# ngVLA Technical and Scientific Development Plan

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## Change Record

| Version | Date | Author | Affected Section(s) | Reason |
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| A | 09-13-2022 | E. Murphy | All | Final edits and resolution of remaining comments. |
| A.01 | 02-07-2023 | E. Murphy | All | Synching to updates made in release of the Ops Plan for CDR |
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# 1 Executive Summary

The National Radio Astronomy Observatory (NRAO) is designing the next-generation Very Large Array (ngVLA) for an operational life spanning decades, with a need to develop new capabilities to maximize the productivity of the array for current users, and to support future projects. There will also be opportunities to extend the operational lifetime of the instrument with the identification new areas of technical development and corresponding enhancements to the facility.

Given the importance of long-term facility development, the ngVLA Operations Plan includes dedicated Development and Legacy Science Programs, which are essential to ensure the array's scientific growth and productivity throughout the lifetime of the facility. Combined, these programs will fund competitive studies and projects designed to encourage three areas of development outside the scope of routine array operations:

- Scientific development projects or studies focused on expanding the observing capabilities of the array and enabling scientific advancements.
- Technical development projects or studies focused on developing new or improved system components, data reduction techniques, and analysis tools.
- Community-led Legacy Science Program (LSP) projects focused on major science observing campaigns that require significant resources and provide the community with enhanced data products/services.

The Development Program will maintain the flagship facility status of the ngVLA by incorporating technical and scientific advances and responding to changes in user needs over the course of the array's operational lifetime. Furthermore, the LSP will ensure that the community receives the highest scientific return from the facility by supporting observing or archival projects that require significant resources and are outside the range of NRAO expertise and/or the scope of normal ngVLA Science Operations. LSP projects will additionally provide the user community with (enhanced) data products/analysis tools, giving PI's the opportunity to construct more scientifically compelling and technically sound proposals for general observing.

The overarching Technical and Scientific Development (TSD) Program will coordinate between routine operations efforts and long-term research and development initiatives. A TSD Office will be included as part of ngVLA Operations, which will administer the TSD Programs, associated proposal calls, and program awards. Establishing a TSD Office will reduce the burden on the operations groups while also providing leadership and direction within the Observatory for these programs. The ngVLA Operations Assistant Director will ultimately be responsible for the overall execution of many TSD initiatives (e.g., technical development projects), ensuring that relative priorities and timelines are established and the TSD initiatives do not excessively stress or negatively impact routine array operations.

Requirements for development study and project proposals, as well as requirements for projects once awarded, will follow established NRAO processes and standards. Project requirements include steps for reviews, product assurance, and deliverable commissioning. Finally, it is expected that this document will undergo additional revisions as the ngVLA project is further defined and international or institutional partnerships are formalized.

# 2 Related Documents

## 2.1 Applicable Documents

The following documents are applicable to this Development Plan to the extent specified:

| Ref. No. | Document Title | Rev/Doc. No. |
| --- | --- | --- |
| AD01 | ngVLA Operations Plan | 020.10.05.05.00-0001-PLA |
| AD02 | ngVLA Operations Concept | 020.10.05.00.00-0002-PLA |
| AD03 | ngVLA Legacy Science Program | 020.10.05.00.00-0004-PLA |

## 2.2 Reference Documents

The following references provide supporting context:

| Ref. No. | Document Title | Rev/Doc. No. |
| --- | --- | --- |
| RD01 | Systems Engineering Management Plan (SEMP) | 020.10.00.00.00-0001-PLA |
| RD02 | ALMA Cycle 9 Call for Project Proposal Instructions | https://science.nrao.edu/facilities/alma/science_sustainability/cycle9-cfp |

# 3 Purpose

After the completion of construction, the ngVLA requires a formalized process to develop new hardware, software, infrastructure, or observing and data processing modes beyond the set of capabilities delivered by the construction project. This document describes the necessary TSD goals, principles, and processes needed for generating and approving proposed development projects and studies. It also outlines the basic management structure and proposed budget of the Development and Legacy Science Programs, as well as how these programs fit within ngVLA Operations, as input to the ngVLA Operations Plan [AD01].

## *3.1 Development Program Goals and Principles*

The primary goal of the Development Program is to maintain the world-class excellence of the ngVLA while incorporating technical and scientific advances and changes in user needs over the course of the array's operational lifetime. This goal was informed by the Operations Concept and visions for maintaining the array's excellence [AD02, AD03].

