Time New Roman, size 12 font)

Describe the science or engineering problem that would be addressed, the plan of attack, any special research methods, and the capability of the research team to accomplish the goals of the project. The following outline must be used. *(References Cited may be included and will not count toward the 5-page limit.)*

Project Purpose: Describe how the proposed research activities will make significant contributions to the strategic research and technology development priorities of one or more of the Mission Directorates or the OCT and contribute to the overall research infrastructure, science and technology capabilities, higher education, and economic development in Maine.

The Project Purpose must include a separate subsection entitled ***"Relevance to NASA"*** and a subsection entitled ***"Relevance to Maine.***" Proposers should provide specific information on how they determined the relevance of the proposed effort to NASA. The relevance to NASA and Maine must be balanced.

Goals and Objectives: Clearly state goals and objectives for the proposed effort and provide a rationale for the approach that will be used to achieve them.

Project Content: Describe the proposed effort and how the goals and objectives will be achieved. Please note, when preparing a proposal that involves the use of human subjects, animals, hazardous materials, select agents, and/or recombinant DNA, the proposers will need to address applicable compliance issues.

Anticipated Results: Describe the anticipated results of the proposed effort.

Partnerships and Interactions: Describe any partnerships or cooperative arrangements among academia, government agencies, business and industry, private research foundations, jurisdiction agencies, and local agencies as well as partnerships with minority-serving institutions and the inclusion of faculty and students from underrepresented/underserved groups.

Timeline: Include a timeline for achieving stated goals and objectives, including significant milestones.

Sustainability: Describe how the research capability will be sustained beyond the funding period. There should be a clear plan for sustaining the research beyond NASA EPSCoR funding and for seeking non-EPSCoR funding. Identify potential funding opportunities specifically as examples.

Dissemination: Outline the plan for disseminating the results to NASA and the broader community.

Evaluation: This section must include two subsections. The first subsection is for the research evaluation and the second subsection is for the overall program evaluation. In the first subsection the applicant must describe an evaluation plan for measuring research project's success. In other words, clearly discuss what will constitute research success and how you will measure the research's progress toward achieving the goals and objectives and to determining research success. Applicants may want to consider including preliminary indicators and benchmarks that will be used to determine which implementation strategies are proving to be effective; and methods that will help the project to determine how implementations might be improved, and to determine early on whether specific strategies are likely to be effective. The evaluation plan should be appropriate for the scope of the proposed activity and include a discussion of data collection and analysis procedures. Note the evaluation plan may need to be modified at the time of the award to ensure it includes contribution to NASA's Program Performance Measures.

In this section, the two statements in blue italics and table must be included ***(PLEASE REPLACE THE BOLD NUMBERS WITH TARGETS APPROPRIATE FOR YOUR PROJECT. CROSS OUT AND/OR INCLUDE METRICS AND OUTCOMES THAT ARE MORE APPROPRIATE FOR YOUR PROJECT).***

Program Evaluation: The MSGC will conduct an annual evaluation of the research project with the assistance of the Maine NASA EPSCoR TAC. Data will be gathered on the identified parameters for the prior 3 calendar years and used as a baseline comparison for the data collected annually during the project timeframe. Evaluation data will be presented to the TAC at annual meetings to assess progress towards national competitiveness and sustainability, and to solicit recommendations for improvement. The table below provides the metrics and outcomes by which the overall success of the research infrastructure project will be evaluated.

Category	*Metrics (expected results)*	*Outcomes*
Research Competitiveness	***4*** *papers published in refereed journals;* ***6*** *presentations or abstracts at scientific meetings;* ***4*** *grant proposals submitted*	*Increased expertise and recognition as leaders in the utilization of NASA data in coastal ocean applications*
Student Research successes	***1*** *post doc &* ***2*** *graduate students mentored,* ***12*** *undergraduate STEM research opportunities;* ***3*** *presentations at professional meetings*	*Increased Maine young scientist capability with NASA data; Increased Maine undergraduate participation in STEM research*
Collaboration with Universities	***3*** *multi-institutional manuscripts submitted, development of ocean remote sensing undergraduate curricula at UM and UMM*	*Increased NASA ocean-related R&D and applications capacity in; new collaborative teams*
Collaboration with NASA Centers	*NASA participation in project development, NASA at project meetings, delivery of GNATS data into NASA database*	*Increased research and collaboration with NASA scientists and centers*
Continuity	*4 proposals submitted using new instrumentation / new capabilities, teaching and mentoring on NASA ocean data / applications*	*Increased research / teaching capacity within Maine and collaboration with NASA scientists*
Sustainability	***3*** *funded grant proposals, improved ocean data products from satellites, new GIS applications for local municipalities*	*Increased expertise and recognition as leaders in multi and hyperspectral coastal data applications*

Student Tracking: MSGC has a longitudinal tracking system for students who receive a significant award or experience. Notices are sent out to all students twice annually requesting information on their academic and workforce status as well as data on publications, presentations, and proposals submitted to other funding agencies as a result of their award. Tracking is terminated once the students advance to their next level. We will report the results annually to NASA OEPM.

Management: This section must include two subsections. The first subsection is for the research management and the second subsection is for the overall program management. In the research management, identify the roles and responsibilities of team members involved in the development and execution of proposed research activity. This could be in table or narrative form. In the program management subsection, the following statement must be included.

Program Management: The MSGC is the lead institution and fiscal agent for this proposal and is governed by a Board of Directors that reflects a balanced representation of private and public affiliate members involved in space and aeronautics-related research and education activities. Dr. Terry Shehata, Director of MSGC and the State NASA EPSCoR Director, is the Principal Investigator and will have oversight of the cooperative agreement. The Technical Advisory Committee (TAC) provides guidance to the Maine NASA EPSCoR program, and assists in reviewing program and research progress and accomplishments. The TAC is chaired by Dr. Shehata and includes the State EPSCoR Director, one representative from the state industry, one *representative from state government, and one member from one of the affiliates of the state's NASA Space Grant Program. With the assistance of the TAC, MSGC will monitor the progress of the proposed research program according to the proposed program evaluation (next section).*

Prior NASA EPSCoR Research Support: *(LAST TWO PAGES; DOES NOT COUNT TOWARD 15-PAGE LIMIT). Leave page blank. Information will be provided by the Maine NASA EPSCoR Director if your proposal is selected for submission to NASA.*

E. Other Parts of the Application

Follow the instructions in the 2020 CAN for References and Citations, Current and Pending Support for Research, Biographical Sketches, Budget and Budget Narrative, and Letters of Commitment. The budget section should include budget details (table or worksheet format) and a budget narrative. Include separate annual budgets plus a three-year cumulative budget broken out by federal request and cost share. The budget should include itemized expenses within major budget categories (Salaries/benefits, subcontracts, consultants, equipment, travel, supplies, other, indirect costs, etc.). The budget narrative should include enough detail to clearly understand the connection to the proposed project. Budget information should include cost share. *The maximum funding request per proposal is $750,000. MSGC is the applicant and will deduct $6,250 for management support. Therefore, your budget cannot exceed $743,750. This amount is to be expended over a three-year period. All NASA EPSCoR monies must be matched 50% with non-federal monies for a total of $375.000. In-kind matches are allowable.*

12. Proposal Submission Instructions

Submissions via e-mail are required as a **single PDF** attachment. Faxed or postal mail will **not** be accepted. Send all materials to:

Jana Hall, Director of Education Programs
Maine Space Grant Consortium
87 Winthrop Street, Suite 200
Augusta, ME 04330
Phone: (207) 622-4688
jana.hall@msgc.org

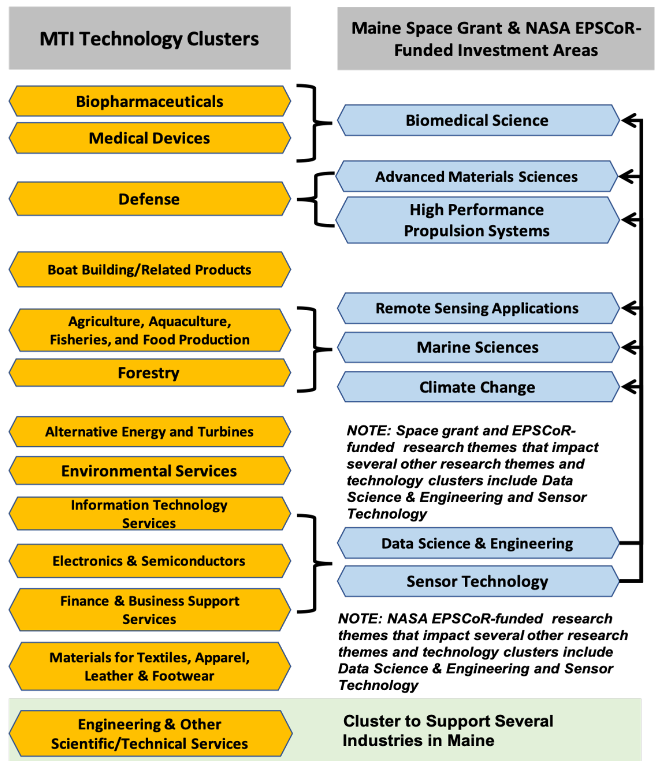
If you have questions about this announcement, e-mail jana.hall@msgc.org or terry.shehata@msgc.org, or call toll-free at 1-877-397-7223. For more information about Maine Space Grant Consortium and NASA please visit www.msgc.org.

Appendix A: A New Space Economy Vision for Maine

Maine and NASA

Over the past two decades, the Maine Space Grant Consortium has invested NASA space grant and EPSCoR funds to support students and researchers at our Affiliates in thematic research areas (Figure 1) that align with the interests of NASA and the Maine Technology Institute's (MTI) technology clusters[1]. These areas represent Maine's current strengths in NASA-related research and education.

Figure 1: Maine Space Grant and NASA EPSCoR Investments



These investments have enabled students and researchers to create or expand their relationships with NASA and Maine's aerospace community. Researchers at the University of Maine (UMaine) are helping NASA test the integrity of a hypersonic inflatable aerodynamic decelerator that could be used for safe Mars descents and are testing the potential of using sensor technology to detect leaks in the ISS created by micrometeorites. Other researchers at UMaine and the Gulf of Maine Research Institute are using NASA remote sensing data to develop solutions for detecting and adapting to climate change in the Gulf of Maine; to assess forest health assessment; and to inform Maine harmful algal blooms shellfish toxicity monitoring and coastal management, and to demonstrate the possibilities afforded by new hyperspectral data. A few graduate students are now employed at NASA centers and aerospace companies such as JSC, SpaceX and United Launch Alliance. VALT Enterprises and bluShift Aerospace are developing small rockets for launching nanosatellites.

Maine is also involved with NASA in ways unrelated to NASA space grant and EPSCoR investments. For example, Astronauts Chris Cassidy and Jessica Meir, Dr. George Nelson, Director of the Technology and Science Research Office for the International Space Station, and Bridget Ziegelaar, Operations Manager for the ISS Research Integration Office are Maine natives. Fiber Materials Inc, a Maine business, is working an essential component of the Ascent Abort-2 for the Orion. A small Maine startup, bluShift Aerospace, was recently awarded a grant from NASA to conduct R&D on small rockets to launch nanosatellites.

As the public becomes increasingly aware of these examples and others, they express amazement about the extent Maine is involved in space exploration. With these positive reactions and as

[1] Maine Technology Institute (2014). Re-Examining Maine's Economic Position, Innovation Ecosystem and Prospects for Growth in its Technology Intensive Industry Clusters. Prepared by Battelle Technology Partnership Practice. 136 pages. 2014. https://nces.ed.gov/programs/digest/d17/tables/dt17_306.60.asp

NASA prepares to return to the Moon by 2024 and Mars thereafter, we asked the following question: (a) *How can we leverage our investments over the past two decades to create an environment and culture in Maine that would significantly increase the involvement of Maine's future workforce in NASA missions while supporting economic growth in Maine? (b) With limited funds, what should be the integrated portfolio of programs and activities we can propose that will align with NASA requirements and ours and yield the best return on investment?* The answer requires complimentary visions and strategies for space exploration and economic growth, which NASA has. Currently, the State of Maine does not have an economic development plan but is in the process of developing one which should be released in Fall 2019.

Maine's STEM Research and Education Strategies

In the absence of an economic growth strategy for the state, four separate groups developed goals to increase degree attainment, strengthen STEM education, science and technology infrastructure and human capital, and quality jobs in specific sectors. These goals are summarized in Table 1.

Table 1: Goals and Objectives in STEM Education, R&D and Business Growth in Maine

Strategy	Goal
Education Attainment	The *MaineSpark* Coalition (2018) "*…set a goal that 60% of the Maine workforce will have a credential of value beyond high school by 2025"* to address Maine's urgent need for a talented workforce skilled for the jobs available, and this need can only be met by more people earning college degrees, industry certifications and other high-quality credentials. 46% of Mainers ages 25-64 hold a credential beyond high school, lower than the national rate of 47.6% (Lumina Foundation, 2019a, 2019b).
STEM Education	The Maine STEM Council (2016) identified five goals to enhance STEM education: (a) improve STEM achievement and interest among grades preK-12 students; (b) increase the percentage of students completing postsecondary STEM degrees; (c) align secondary and postsecondary training with the state's workforce needs; (d) create conditions across industry sectors that promote STEM education and careers; and (e) broaden opportunities for low-income, first-generation college students and minorities, including females, in all STEM fields and workforce.
S&T Infrastructure & Human Capital	The Maine Innovation Economy Advisory Board (2017) released the state's S&T Plan that outlined a three-pronged strategy to diversify and strengthen the state's innovation-based economy by: (a) growing R&D capacity; (b) increasing human capital; and (c) cultivating entrepreneurship and innovation.
Quality Job Creation	*FocusMaine* (2018), a private sector group, developed a master plan to accelerate the creation of quality jobs in the state's highest-growth fields: agriculture, aquaculture, and biopharmaceuticals.

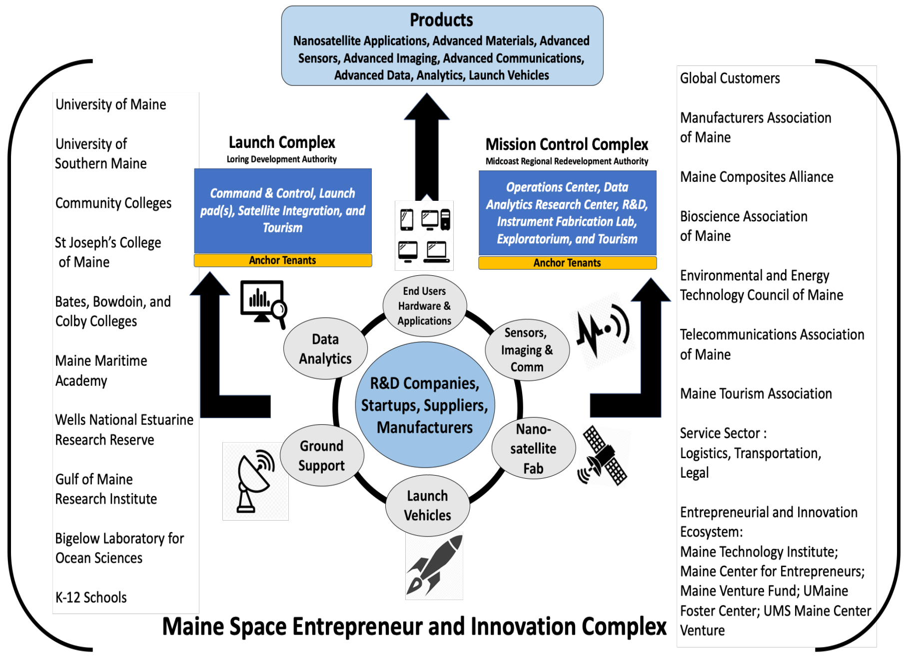
Collectively, these efforts are essential to the state's economic growth, but they lack an overall economic growth vision that would convey to the public *to what end are we investing in education, research and workforce development*. Such a vision would inform us how best to impact economic growth by investing NASA space grant and EPSCoR funds in a meaningful manner that achieves the mutual goals NASA, the Federal STEM Strategy, and the State of Maine.

Building a Foundation for a New Space Economy in Maine

On May 28-March 1, 2018, we hosted a two-day workshop to discuss the potential for Maine to create a spaceport complex as the vision that could galvanize the public and all sectors of Maine's economy to generate excitement and investments in research and education infrastructure for a new space economy (Figure 2). Over 60 people participated including representatives from research, education, government and private sectors, NASA and the FAA. The participants agreed that Maine is poised for a leadership role in the emerging and fast-growing market for nanosatellites, by launching nanosatellites using small, low cost launch vehicles for the following reasons:

a) the state's longitude/ latitude and coastline offer direct polar orbit access (1st on east coast) and very low population density;
b) unique space access offering to New England aerospace community and beyond;
c) low market barriers to entry (low-cost/low-risk) enabled by bluShift Aerospace and VALT Enterprises;
d) high return on investment (high-tech & manufacturing job creation/STEM education); and
e) existing resources and infrastructure (former air and naval air bases in Limestone and Brunswick, land, coastline, & airspace, aerospace-related supply chain, aerospace-related R&D in the New England private sector and higher education institutions.

Figure 2: Vision for a new Space Economy in Maine



Growing the new space economy would help train and retain Maine's students graduating with aerospace-related STEM degrees; encourage startups; attract skilled workers and their families from out of state; and analysis of data generated by satellites can enhance decision making and improve management of natural resources.

After the workshop, we conducted a MTI-funded market study on the viability of the spaceport complex. Some of the major findings of the study included: (a) NASA, DOD, several small and large aerospace companies and academic institutions in the Northeast region are highly interested in using the *Complex's* launch facilities; and (b) Maine's spaceport complex must follow a path different from the existing FAA-approved spaceports, which have struggled due to the lack of large launch vehicles. To this end, the study identified three business units of the *Complex* as illustrated in Figure 3 and described in Table 2.

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Figure 3: Proposed Business Units of the Maine SpacePort Complex

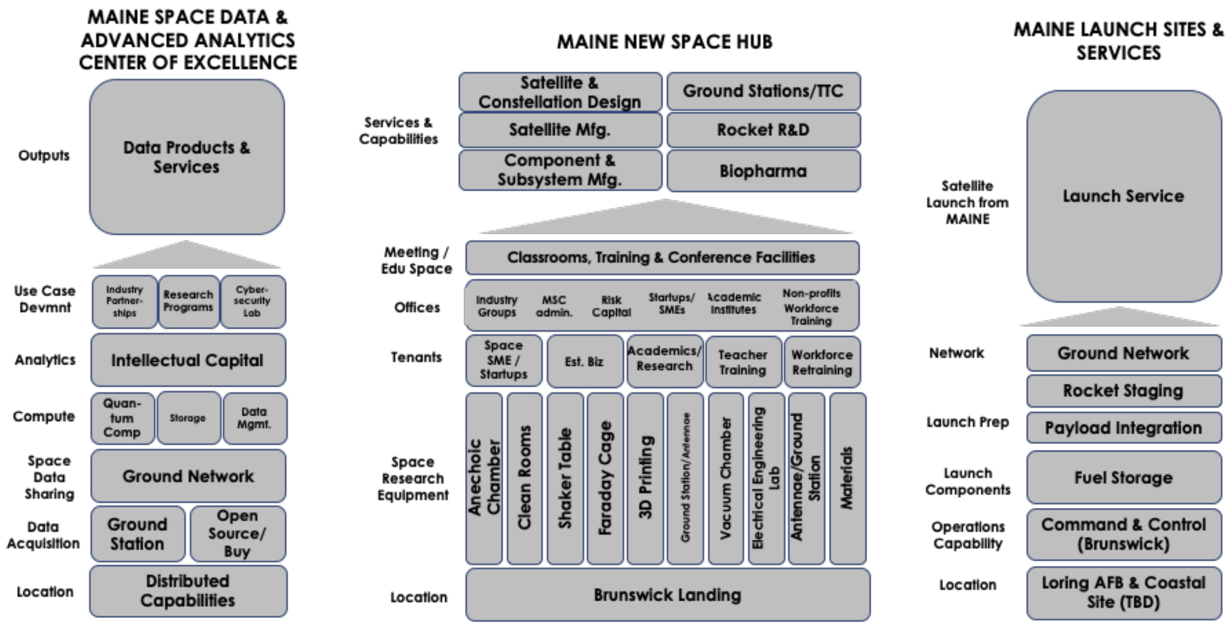

Table 2: Value Statements for Proposed Business Units

Business Unit	Value
Maine Space Data & Advanced Analytics Center of Excellence	This unit will serve to develop next generation cross-cutting skills and capabilities necessary for competition in an increasingly digital world. It will help reduce the siloed set of activities across the various academic institutions and build upon Maine's academic capacity in computer science, data analytics, and geospatial informatics. It will strategically build the low risk, downstream portion of the New Space value chain with focus on Earth orbit & communications technology that align to polar orbit missions.
Maine New Space Innovation Hub	K-12 engagement and development (in person and digitally); Data & analytics physical meeting place/ node for industry engagement and collaboration; Hosting national/international industry events to shine spotlight on Maine's progress; Classroom for aerospace, computer science, physics, mathematics related courses that want to explore new space more deeply; Support of aerospace collaboration amongst startups and established businesses with in-kind grant money and tax breaks for collaborations.
Maine Launch Sites & Services	Developing launch capability focused on low-cost access to polar orbit will create demand as new space industry grows among commercial and gov't stakeholders, creating highly skilled jobs and workforce retraining opportunities, spurring innovation and creating a foothold to capture future opportunities as the industry matures and develops. It will leverage the current capabilities Maine is building in rocketry and geospatial analytics, to become a more visible national and international aerospace industry destination.