Development Program Principles:

1. Development priorities should be determined by both user community and operational needs.
2. The program shall advance the continuing development and upgrade of software, hardware, and data processing and analysis tools outside of normal operations for the ngVLA.
3. The ngVLA Science Advisory Committee will identify strategic development needs by surveying users, stakeholder groups, and observatory operations in order to provide a roadmap of recommended future developments.
4. The program shall fund studies and projects approved through a TSD Office sponsored proposal review process.
5. ngVLA Operations shall provide the personnel and resources necessary to run the Development Program.
6. Development Program funding should be separately allocated to ensure that these long-term investments receive appropriate resources.
7. Proposal processes shall have a fair merit-based method of evaluating and awarding development proposals that is similar to the process used for evaluating observing proposals.
8. Development studies and projects shall also include obsolescence planning and other system development necessary to ensure the array meets its operational lifetime requirements.
9. Development activities must engage the technical experts of NRAO and ngVLA partners after the completion of ngVLA project design, construction, and commissioning activities.

## *3.2 Legacy Science Program Goals and Principles*

The primary goal of the LSP is to ensure that the community receives the highest scientific return from the facility by supporting observing or archival projects that require significant resources that are outside the reach of NRAO expertise and/or the scope of normal ngVLA Science Operations [AD03]. The LSP Projects provide an opportunity for faculty members at US academic institutions to have access to the necessary resources to support the conception of more scientifically compelling proposals for general observing.

Legacy Science Program Principles:

1. Legacy Science projects are necessary to address the need for complex, multi-year science investigations that take advantage of the full capabilities of the ngVLA. Calls for LSP proposals may

therefore only be made in certain years as such projects are also likely to stress, as well as help identify unknown issues with, the system.

2. Proposal processes shall have a fair merit-based method of evaluating and awarding LSP proposals that is similar to the process used for evaluating observing proposals. The program shall fund studies and projects based on the ranking established by TSD Office sponsored proposal review process.
3. Commissioning of developed capabilities and systems, along with archival ingestion of LSP-provided (enhanced) data products/analysis tools, shall not excessively stress or negatively impact ongoing operations.

# 4 Development Program Studies and Projects, and Legacy Science Program Projects

Combining the administration of the Development Program and Legacy Science Program, three types of development initiatives are to be managed through the TSD Office:

- Scientific development projects or studies, focusing on developing enhancements of the observing capabilities of the array.
- Technical development projects or studies, focusing on developing new or improved system components, data reduction techniques, and analysis tools.
- Community-led legacy science projects, focusing on major science observing projects that require significant resources and provide the community with enhanced data products/services.

## *4.1 Development Studies*

Development Studies have the goal of encouraging investigations and experiments into developing technologies and observing capabilities to support emergent areas of research. Studies may consist of research and testing that could lead to tangible improvements to ngVLA consistent with the array's scientific goals and with any other strategic plans or operational needs. These studies may therefore lead to the submission of Development Projects and/or LSP proposals as potential areas of interest are explored, evaluated and understood. The primary deliverable from a Development Study is typically, but not limited to, a project memo, technical report, or other publication that summarizes the findings of the study.

## *4.1 Development Projects*

Development Projects are clearly defined efforts that result in unique products or the improvement of capabilities, systems, or tools for the array. Projects will produce fully incorporated and commissioned capabilities in the array, typically accessible to all users through standard observing modes. Potential scientific and technical development projects could be:

- Complete new additions of capabilities to the array for general use.
- Extension of existing capabilities with new data products, more sensitivity, improved image quality, better dynamic range, etc.
- Improvements to existing hardware or software systems resulting in enhanced availability, reliability, or maintainability.
- Improved infrastructure that reduces risks, increases availability, and makes operation more efficient or less expensive.

As with Development Studies, Development Projects may ultimately lead to the submission of LSP proposals that scientifically capitalize on the investment of a successful project.

### 4.2 Legacy Science Program

The ngVLA Legacy Science Program [AD03] is a collection of observing or archival projects that are distinguished from typical Principal Investigator (PI)-led observing investigations by the following fundamental characteristics:

- They are large and coherent science projects, not reproducible by any reasonable number or combination of smaller general observing investigations.
- They have general and lasting importance to the broader astronomical community for which the ngVLA data will yield a substantial and coherent database.
- They generate raw and pipeline-processed data products that enter the public domain immediately upon ingestion into the ngVLA data archive, thereby enabling timely and effective opportunities for follow-on observations and for archival research, with both the ngVLA and other observatories.
- They provide community developed data products, pipelines, etc. that are outside the scope of standard observing modes and routine operations.

Each LSP projects' designated PI or collaborators are responsible for developing the tools that will be necessary to support the project. The ngVLA is committed to serving the data products from the ngVLA archive, but maintenance, support, quality assurance of these tools is fundamentally the responsibility of the collaborators. The tools developed may not proceed to become integrated capabilities available for all users through standard observing modes, as they are primarily designed for supporting the unique LSP project's needs.