Currently, we are working with the Governor to establish a public-private governance body to develop an implementation plan, secure finance and human resources, and integrate outside and downstream interests to pursue development opportunities efficiently and effectively. As this process unfolds, the market study recommended seeding the development of higher education resources and collaborations (Table 3) that align both with NASA priorities and Maine's current and aspirational capabilities in space exploration thus laying the foundation for realizing the potential of the *Complex.*

Table 3: Proposed Seed Investments in the *Complex's* Higher Education Resources and Collaborations

1. Develop intellectual capital to support the growth of aerospace research and curricula programs with focal areas in spacecraft systems, rocketry, telemetry, tracking and control, telecommunications, electronics and data science.
2. Build capability in small satellites to support R&D with leading Earth Observation sensing & measurement technologies.
3. Develop computer and data science curricula with space science focus to develop downstream capabilities across Maine universities and colleges.
4. Invest in quantum computing resources and capability development.
5. Develop the space science and advanced analytics to support collaboration and facilitate innovation.
6. Pursue technology transfer opportunities with businesses, local and regional institutions across the state & region.
7. Build STEM capability in K-12 curricula across the state with emphasis on computer science.

In this context, Table 4 identifies initial R&D and education topic areas associated with seeding the *Complex's* business units that align with Mission Directorates and Centers and will be the priority for NASA space grant and EPSCoR investments for the next four years.

Table 4: Alignment of R&D and Education Topic Areas with NASA Mission Directorates and Centers

Maine SpacePort Complex Topic Area	Mission Directorate*	NASA Center**
Big Data & Analytics and Data Management	HEOMD	LRC, ARC, GSFC, JPL
Quantum Computing & Storage	HEOMD	GSFC, ARC
Ground Communication	HEOMD	KSC, MSFC, JSC, JPL, GSFC
CubeSat & Constellation Design	STMD	GSFC, ARC, MSFC
Vehicle and payload integration	HEOMD, STMD	KSC
Launch services	HEOMD	KSC, GRC, GSFC, SSC, MSFC, JPL
S&E Payload R&D	HEOMD, STMD, SMD	LRC, JPL, GSFC, ARC
Navigation & Tracking	HEOMD, STMD	GSFC, MSFC, GRC, JPL, MSFC
Geospatial Informatics and remote sensing	STMD	GSFC, JPL, LRC
Communications	HEOMD	JSC, GRC, JPL
Small launch vehicles, components, subsys mfg.	HEOMD, STMD	LRC, KSC, MSFC, GRC, JSC, JPL
Satellite manufacturing	STMD	MSFC, KSC, JPL, LRC
K-12 STEM Capability	All	All

* Mission Directorates: HEOMD (Human Exploration and Operations); STMD (Space Technology); SMD (Science). ** NASA Centers: GSFC (Goddard Space Flight Center); JSC (Johnson Space Center); KSC (Kennedy Space Center); MSFC (Marshall Space Flight Center); JPL (Jet Propulsion Laboratory); SSC (Stennis Space Center); LRC (Langley Research Center); ARC (Ames Research Center); GRC (Glenn Research Center).

Appendix B: NASA Mission Directorates Interests

NASA's Mission *to pioneer the future in space exploration, scientific discovery, and aeronautics research,* draws support from four Mission Directorates, nine NASA Centers, and JPL, each with a specific responsibility.

B.1 Aeronautics Research Mission Directorate (ARMD) conducts high-quality, cutting-edge research that generates innovative concepts, tools, and technologies to enable revolutionary advances in our Nation's future aircraft, as well as in the airspace in which they will fly. ARMD's four research programs develop advanced technologies to reduce aviation's environmental impact & transform the way we fly.

- Advanced Air Vehicles
- Airspace Operations and Safety
- Integrated Aviation Systems
- Transformative Aeronautics Concepts Program

Additional information on the Aeronautics Research Mission Directorate (ARMD) can be found at: https://www.nasa.gov/aeroresearch.

Areas of Interest - POC: Karen Rugg, karen.l.rugg@nasa.gov
Proposers are directed to the following:

- ARMD Programs: https://www.nasa.gov/aeroresearch/programs
- The ARMD current year version of the NASA Research Announcement (NRA) entitled, "Research Opportunities in Aeronautics (ROA)" is posted on the NSPIRES web site at http://nspires.nasaprs.com (*Key word: Aeronautics*). This solicitation provides a complete range of ARMD research interests.

B.2 Human Exploration & Operations Mission Directorate (HEOMD) provides the Agency with leadership and management of NASA space operations related to human exploration in and beyond low-Earth orbit. HEO also oversees low-level requirements development, policy, and programmatic oversight. The International Space Station, currently orbiting the Earth with a crew of six, represents the NASA exploration activities in low-Earth orbit. Exploration activities beyond low Earth orbit include the management of Commercial Space Transportation, Exploration Systems Development, Human Space Flight Capabilities, Advanced Exploration Systems, and Space Life Sciences Research & Applications. The directorate is similarly responsible for Agency leadership and management of NASA space operations related to Launch Services, Space Transportation, and Space Communications in support of both human and robotic exploration programs. Additional information on the Human Exploration & Operations Mission Directorate (HEOMD) can be found at: (http://www.nasa.gov/directorates/heo/home/index.html)

Areas of Interest - POC: Bradley Carpenter, bcarpenter@nasa.gov

Human Research Program

The Human Research Program (HRP) is focused on investigating and mitigating the highest risks to human health and performance in order to enable safe, reliable, and productive human space exploration. The HRP budget enables NASA to resolve health risks in order for humans to safely live and work on missions in the inner solar system. HRP conducts research, develops countermeasures, and undertakes technology development to address human health risks in space and ensure compliance with NASA's health, medical, human performance, and environmental standards.

Space Life Sciences

The Space Life Sciences, Space Biology Program has three primary goals:

- To effectively use microgravity and the other characteristics of the space environment to enhance our understanding of fundamental biological processes;
- To develop the scientific and technological foundations for a safe, productive human presence in space for extended periods and in preparation for exploration; and
- To apply this knowledge and technology to improve our nation's competitiveness, education, and the quality of life on Earth.

These goals will be achieved by soliciting research using its three program elements:

- Cell and Molecular Biology and Microbial Biology - studies of the effect of gravity and the space environment on cellular, microbial and molecular processes;
- Organismal & Comparative Biology - studies and comparisons of responses of whole organisms and their systems; and
- Developmental Biology – studies of how spaceflight affects reproduction, development, maturation and aging of multi-cellular organisms, as described in NASA's Fundamental Space Biology Science Plan (PDF, 7.4 MB).

Further details about ongoing activities specific to Space Biology are available at: Space Biosciences website

Physical Science Research

The Physical Science Research Program, along with its predecessors, has conducted significant fundamental and applied research, both which have led to improved space systems and produced new products offering benefits on Earth. NASA's experiments in various disciplines of physical science reveal how physical systems respond to the near absence of gravity. They also reveal how other forces that on Earth are small compared to gravity, can dominate system behavior in space.

The Physical Science Research Program also benefits from collaborations with several of the International Space Station international partners—Europe, Russia, Japan, and Canada—and foreign governments with space programs, such as France, Germany and Italy. The scale of this research enterprise promises new possibilities in the physical sciences, some of which are already being realized both in the form of innovations for space exploration to improve the quality of life on Earth.

Research in physical sciences spans from basic and applied research in the areas of:

- Fluid physics: two-phase flow, phase change, boiling, condensation and capillary and interfacial phenomena;
- Combustion science: spacecraft fire safety, solids, liquids and gasses, supercritical reacting fluids, and soot formation;
- Materials science: solidification in metal and alloys, crystal growth, electronic materials, glasses and ceramics;
- Complex Fluids: colloidal systems, liquid crystals, polymer flows, foams and granular flows; and
- Fundamental Physics: critical point phenomena, atom interferometry and atomic clocks in space.