### 4.3 Development Plan Interrelationships

As a concept progresses in technical or scientific maturity, the next stage of development may involve the progression from one type of initiative within the TSD Program to another. For this reason, Development Program Studies and Projects are not mutually exclusive from LSP projects.

A Development Study may naturally lead to the submission of a Development Program project. However, if the resources required and data products produced are better aligned with a community-developed and led initiative, a study may instead lead to a submission to the LSP. There may also be scenarios when an LSP project is dependent on the completion of a Development Program project that introduces new capabilities to standard observing modes.

Since the evolution of a research idea can progress into multiple areas of the Development Roadmap (see Section 5.2.1), it is advantageous for the Development and Legacy Science Programs to have a common management framework.

## 5 Development Program Organization and Funding

### 5.1 Organization Structure

Due to the preliminary nature of the ngVLA operations planning, this section is expected to undergo revision as ngVLA operational structure and requirements are refined [AD01]. Terms used below for teams or groups are informed by VLA/ALMA operations and should be considered placeholders.

### 5.1.1 ngVLA Operations

The following divisions or groups, shown in Figures 1 and 2, are those that are integral to the Development Program and are considered to be part of ngVLA Operations, either by direct appointment or through matrixed management:

- Operations Management — ultimately responsible for the execution of the TSD Program
- Technical and Scientific Development Office, including the ngVLA Legacy Scientist
- Array Operations Division
- Science and Data Center Operations Division
- Engineering Operations Division
- ngVLA Computing and Software Operations (DMS)Education & Public Outreach
- Business Services
- Array Safety
- Diversity and Inclusion
- Project Management (under NRAO Supporting Functions)
- Internal (i.e., NRAO and partner organization staff) development proposers

### 5.1.2 Auxillary TSD Office Groups

The following groups or parties, shown in Figure 3, are those that are considered to be outside of ngVLA Operations:

- Science Advisory Committee
- Principal Investigators
- Proposal review panel
- Scientific community
- External development proposers (e.g. industry, universities, other observatories)
- Funding agencies
- Funding partner organizations (international or institutional)

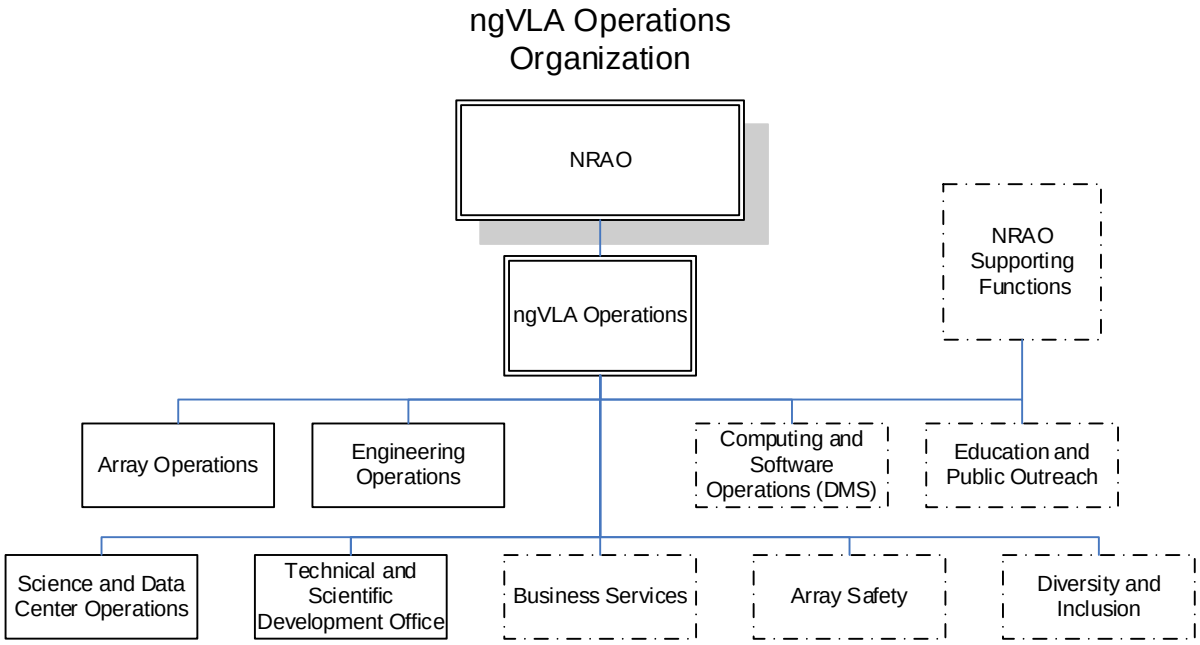


**Figure 1: ngVLA Operations high-level organization. Divisions directly managed by ngVLA Operations are indicated by solid boxes; those managed by other NRAO Departments are indicated by dashed boxes. The structure of ngVLA Operations is notional, intended to show the relationship of the TSD Office to the broader Observatory.**