Implementing Centers: NASA's Physical Sciences Research Program is carried out at the Glenn Research Center (GRC), Jet Propulsion Laboratory (JPL) and Marshall Space Flight Center (MSFC). Further information on physical sciences research is available at http://issresearchproject.nasa.gov/

Engineering Research

- Spacecraft: Guidance, navigation and control; thermal; electrical; structures; software; avionics; displays; high speed re-entry; modeling; power systems; interoperability/commonality; advanced spacecraft materials; crew/vehicle health monitoring; life support.
- Propulsion: Propulsion methods that will utilize materials found on the moon or Mars, “green” propellants, on-orbit propellant storage, motors, testing, fuels, manufacturing, soft landing, throttle-able propellants, high performance, and descent.
- Robotic Systems for Precursor Near Earth Asteroid (NEA) Missions: Navigation and proximity operations systems; hazard detection; techniques for interacting and anchoring with Near Earth Asteroids; methods of remote and interactive characterization of Near Earth Asteroid (NEA) environments, composition and structural properties; robotics (specifically environmental scouting prior to human arrival and later to assist astronauts with NEA exploration); environmental analysis; radiation protection; spacecraft autonomy, enhanced methods of NEA characterization from earth-based observation.
- Robotic Systems for Lunar Precursor Missions: Precision landing and hazard avoidance hardware and software; high-bandwidth communication; in-situ resource utilization (ISRU) and prospecting; navigation systems; robotics (specifically environmental scouting prior to human arrival, and to assist astronaut with surface exploration); environmental analysis, radiation protection.
- Data and Visualization Systems for Exploration: Area focus on turning precursor mission data into meaningful engineering knowledge for system design and mission planning of lunar surface and NEAs. Visualization and data display; interactive data manipulation and sharing; mapping and data layering including coordinate transformations for irregular shaped NEAs; modeling of lighting and thermal environments; simulation of environmental interactions including proximity operations in irregular micro-G gravity fields and physical stability of weakly bound NEAs.
- Research and technology development areas in HEOMD support launch vehicles, space communications, and the International Space Station. Examples of research and

technology development areas (and the associated lead NASA Center) with great potential include:

- *Processing and Operations*
  - Crew Health and Safety Including Medical Operations (Johnson Space Center (JSC))
  - In-helmet Speech Audio Systems and Technologies (Glenn Research Center (GRC))
  - Vehicle Integration and Ground Processing (Kennedy Space Center (KSC))
  - Mission Operations (Ames Research Center (ARC))
  - Portable Life Support Systems (JSC)
  - Pressure Garments and Gloves (JSC)
  - Air Revitalization Technologies (ARC)
  - In-Space Waste Processing Technologies (JSC)
  - Cryogenic Fluids Management Systems (GRC)
- *Space Communications and Navigation*
  - Coding, Modulation, and Compression (Goddard Spaceflight Center (GSFC)
  - Precision Spacecraft & Lunar/Planetary Surface Navigation and Tracking (GSFC)
  - Communication for Space-Based Range (GSFC)
  - Antenna Technology (Glenn Research Center (GRC))
  - Reconfigurable/Reprogrammable Communication Systems (GRC)
  - Miniaturized Digital EVA Radio (JSC)
  - Transformational Communications Technology (GRC)
  - Long Range Optical Telecommunications (Jet Propulsion Laboratory (JPL))
  - Long Range Space RF Telecommunications (JPL)
  - Surface Networks and Orbit Access Links (GRC)
  - Software for Space Communications Infrastructure Operations (JPL)
  - TDRS transponders for launch vehicle applications that support space communication and launch services (GRC)
- *Space Transportation*
  - Optical Tracking and Image Analysis (KSC)
  - Space Transportation Propulsion System and Test Facility Requirements and Instrumentation (Stennis Space Center (SSC)
  - Automated Collection and Transfer of Launch Range Surveillance/Intrusion Data (KSC)
  - Technology tools to assess secondary payload capability with launch vehicles (KSC)
  - Spacecraft Charging/Plasma Interactions (Environment definition & arcing mitigation) (Marshall Space Flight Center (MSFC)

B.3 Science Mission Directorate (SMD) leads the Agency in four areas of research: Earth Science, Heliophysics, Planetary Science, and Astrophysics. SMD, using the vantage point of space to achieve with the science community and our partners a deep scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effects on the solar system, and the universe beyond. In so doing, we lay the intellectual foundation for the robotic and human expeditions of the future while meeting today's needs for scientific information to address national concerns, such as climate change and space weather. SMD's high-level strategic objectives are presented in the 2018 NASA Strategic Plan. Detailed plans by science area corresponding to the science divisions of SMD: Heliophysics, Earth Science, Planetary Science, and Astrophysics appear in Chapter 4 of the 2014 NASA Science Plan. The best expression of specific research topics of interest to each Division within SMD are represented in by the topics listed in SMD's "ROSES" research solicitation, see Table 3 of ROSES-2019 and the text in the Division research overviews of ROSES, i.e., the Earth Science Research Overview, the Heliophysics Division Overview, the Planetary Science Research Program Overview and the Astrophysics Research Program Overview. Please note, even if particular topic is not solicited in ROSES this year it is still a topic of interest and eligible for this solicitation. Additional information about the Science Mission Directorate may be found at: http://nasascience.nasa.gov.

SMD POC: Kristen Erickson kristen.erickson@nasa.gov

Heliophysics Division
Heliophysics encompasses science that improves our understanding of fundamental physical processes throughout the solar system, and enables us to understand how the Sun, as the major driver of the energy throughout the solar system, impacts our technological society. The scope of heliophysics is vast, spanning from the Sun's interior to Earth's upper atmosphere, throughout interplanetary space, to the edges of the heliosphere, where the solar wind interacts with the local interstellar medium. Heliophysics incorporates studies of the interconnected elements in a single system that produces dynamic space weather and that evolves in response to solar, planetary, and interstellar conditions.

The Agency's strategic objective for heliophysics is to **understand the Sun and its interactions with Earth and the solar system, including space weather.** The heliophysics decadal survey conducted by the National Research Council (NRC), *Solar and Space Physics: A Science for a Technological Society (http://www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society*), articulates the scientific challenges for this field of study and recommends a slate of design reference missions to meet them, to culminate in the achievement of a predictive capability to aid human endeavors on Earth and in space. The fundamental science questions are:

- What causes the Sun to vary?
- How do the geospace, planetary space environments and the heliosphere respond?
- What are the impacts on humanity?

To answer these questions, the Heliophysics Division implements a program to achieve three overarching goals:

- Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system
- Advance our understanding of the connections that link the Sun, the Earth, planetary space environment, and the outer reaches of our solar system
- Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth

Further information on the objectives and goals of NASA's Heliophysics Program may be found in the *2014 Science Plan and Our Dynamic Space Environment: Heliophysics Science and Technology Roadmap for 2014-2033* (download PDF). The Heliophysics research program is described in Chapter 4.1 of the *SMD Science Plan 2014* available at http://science.nasa.gov/about-us/science-strategy/. The program supports theory, modeling, and data analysis utilizing remote sensing and *in situ* measurements from a fleet of missions; the Heliophysics System Observatory (HSO). Frequent CubeSats, suborbital rockets, balloons, and ground-based instruments add to the observational base. Investigations that develop new observables and technologies for heliophysics science are sought.

Supported research activities include projects that address understanding of the Sun and planetary space environments, including the origin, evolution, and interactions of space plasmas and electromagnetic fields throughout the heliosphere. The program seeks to characterize these phenomena on a broad range of spatial and temporal scales, to understand the fundamental processes that drive them, to understand how these processes combine to create space weather events, and to enable a capability for predicting future space weather events.

The program supports investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun. It supports investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere and their interaction with the Earth and other planets, as well as with the interstellar medium.

The program also supports investigations of the physics of magnetospheres, including their formation and fundamental interactions with plasmas, fields, and particles and the physics of the terrestrial mesosphere, thermosphere, ionosphere, and auroras, including the coupling of these phenomena to the lower atmosphere and magnetosphere. Proposers may also review the information in the ROSES-19 Heliophysics Division Overview for further information about the Heliophysics Research Program.

Earth Science Division

Our planet is changing on all spatial and temporal scales and studying the Earth as a complex system is essential to understanding the causes and consequences of global change. The Earth Science Division of the Science Mission Directorate (https://science.nasa.gov/earth-science) contributes to NASA's mission, in particular, Strategic Objective 1.1: Understanding The Sun, Earth, Solar System, And Universe. This strategic objective is motivated by the following key questions:

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

These science questions translate into seven overarching science goals to guide the Earth Science Division’s selection of investigations and other programmatic decisions:

- Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition (Atmospheric Composition)
- Improve the capability to predict weather and extreme weather events (Weather)
- Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle (Carbon Cycle and Ecosystems)
- Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change (Water and Energy Cycle)
- Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system (Climate Variability and Change)
- Characterize the dynamics of Earth's surface and interior, improving the capability to assess and respond to natural hazards and extreme events (Earth Surface and Interior)
- Further the use of Earth system science research to inform decisions and provide benefits to society

The most recent decadal survey (2017-2027) from the National Academies of Science, Engineering, and Medicine, *Thriving on our Changing Planet: A Decadal Strategy for Earth Observation from Space*, serves as a foundational document to guide the overall approach to the Earth science program (see https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth).

NASA's ability to view the Earth from a global perspective enables it to provide a broad, integrated set of uniformly high-quality data covering all parts of the planet. NASA shares this unique knowledge with the global community, including members of the science, government, industry, education, and policy-maker communities.

Planetary Science Division

The Planetary Science Research Program, managed by the Planetary Science Division, sponsors research that addresses the broad strategic objective to "Ascertain the content, origin, and evolution of the Solar System and the potential for life elsewhere." To pursue this objective, the Planetary Science Division has five science goals that guide the focus of the division's science research and technology development activities. As described in Chapter 4.3 of the SMD 2014 Science Plan (https://science.nasa.gov/about-us/science-strategy), these are:

- Explore and observe the objects in the Solar System to understand how they formed and evolve.
- Advance the understanding of how the chemical and physical processes in the Solar System operate, interact and evolve.
- Explore and find locations where life could have existed or could exist today.
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere.
- Identify and characterize objects in the Solar System that pose threats to Earth or offer resources for human exploration.

In order to address these goals, the Planetary Research Program invites a wide range of planetary science and astrobiology investigations. Example topics include, but are not limited to:

- Investigations aimed at understanding the formation and evolution of the Solar System and (exo) planetary systems in general, and of the planetary bodies, satellites, and small bodies in these systems;
- Investigations aimed at understanding materials present, and processes occurring, in the early stages of Solar System history, including the protoplanetary disk;
- Investigations aimed at understanding planetary differentiation processes;
- Investigations of extraterrestrial materials, including meteorites, cosmic dust, presolar grains, and samples returned by the Apollo, Stardust, Genesis, and Hayabusa missions;
- Investigations of the properties of planets, satellites (including the Moon), satellite and ring systems, and smaller Solar System bodies such as asteroids and comets;
- Investigations of the coupling of a planetary body's intrinsic magnetic field, atmosphere, surface, and interior with each other, with other planetary bodies, and with the local plasma environment;
- Investigations into the origins, evolution, and properties of the atmospheres of planetary bodies (including satellites, small bodies, and exoplanets);
- Investigations that use knowledge of the history of the Earth and the life upon it as a guide for determining the processes and conditions that create and maintain habitable environments and to search for ancient and contemporary habitable environments and explore the possibility of extant life beyond the Earth;
- Investigations into the origin and early evolution of life, the potential of life to adapt to different environments, and the implications for life elsewhere;
- Investigations that provide the fundamental research and analysis necessary to characterize exoplanetary systems;
- Investigations related to understanding the chemistry, astrobiology, dynamics, and energetics of exoplanetary systems;
- Astronomical observations of our Solar System that contribute to the understanding of the nature and evolution of the Solar System and its individual constituents;
- Investigations to inventory and characterize the population of Near Earth Objects (NEOs) or mitigate the risk of NEOs impacting the Earth;
- Investigations into the potential for both forward and backward contamination during planetary exploration, methods to minimize such contamination, and standards in these areas for spacecraft preparation and operating procedures;
- Investigations which enhance the scientific return of NASA Planetary Science Division missions through the analysis of data collected by those missions;
- Advancement of laboratory- or spacecraft-based (including small satellites, e.g., CubeSats) instrument technology that shows promise for use in scientific investigations on future planetary missions; and
- Analog studies, laboratory experiments, or fieldwork to increase our understanding of Solar System bodies or processes and/or to prepare for future missions.

Proposers may also review the information in the ROSES-2019 Planetary Science Research Program Overview for further information about the Planetary Science Research Program.

Astrophysics Division

Astrophysics is the study of phenomena occurring in the universe and of the physical principles that govern them. Astrophysics research encompasses a broad range of topics, from the birth of the universe and its evolution and composition, to the processes leading to the development of planets and stars and galaxies, to the physical conditions of matter in extreme gravitational fields, and to the search for life on planets orbiting other stars. In seeking to understand these phenomena, astrophysics science embodies some of the most enduring quests of humankind. NASA's strategic objective in astrophysics is to discover how the universe works, explore how it began and evolved, and search for life on planets around other stars. Three broad scientific questions flow from this objective:

- How does the universe work?
- How did we get here?
- Are we alone?

Each of these questions is accompanied by a science goal that shapes the Astrophysics Division's efforts towards fulfilling NASA's strategic objective:

- Probe the origin and destiny of our universe, including the nature of black holes, dark energy, dark matter and gravity
- Explore the origin and evolution of the galaxies, stars and planets that make up our universe
- Discover and study planets around other stars, and explore whether they could harbor life

The scientific priorities for astrophysics are outlined in the NRC decadal survey New Worlds, New Horizons in Astronomy and Astrophysics (http://www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics). These priorities include understanding the scientific principles that govern how the universe works; probing cosmic dawn by searching for the first stars, galaxies, and black holes; and seeking and studying nearby habitable planets around other stars.

The multidisciplinary nature of astrophysics makes it imperative to strive for a balanced science and technology portfolio, both in terms of science goals addressed and in missions to address these goals. All the facets of astronomy and astrophysics—from cosmology to planets—are intertwined, and progress in one area hinges on progress in others. However, in times of fiscal constraints, priorities for investments must be made to optimize the use of available funding. NASA uses the prioritized recommendations and decision rules of the decadal survey to set the priorities for its investments.

The broad themes of the Astrophysics Research Program are:

(i) Physics of the Cosmos: to discover how the universe works at the most fundamental level; to explore the behavior and interactions of the particles and fundamental forces of nature, especially their behavior under the extreme conditions found in astrophysical situations; and to explore the processes that shape the structure and composition of the universe as a whole, including the forces which drove the Big Bang and continue to drive the accelerated expansion of the universe.

(ii) Cosmic Origins: to discover how the universe expanded and evolved from an extremely hot and dense state into the galaxies of stars, gas, and dust that we observe around us today; to discover how dark matter clumped under gravity into the tapestry of large-scale filaments and structures which formed the cosmic web for the formation of galaxies and clusters of galaxies; to discover how stars and planetary systems form within the galaxies; and to discover how these complex systems create and shape the structure and composition of the universe on all scales.

(iii) Exoplanet Exploration: to search for planets and planetary systems about nearby stars in our Galaxy; to determine the properties of those stars that harbor planetary systems; to determine the percentage of planets that are in or near the habitable zone of a wide variety of stars, and identify candidates that could harbor life.

(iv) Research Analysis and Technology Development: a vital component of the astrophysics program is the development of new techniques that can be applied to future major missions: the test-beds for these new techniques are the balloons and rockets that are developed and launched from NASA's launch range facilities. This program also supports technology development that includes detectors covering all wavelengths and fundamental particles, as well as studies in laboratory astrophysics. Examples of these studies could include atomic and molecular data and properties of plasmas explored under conditions approximating those of astrophysical environments.

Investigations submitted to the Astrophysics research program should explicitly support past, present, or future NASA astrophysics missions. These investigations can include theory, simulation, data analysis, and technology development. The Astrophysics research program and missions are described in Chapter 4.4 of the SMD 2014 Science Plan available at https://science.nasa.gov/about-us/science-strategy.

Proposers may also review the information in the ROSES-19 Astrophysics Research Program Overview for further information about the Astrophysics Research Program.

B.4 The Space Technology Mission Directorate (STMD) is responsible for developing the crosscutting, pioneering, new technologies, and capabilities needed by the agency to achieve its current and future missions. STMD rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of the aerospace enterprise. STMD employs a merit-based competition model with a portfolio approach, spanning a range of discipline areas and technology readiness levels. By investing in bold, broadly applicable, disruptive technology that industry cannot tackle today, STMD seeks to mature the technology required for NASA's future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities.

Research and technology development takes place within NASA Centers, at JPL, in academia and industry, and leverages partnerships with other government agencies and international partners. STMD engages and inspires thousands of technologists and innovators creating a community of our best and brightest working on the nation's toughest challenges. By pushing the boundaries of technology and innovation, STMD allows NASA and our nation to remain at the cutting edge. Additional information on STMD can be found at: (http://www.nasa.gov/directorates/spacetech/about_us/index.html).

Areas of Interest – POC: Damian.Taylor@nasa.gov

Space Technology Mission Directorate (STMD) expands the boundaries of the aerospace enterprise by rapidly developing, demonstrating, and infusing revolutionary, high-payoff technologies through collaborative partnerships. STMD employs a merit-based competition model with a portfolio approach, spanning a wide range of space technology discipline areas and technology readiness levels. Research and technology development takes place at NASA Centers, academia, and industry, and leverages partnerships with other government agencies and international partners.

STMD plans future investments to support the following strategic thrusts:

- ***Go***: *Rapid, Safe, & Efficient Space Transportation*
  - Provide safe, affordable, and routine access to space
  - Provide cost-efficient, reliable propulsion for long duration missions
  - Enable significantly faster, more efficient deep space missions
- ***Land***: *Expanded Access to Diverse Surface Destinations*
  - Safely and precisely deliver humans & payloads to planetary surfaces
  - Increase access to high-value science sites across the solar system
  - Provide efficient, highly-reliable sample return reentry capability
- ***Live***: *Sustainable Living and Working Farther from Earth*
  - Provide in-space habitation and enable humans to live on other planets
  - Provide efficient/scalable infrastructure to support exploration at scale
  - Providing ability to safely explore and investigate high-value sites
- ***Explore***: *Transformative Missions and Discoveries*
  - Expand access to new environments, sites, and resources
  - Develop new means of observation, exploration, and characterization
  - Enable new mission operations and increased science data

Current space technology topics of particular interest include:

- Methods for space and in space manufacturing
- Autonomous in-space assembly of structures and spacecraft
- Ultra-lightweight materials for space applications
- Materials, structures and mechanisms for extreme environments (low and high temperatures, radiation, etc.).
- Resource prospecting, mining, excavation, and extraction of in situ resources. Efficient in situ resource utilization to produce items required for long-duration deep space missions including fuels, water, oxygen, food, nutritional supplements, pharmaceuticals, building materials, polymers (plastics), and various other chemicals
- High performance space computing
- Smart habitats

- Extreme environment (including cryogenic) electronics for planetary exploration
- Advanced robotics for extreme environment sensing, mobility, manipulation and repair
- Advanced power generation, storage, and distribution for deep space missions and surface operations
- Advanced entry, decent, and landing systems for planetary exploration including materials response models and parachute models
- Radiation modeling, detection and mitigation for deep space crewed missions
- Biological approaches to environmental control, life support systems and manufacturing
- Autonomous systems for deep space missions
- Low size, weight, and power components for small spacecraft including high-bandwidth communication from space to ground, inter-satellite communication, relative navigation and control for swarms and constellations, precise pointing systems, power generation and energy storage, thermal management, system autonomy, miniaturized instruments and sensors, and in-space propulsion
- Technologies that take advantage of small launch vehicles and small spacecraft to conduct more rapid and lower-cost missions
- Advancements in engineering tools and models that support Space Technology advancement and development

Applicants are strongly encouraged to familiarize themselves with the roadmap document most closely aligned with their space technology interests. The roadmap documents may be downloaded at the following link: http://www.nasa.gov/offices/oct/home/roadmaps/index.html. Please note, however, that the 2015 technology taxonomy (outline structure for the roadmaps) currently found under this link is under revision. The 2020 revised technology taxonomy will be uploaded by 30 September 2019 under the same link.

The National Aeronautics and Space Administration (NASA) Space Technology Mission Directorate (STMD) current year version of the NASA Research Announcement (NRA) entitled, "Space Technology Research, Development, Demonstration, and Infusion" has been posted on the NSPIRES web site at http://nspires.nasaprs.com (select "Solicitations" and then "Open Solicitations"). The NRA provides detailed information on specific proposals being sought across STMD program.

Appendix C: NASA Centers Areas of Interest

Examples of Center research interest areas include these specific areas from the following Centers. If no POC is listed in the Center write-up and contact information is needed, please contact the POC listed in Appendix A for that Center and request contacts for the research area of interest.

C.1 Ames Research Center (ARC)

POC: Brenda Collins (brenda.j.collins@nasa.gov)

Ames research Center enables exploration through selected development, innovative technologies, and interdisciplinary scientific discovery. Ames provides leadership in the following areas: astrobiology; small satellites; entry decent and landing systems; supercomputing; robotics and autonomous systems; life Sciences and environmental controls; and air traffic management.

- Entry systems: *Safely delivering spacecraft to Earth & other celestial bodies*
- Supercomputing: *Enabling NASA's advanced modeling and simulation*
- NextGen air transportation: *Transforming the way we fly*
- Airborne science: *Examining our own world & beyond from the sky*
- Low-cost missions: *Enabling high value science to low Earth orbit, the moon and the solar system*
- Biology & astrobiology: *Understanding life on Earth and in space*
- Exoplanets: *Finding worlds beyond our own*
- Autonomy & robotics: *Complementing humans in space*
- Lunar science: *Rediscovering our moon*
- Human factors: *Advancing human-technology interaction for NASA missions*
- Wind tunnels**:** *Testing on the ground before you take to the sky*

Additional Center core competencies include:

- Space Sciences
- Applied Aerospace and Information Technology
- Biotechnology
- Synthetic biology.
- Biological Sciences
- Earth Sciences
- High Performance Computing,
- Intelligent Systems
- Quantum Computing
- Nanotechnology-electronics and sensors.
- Small Spacecraft and Cubesats
- Airspace Systems
- Augmented Reality
- Digital materials

C.2 Armstrong Flight Research Center (AFRC)

POC: Dave Berger, dave.e.berger@nasa.gov

Autonomy (Collision Avoidance, Separation assurance, formation flight, peak seeking control)
(POC: Jack Ryan, AFRC-RC)

- Adaptive Control
  (POC: Curt Hanson, AFRC-RC)
- Hybrid Electric Propulsion
  (POC: Starr Ginn, AFRC-R)
- Control of Flexible Structures using distributed sensor feedback
  (POC: Marty Brenner, AFRC-RS; Peter Suh, AFRC-RC)
- Supersonic Research (Boom mitigation and measurement)
  (POC: Ed Haering, AFRC-RA)
- Supersonic Research (Laminar Flow)
  (POC: Dan Banks, AFRC-RA)
- Environmental Responsive Aviation
  (POC: Mark Mangelsdorf, AFRC-RS)
- Hypersonic Structures & Sensors
  (POC: Larry Hudson, AFRC-RS)
- Large Scale Technology Flight Demonstrations (Towed Glider)
  (POC: Steve Jacobson, AFRC-RC)
- Aerodynamics and Lift Distribution Optimization to Reduce Induced Drag
  (POC: Al Bowers, AFRC-R)

C.3 Glenn Research Center (GRC)

POC: Mark David Kankam, Ph.D. mark.d.kankam@nasa.gov

Research and technology, and engineering engagements comprise including:

- Acoustics / Propulsion Acoustics
- Advanced Energy (Renewable Wind and Solar, Coal Energy and Alternative Energy)
- Advanced Microwave Communications
- Aeronautical and Space Systems Analysis
- Electrified Aircraft
- Computer Systems and Networks
- Electric (Ion) Propulsion
- Icing and Cryogenic Systems/Engine and Airframe Icing
- Instrumentation, Controls and Electronics
- Fluids, Computational Fluid Dynamics (CFD) and Turbomachinery
- Materials and Structures, including Mechanical Components and Lubrication
- Microgravity Fluid Physics, Combustion Phenomena and Bioengineering
- Nanotechnology
- Photovoltaics, Electrochemistry-Physics, and Thermal Energy Conversion
- Propulsion System Aerodynamics
- Space Power Generation, Storage, Distribution and Management

- Urban Air Mobility (UAM)
- Systems Engineering

The above engagement areas relate to the following key Glenn Areas of Expertise:

- Aircraft Propulsion
- Communications Technology and Development
- Space Propulsion and Cryogenic Fluids Management
- Power, Energy Storage and Conversion
- Materials and Structures for Extreme Environment
- Physical Sciences and Biomedical Technologies in Space

C.4 Goddard Space Flight Center (GSFC)

POC: James Harrington james.l.harrington@nasa.gov

Applied Engineering and Technology Directorate: POC: Danielle Margiotta, Danielle.V.Margiotta@nasa.gov

- Advanced Manufacturing - facilitates the development, evaluation, and deployment of efficient and flexible additive manufacturing technologies. (ref: NAMII.org)
- **Advanced Multi-functional Systems and Structures** - novel approaches to increase spacecraft systems resource utilization
- **Micro - and Nanotechnology - Based Detector Systems** - research and application of these technologies to increase the efficiency of detector and optical systems
- **Ultra-miniature Spaceflight Systems and Instruments** - miniaturization approaches from multiple disciplines - materials, mechanical, electrical, software, and optical - to achieve substantial resource reductions
- **Systems Robust to Extreme Environments** - materials and design approaches that will preserve designed system properties and operational parameters (e.g. mechanical, electrical, thermal), and enable reliable systems operations in hostile space environments.
- **Spacecraft Navigation Technologies**
  - Spacecraft GNSS receivers, ranging crosslink transceivers, and relative navigation sensors
  - Optical navigation and satellite laser ranging
  - Deep-space autonomous navigation techniques
  - Software tools for spacecraft navigation ground operations and navigation analysis
  - Formation Flying
- **Automated Rendezvous and Docking (AR&D) techniques**
  - Algorithm development
  - Pose estimation for satellite servicing missions
  - Sensors (e.g., LiDARs, natural feature recognition)
  - Actuation (e.g., micro propulsion, electromagnetic formation flying)
- **Mission and Trajectory Design Technologies**
  - Mission design tools that will enable new mission classes (e.g., low thrust planetary missions, precision formation flying missions)

    - Mission design tools that reduce the costs and risks of current mission design methodologies
    - Trajectory design techniques that enable integrated optimal designs across multiple orbital dynamic regimes (i.e. earth orbiting, earth-moon libration point, sun-earth libration point, interplanetary)
- **Spacecraft Attitude Determination and Control Technologies**
    - Modeling, simulation, and advanced estimation algorithms
    - Advanced spacecraft attitude sensor technologies (e.g., MEMS IMU's, precision optical trackers)
    - Advanced spacecraft actuator technologies (e.g. modular and scalable momentum control devices, 'green' propulsion, micropropulsion, low power electric propulsion)
- **CubeSats** - Participating institutions will develop CubeSat/Smallsat components, technologies and systems to support NASA technology demonstration and risk reduction efforts. Student teams will develop miniature CubeSat/Smallsat systems for: power generation and distribution, navigation, communication, on-board computing, structures (fixed and deployable), orbital stabilization, pointing, and de-orbiting. These components, technologies and systems shall be made available for use by NASA for integration into NASA Cubesat/Smallsats. They may be integrated into complete off-the-shelf "CubeSat/Smallsat bus" systems, with a goal of minimizing "bus" weight/power/volume/cost and maximizing available "payload" weight/power/volume. NASA technologists will then use these components/systems to develop payloads that demonstrate key technologies to prove concepts and/or reduce risks for future Earth Science, Space Science and Exploration/Robotic Servicing missions. POC: Thomas P. Flatley (Thomas.P.Flatley@nasa.gov).
- **On-Orbit Multicore Computing** - High performance multicore processing for advanced automation and science data processing on spacecraft. There are multiple multicore processing platforms in development that are being targeted for the next generation of science and exploration missions, but there is little work in the area of software frameworks and architectures to utilize these platforms. It is proposed that research in the areas of efficient inter-core communications, software partitioning, fault detection, isolation & recovery, memory management, core power management, scheduling algorithms, and software frameworks be done to enable a transition to these newer platforms. Participating institutions can select areas to research and work with NASA technologists to develop and prototype the resulting concepts. POC: Alan Cudmore (Alan.p.cudmore@nasa.gov).
- **Integrated Photonic components and systems** - Integrated photonic components and systems for Sensors, Spectrometers, Chemical/biological sensors, Microwave, Sub-millimeter and Long-Wave Infra-Red photonics, Telecom- inter and intra satellite communications.
- **Radiation Effects and Analysis**
    - Flight validation of advanced event rate prediction techniques
    - New approaches for testing and evaluating 3-D integrated microcircuits and other advanced microelectronic devices
    - End-to-end system (e.g., integrated component level or higher) modeling of radiation effects

- Statistical approaches to tackle radiation hardness assurance (i.e., total dose, displacement damage, and/or single-event effects) for high-risk, low-cost missions.

Sciences and Exploration Directorate: POC: Blanche Meeson, Blanche.W.Meeson@nasa.gov

The Sciences and Exploration Directorate at NASA Goddard Space Flight Center (http://science.gsfc.nasa.gov) is the largest Earth and space science research organization in the world. Its scientists advance understanding of the Earth and its life-sustaining environment, the Sun, the solar system, and the wider universe beyond. All are engaged in the full life cycle of satellite missions and instruments from concept development to implementation, analysis and application of the scientific information, and community access and services.

- The **Earth Sciences Division** plans, organizes, evaluates, and implements a broad program of research on our planet's natural systems and processes. Major focus areas include climate change, severe weather, the atmosphere, the oceans, sea ice and glaciers, and the land surface. To study the planet from the unique perspective of space, the Earth Science Division develops and operates remote-sensing satellites and instruments. We analyze observational data from these spacecraft and make it available to the world's scientists and policy makers. The Division conducts extensive field campaigns to gather data from the surface and airborne platforms. The Division also develops, uses, and assimilates observations into models that simulate planetary processes involving the water, energy, and carbon cycles at multiple scales up to global. POC: Eric Brown de Colstoun (eric.c.browndecolsto@nasa.gov).
- The **Astrophysics Science Division** conducts a broad program of research in astronomy, astrophysics, and fundamental physics. Individual investigations address issues such as the nature of dark matter and dark energy, which planets outside our solar system may harbor life, and the nature of space, time, and matter at the edges of black holes. Observing photons, particles, and gravitational waves enables researchers to probe astrophysical objects and processes. Researchers develop theoretical models, design experiments and hardware to test theories, and interpret and evaluate observational data. POC: Amber Straughn (Amber.n.Straughn@nasa.gov).
- The **Heliophysics Science Division** conducts research on the Sun, its extended solar-system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere. Division research also encompasses Geospace, Earth's magnetosphere and its outer atmosphere, and Space Weather—the important effects that heliospheric disturbances have on spacecraft and terrestrial systems. Division scientists develop spacecraft missions and instruments, systems to manage and disseminate heliophysical data, and theoretical and computational models to interpret the data. Possible heliophysics-related research include: advanced software environments and data-mining strategies to collect, collate and analyze data relevant to the Sun and its effects on the solar system and the Earth ("space weather"); and advanced computational techniques, including but not limited to parallel architectures and the effective use of graphics processing units, for the simulation of magnetized and highly dynamic plasmas and neutral gases in the heliosphere. POC: Doug Rabin (Douglas.Rabin@nasa.gov).

- The **Solar System Exploration Division** builds science instruments and conducts theoretical and experimental research to explore the solar system and understand the formation and evolution of planetary systems. Laboratories within the division investigate areas as diverse as astrochemistry, planetary atmospheres, extrasolar planetary systems, earth science, planetary geodynamics, space geodesy, and comparative planetary studies. To study how planetary systems form and evolve, division scientists develop theoretical models as well as the investigations and space instruments to test them. The researchers participate in planetary and Earth science missions, and collect, interpret, and evaluate measurements. POC: Lora Bleacher (Lora.V.Bleacher@nasa.gov).
- **Quantum computing:** Quantum computing is based on quantum bits or qubits. Unlike traditional computers, in which bits must have a value of either zero or one, a qubit can represent a zero, a one, or both values simultaneously. Representing information in qubits allows the information to be processed in ways that have no equivalent in classical computing, taking advantage of phenomena such as quantum tunneling and quantum entanglement. As such, quantum computers may theoretically be able to solve certain problems in a few days that would take millions of years on a classical computer..
- **Artificial intelligence and machine learning**: Artificial Intelligence (AI) is a collection of advanced technologies that allows machines to think and act, both humanly and rationally, through sensing, comprehending, acting and learning. AI's foundations lie at the intersection of several traditional fields - Philosophy, Mathematics, Economics, Neuroscience, Psychology and Computer Science. Current AI applications include big data analytics, robotics, intelligent sensing, assisted decision making, and speech recognition just to name a few
- **(Big) data analytics:** Data Analytics, including Data Mining and Pattern Recognition for Science applications and with special emphasis on:
  - Quantification of uncertainty in inference from big data
  - Experiment design to create data that is AI/ML ready and robust against misleading correlations
  - Methods for prediction of new discovery spaces
  - Strength of evidence and reproducibility in inference from big data

Scientists in all four divisions publish research results in the peer-reviewed literature, participate in the archiving and pubic dissemination of scientific data, and provide expert user support.

C.5 Jet Propulsion Laboratory (JPL)

POC: Linda Rodgers, linda.l.rodgers@jpl.nasa.gov
Petra Kneissl, petra.a.kneissl-milanian@jpl.nasa.gov

- **Solar System Science**
  Planetary Atmospheres and Geology
  Solar System characteristics and origin of life
  Primitive solar systems bodies
  Lunar science
  Preparing for returned sample investigations
- **Earth Science**
  Atmospheric composition and dynamics

Land and solid earth processes
Water and carbon cycles
Ocean and ice
Earth analogs to planets
Climate Science

- **Astronomy and Fundamental Physics**
  Origin, evolution, and structure of the universe
  Gravitational astrophysics and fundamental physics
  Extra-solar planets and star and planetary formation
  Solar and Space Physics
  Formation and evolution of galaxies
- **In-Space Propulsion Technologies**
  Chemical propulsion
  Non-chemical propulsion
  Advanced propulsion technologies
  Supporting technologies
- **Space Power and Energy Storage**
  Power generation
  Energy storage
  Power management & distribution
  Cross-cutting technologies
- **Robotics, Tele-Robotics and Autonomous Systems**
  Sensing
  Mobility
  Manipulation technology
  Human-systems interfaces
  Autonomy
  Autonomous rendezvous & docking
  Systems engineering
- **Communication and Navigation**
  Optical communications & navigation technology
  Radio frequency communications
  Internetworking
  Position, navigation and timing
  Integrated technologies
  Revolutionary concepts
- **Human Exploration Destination Systems**
  In-situ resource utilization and Cross-cutting systems
- **Science Instruments, Observatories and Sensor Systems**
  Science Mission Directorate Technology Needs
  Remote Sensing instruments/sensors
  Observatory technology
  In-situ instruments/sensor technologies
- **Entry, Descent and Landing Systems**
  Aerobraking, aerocapture, and entry systems
  Descent

Landing
Vehicle system technology

- **Nanotechnology**
  Engineered materials
  Energy generation and storage
  Propulsion
  Electronics, devices and sensors
- **Modeling, Simulation, Information Technology and Processing**
  Flight and ground computing
  Modeling
  Simulation
  Information processing
- **Materials, Structures, Mechanical Systems and Manufacturing**
  Materials
  Structures
  Mechanical systems
  Cross cutting
- **Thermal Management Systems**
  Cryogenic systems
  Thermal control systems (near room temperature)
  Thermal protection systems

C.6 Johnson Space Center (JSC)

POC: Kamlesh Lulla, kamlesh.p.lulla@nasa.gov

- In-space propulsion technologies
  - Energy Storage technologies-Batteries, Fuel cells
  - Robotics and TeleRobotics
  - Crew decision support systems
  - Immersive Visualization
- Virtual windows leading to immersive environments and telepresence systems
  - Human Robotic interface
  - Flight and Ground communication systems
- Audio
  - Adaptive-environment Array Microphone Systems and processing
  - Large bandwidth (audio to ultra-sonic) MEMs Microphones
  - Front end audio noise cancellation algorithms implementable in FPGAs-example Independent Component Analysis
  - Audio Compression algorithms implementable in FPGAs.
  - COMSOL Acoustic modeling
  - Sonification Algorithms implementable in DSPs/FPGAs
- Video
  - Ultra High Video Compressions
  - H265 Video Compression
  - Rad-Tolerant Imagers
  - Lightweight/low power/radiation tolerant displays

- Advanced habitat systems
  - GN&C for descent systems
  - Large body GN&C
  - Human-in-the-loop system data acquisition and performance modeling
  - Imaging and information processing
- Lightweight/Low power Display Technology
  - Scalable software-implementable graphics processing unit
- Simulation and modeling
  - Materials and structures
  - Lightweight structure
  - Human Spaceflight Challenges
  - http://humanresearchroadmap.nasa.gov/explore
- Human System Interfaces
  - OLED Technology Evaluation for Space Applications
  - Far-Field Speech Recognition in Noisy Environments
  - Radiation-Tolerant/ Hardened Graphics Processing
  - Machine-Learning human interfaces and methods
  - Human Computer Interaction design methods (Multi-modal and Intelligent Interaction) and apparatuses
  - Human Systems Integration, Human Factors Engineering: state of the art in Usability and performance assessment methods and apparatus.
  - Humans Systems Integration Inclusion in Systems Engineering
- ECLSS
  - Air Revitalization
  - Advanced water, O2 and CO2 monitoring and sensors
  - Advance thermally regenerated ionic fluids for CO2 and Humidity Control
  - Water Recovery and Management
  - Brine water recovery systems and wastewater treatment chemical recover for reuse or repurpose
  - Waste Management
  - Advance wastewater treatment systems (lower toxicity, recoverable)
  - Advanced trace contaminant monitoring and control technology
  - Quiet fan technologies
- Active Thermal Control
  - Lightweight heat exchangers and cold plates
  - Condensing heat exchanger coatings with robust hydrophilic, antimicrobial properties
  - Development and demonstration of wax and water-based phase change material heat exchangers
- EVA
  - Pressure Garment
  - Portable Life Support System
  - Power, Avionics and Software
- Autonomous Rendezvous and Docking
  - Crew Exercise
- Small form Equipment
  - Biomechanics

- EDL (thermal)
  - Wireless and Comm Systems
  - Wireless Energy Harvesting Sensor Technologies
  - Robust, Dynamic Ad hoc Wireless Mesh Communication Networks
  - Radiation Hardened EPCglobal Radio Frequency Identification (RFID) Readers
  - Computational Electromagnetics (CEM) Fast and Multi-Scale Methods/Algorithms
  - EPCglobal-type RFID ICs at frequencies above 2 G
- Radiation and EEE Parts
  - Monitoring
  - Mitigation and Biological countermeasures
  - Protection systems
  - Space weather prediction
  - Risk assessment modeling
- Wearable Tech
  - Wearable Sensors and Controls
  - Wearable far-field Audio Communicator
  - Wearable sensing and hands-free control
  - Tattooed Electronic Sensors
- In-Situ Resource Utilization
  - Mars atmosphere processing
  - CO2 collection, dust filtering, Solid Oxide CO2 electrolysis, Sabatier
  - Reverse water gas shift
  - Lunar/Mars regolith processing
  - Regolith collection and drying
  - Water collection and processing, water electrolysis (PEM and Solid Oxide)
  - Carbothermal reduction of regolith
  - Solar concentrator heat collection
  - Methane/Oxygen liquefaction and storage

C.7 Kennedy Space Center (KSC)

POC Jose Nunez, jose.l.nunez@nasa.gov

by Roadmap Technical Area (TA)

- **HEOMD – Commercial Crew systems development and ISS payload and flight experiments**
  - Environmental and Green Technologies
  - Health and Safety Systems for Operations
  - Communications and Tracking Technologies
  - Robotic, automated and autonomous systems and operations
  - Payload Processing & Integration Technologies (all class payloads)
  - R&T Technologies on In-Space Platforms (e.g., ISS, Gateway, Human Habitats)
  - Damage-resistant and self-healing materials
  - Plant Research and Production
  - Water/nutrient recovery and management
  - Plant habitats and Flight Systems
  - Food production and waste management

- Robotic, automated and autonomous food production
- Robotic, automated and autonomous food production
- Damage-resistant and self-healing materials
- Automated and autonomous detection and repair
- Propulsion: Chemical Propulsion flight integration (human transportation)
- Space Environments Test: Right/West Altitude Chamber

NOTE:
The above R&T Focus Areas are described in the KSC R&T Portfolio Data Dictionary

C.8 Langley Research Center (LaRC)

POC: Dr. Kimberly Brush, kimberly.m.brush@nasa.gov

- Intelligent Flight Systems – Revolutionary Air Vehicles
  (POC: Guy Kemmerly 757-864-5070) – retired, awaiting new POC
- Atmospheric Characterization – Active Remote Sensing
  (POC: Allen Larar 757.864.5328)
- Systems Analysis and Concepts - Air Transportation System Architectures & Vehicle Concepts (POC: Phil Arcara 757.864.5978)
- Advanced Materials & Structural System – Advanced Manufacturing
  (POC: David Dress 757-864-5126)
- Aerosciences - Trusted Autonomy
  (POC: Sharon Graves 757-864-5018) –retired, awaiting new POC
- Entry, Decent & Landing - Robotic Mission Entry Vehicles
  (POC: Jeff Herath or Ron Merski)
- Measurement Systems - Advanced Sensors and Optical Measurement
  (POC: Tom Jones 757-864-4903)

C.9 Marshall Space Flight Center (MSFC)

POC: Frank Six, frank.six@nasa.gov

Propulsion Systems

- Launch Propulsion Systems, Solid & Liquid
- In Space Propulsion (Cryogenics, Green Propellants, Nuclear, Fuel Elements, Solar-Thermal, Solar Sails, Tethers)
- Propulsion Testbeds and Demonstrators (Pressure Systems)
- Combustion Physics
- Cryogenic Fluid Management
- Turbomachinery
- Rotordynamics
- Solid Propellant Chemistry
- Solid Ballistics
- Rapid Affordable Manufacturing of Propulsion Components
- Materials Research (Nano Crystalline Metallics, Diamond Film Coatings)
- Materials Compatibility

- Computational Fluid Dynamics
- Unsteady Flow Environments
- Acoustics and Stability
- Low Leakage Valves

Space Systems

- In Space Habitation (Life Support Systems and Nodes, 3D Printing)
- Mechanical Design & Fabrication
- Small Payloads (For International Space Station, Space Launch System)
- In-Space Asset Management (Automated Rendezvous & Capture, De-Orbit, Orbital Debris Mitigation, Proximity Operations)
- Radiation Shielding
- Thermal Protection
- Electromagnetic Interference
- Advanced Communications
- Small Satellite Systems (CubeSats)
- Structural Modeling and Analysis
- Spacecraft Design (CAD)

Space Transportation

- Mission and Architecture Analysis
- Advanced Manufacturing
- Space Environmental Effects and Space Weather
- Lander Systems and Technologies
- Small Spacecraft and Enabling Technologies (Nanolaunch Systems)
- 3D Printing/Additive Manufacturing/Rapid Prototyping
- Meteoroid Environment
- Friction Stir and Ultrasonic Welding
- Advanced Closed-Loop Life Support Systems
- Composites and Composites Manufacturing
- Wireless Data & Comm. Systems
- Ionic Liquids
- Guidance, Navigation and Control (Autonomous, Small Launch Vehicle)
- Systems Health Management
- Martian Navigation Architecture/Systems
- Planetary Environment Modeling
- Autonomous Systems (reconfiguration, Mission Planning)
- Digital Thread / Product Lifecycle Management (for AM and/or Composites)
- Material Failure Diagnostics

Science

- Replicated Optics
- Large Optics (IR, visible, UV, X-Ray)
- High Energy Astrophysics (X-Ray, Gamma Ray, Cosmic Ray)
- Radiation Mitigation/Shielding
- Gravitational Waves and their Electromagnetic Counterparts
- Solar, Magnetospheric and Ionospheric Physics

- Planetary Geology and Seismology
- Planetary Dust, Space Physics and Remote Sensing
- Surface, Atmospheres and Interior of Planetary Bodies
- Earth Science Applications
- Convective and Severe Storms Research
- Lightning Research
- Data Informatics
- Disaster Monitoring
- Energy and Water Cycle Research
- Remote Sensing of Precipitation

C.10 Stennis Space Center (SSC)

POC: Dr. Mitch Krell, email: mitch.krell@nasa.gov

- Active and Passive Nonintrusive Remote Sensing of Propulsion Test Parameters
- Intelligent Integrated System Health Management (ISHM) in Rocket Test-Stands
- Advanced Non-Destructive Evaluation Technologies
- Advanced Propulsion Systems Testing
- Cryogenic Instrumentation and Cryogenic, High Pressure, and Ultrahigh Pressure Fluid Systems
- Ground Test Facilities Technology
- Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Acoustic & Thermal Environments
- Vehicle Health Management/Rocket Exhaust Plume Diagnostics

Propulsion Testing

Active and Passive Nonintrusive Remote Sensing of Propulsion Test Parameters

The vast amount of propulsion system test data is collected via single channel, contact, intrusive sensors and instrumentation. Future propulsion system test techniques could employ passive nonintrusive remote sensors and active nonintrusive remote sensing test measurements over wide areas instead of at a few discrete points. Opportunities exist in temperature, pressure, stress, strain, position, vibration, shock, impact, and many other measured test parameters. The use of thermal infrared, ultraviolet, and multispectral sensors, imagers, and instruments is possible through the SSC sensor laboratory.

Intelligent Integrated System Health Management (ISHM) in Rocket Test-Stands

SHM is a capability to determine the condition of every element of a system continuously. ISHM includes detection of anomalies, diagnosis of causes, and prognosis of future anomalies; as well as making available (to elements of the system and the operator) data, information, and knowledge (DIaK) to achieve optimum operation. In this context, we are interested in methodologies to embed intelligence into the various elements of rocket engine test-stands, e.g., sensors, valves, pumps, tanks, etc. Of particular interest is the extraction of qualitative interpretations from sensor data in order to develop a qualitative assessment of the operation of the various components and processes in the system. The desired outcomes of the research are: (1) to develop intelligent sensor models that are self-calibrating, self- configuring, self- diagnosing, and self- evolving (2) to develop intelligent components such as valves, tanks, etc., (3) to implement intelligent sensor fusion schemes that allow assessment, at the qualitative level, of the condition of the components and processes, (4) to develop a monitoring and diagnostic system that uses the intelligent sensor models and fusion schemes to predict future events, to document the operation of the system, and to diagnose any malfunction quickly, (5) to develop architectures/taxonomies/ontologies for integrated system health management using distributed intelligent elements, and (6) to develop visualization and operator interfaces to effectively use the ISHM capability.

Advanced Non-Destructive Technologies
Advances in non-destructive evaluation (NDE) technologies are needed for fitness-for-service evaluation of pressure vessels used in rocket propulsion systems and test facilities. NDE of ultra- high pressure vessels with wall thicknesses exceeding 10 inches require advanced techniques for the detection of flaws that may affect the safe use of the vessels.

Advanced Propulsion Systems Testing
Innovative techniques will be required to test propulsion systems such as advanced chemical engines, single- stage-to-orbit rocket plane components, nuclear thermal, nuclear electric, and hybrids rockets. New and more cost- effective approaches must be developed to test future propulsion systems. The solution may be some combination of computational- analytical technique, advanced sensors and instrumentation, predictive methodologies, and possibly subscale tests of aspects of the proposed technology.

Cryogenic Instrumentation and Cryogenic, High Pressure, and Ultrahigh Pressure Fluid Systems
Over 40 tons of liquefied gases are used annually in the conduct of propulsion system testing at the Center. Instrumentation is needed to precisely measure mass flow of cryogens starting with very low flow rates and ranging to very high flow rates under pressures up to 15,000 psi. Research, technology, and development opportunities exist in developing instruments to measure fluid properties at cryogenic conditions during ground testing of space propulsion systems. Both intrusive and nonintrusive sensors, but especially nonintrusive sensors, are desired.

Ground Test Facilities Technology
SSC is interested in new, innovative ground-test techniques to conduct a variety of required developmental and certification tests for space systems, stages/vehicles, subsystems, and components. Examples include better coupling and integration of computational fluid dynamics and heat transfer modeling tools focused on cryogenic fluids for extreme conditions of pressure and flow; advanced control strategies for non-linear multi-variable systems; structural modeling tools for ground-test programs; low-cost, variable altitude simulation techniques; and uncertainty analysis modeling of test systems.

Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Acoustic & Thermal Environments

Background: An accurate definition of a propulsion system exhaust plume flow field and its associated plume induced environments (PIE) are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design and minimized costs associated with: 1. propulsion system and/or component testing of both the test article and test facility; 2. any launch vehicle and associated launch facility during liftoff from the Earth, Moon or Mars; 3. any launch vehicle during the ascent portion of flight including staging, effects of separation motors and associated pitch maneuvers; 4. effects of orbital maneuverings systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments; 5. Any vehicle intended to land on and return from the surface of the Moon or Mars; and finally 6. The effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents. Current technology status and requirements to optimally accomplish NASA s mission: In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design. However, further improvements of this technology are required: 1. in an effort to reduce conservatism in the current technology allowing greater optimization of any vehicle and/or payload design keeping in mind crew safety through all mission phases; and 2. to support the efforts to fill current critical technology gaps discussed below. PIE areas of particular interest include: single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects. Current critical technology gaps in needed PIE capabilities include: 1. An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi- engine vehicle configurations. 2. An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems. 3. A validated, user friendly free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.

Vehicle Health Management/Rocket Exhaust Plume Diagnostics

A large body of UV-Visible emission spectrometry experimentation is being performed during the 30 or more tests conducted each year on the Space Shuttle Main Engine at SSC. Research opportunities are available to quantify failure and wear mechanisms, and related plume code validation. Related topics include combustion stability, mixture ratio, and thrust/power level. Exploratory studies have been done with emission/absorption spectroscopy, absorption resonance spectroscopy, and laser induced fluorescence. Only a relatively small portion of the electromagnetic spectrum has been investigated for use in propulsion system testing and exhaust plume diagnostics/vehicle health management.

Appendix D: NASA Center Points of Contact (POCs)

Armstrong Flight Research Center Dave Berger Asst. Technical Manager dave.e.berger@nasa.gov	Johnson Space Center Misti Moore Education Program Specialist misti.m.moore@nasa.gov
Ames Research Center William "Braxton" Toy Specialist william.b.toy@nasa.gov	Kennedy Space Center Theresa Martinez Education Specialist theresa.c.martinez@nasa.gov
Goddard Space Flight Center James Harrington Computer Scientist james.l.harrington@nasa.gov	Langley Research Center Gina Blystone Education Program Specialist gina.r.blystone@nasa.gov
Glenn Research Center Dave Kankam, Ph.D. University Affairs Officer mark.d.kankam@nasa.gov	Marshall Space Flight Center Frank Six, Ph.D. Education Specialist frank.six@nasa.gov
Jet Propulsion Lab Linda Rodgers University Programs Administrator linda.rodgers@jpl.nasa.gov	Stennis Space Center Mitch Krell, Ph.D. University Affairs mitch.krell@nasa.gov