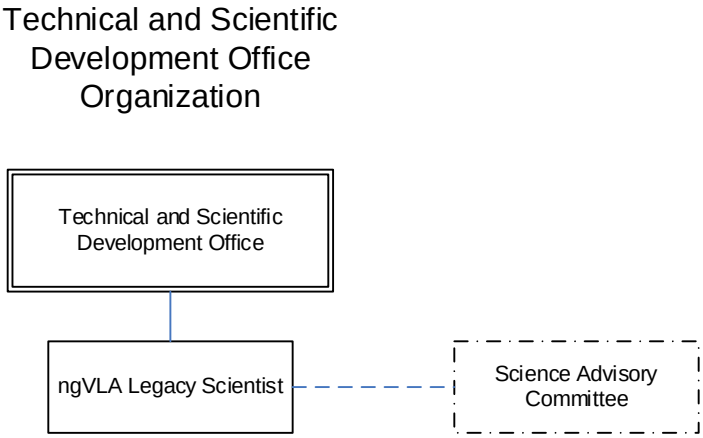


**Figure 2: ngVLA Technical and Scientific Development Office organization. Solid lines show organizational elements with responsibilities to ngVLA while dashed lines denote relationships to external committees. Dashed boxes indicate organizations that are managed outside of ngVLA Operations.**

## *5.2 Framework and Responsibilities*

Development proposals must follow a consistent process in order to fairly and impartially review and approve proposed projects and studies, consider array needs, and maximize the deliverables and value of awarded studies and projects.

Note: The following framework is subject to revision due to changes in international partnerships and funding agency requirements.

### 5.2.1 Advisory Committees

In order to develop a community-driven strategy for development, the ngVLA Legacy Scientist [AD01] will work with an ngVLA Science Advisory Committee to support the TSD office. Other Observatory advisory committees, similar to the Science and Technical Advisory Councils of the construction phase, may participate in providing input to the composition of the Science Advisory Committee.

The Science Advisory Committee is charged with creating and maintaining a Development Roadmap that incorporates ngVLA scientific, technical, and operational needs to achieve a strategic science enhancement vision. This committee will need to gather and assess input from the Array Operations Division, the Science and Data Center Operations Division, the scientific community, and other identified stakeholders. The committee will include ngVLA staff, including the ngVLA Legacy Scientist, in an ex-officio capacity, and the roadmap will be subject to approval by the (NRAO) Observatory Director or a combination of array oversight staff. This work will occur on a ~5-year cycle, starting in the first year of full operations. The delivered roadmap may also propose a suggested approach to desired development areas.

The ngVLA Legacy Scientist will create and execute the Development and Legacy Science Program proposal evaluation processes. The review committee shall consist of impartial reviewers as chosen jointly by the Science Advisory Committee and the TSD Office with the consent of ngVLA Operations management and other stakeholders (e.g., NSF). Members of these groups who are involved in competing proposals will be recused from judging their own, or closely related, proposals. The ngVLA Legacy Scientist will also ensure that the approved proposals are aligned with the Science Advisory Committee's recommended future development projects as well as the high-level goals from ngVLA and NRAO management and the NSF and those highest priority items recommended internally from ngVLA staff. Additional proposal evaluations may be required depending on the size of the requested budget or the technical complexity for those externally submitted proposals.

### 5.2.2 ngVLA Operations

The ngVLA Operations consists of many Divisions that are integral to supporting the long-term Development Program either by direct appointment or through matrix management, as shown in Figure 1. The TSD Office, with input from Science Operations, is responsible for coordinating calls for proposals and soliciting community input and interest in the program. All operational Divisions will help assess the operational impact and technical readiness of proposals that have passed initial evaluation. The ngVLA Operations Assistant Director is ultimately responsible for the overall execution of the TSD initiatives, including obtaining any final approval required of the NRAO Director and other management or oversight parties such as the NSF.

Operations staff also play a critical role in the integration of new capabilities, products, or services into the ngVLA. Practices and requirements developed during the ngVLA construction project will inform the integration and commissioning activities and resources needed to support development projects. It is vital to identify and provide the resources and processes needed to successfully incorporate successful TSD deliverables without overwhelming Operations staff in their day-to-day responsibilities.

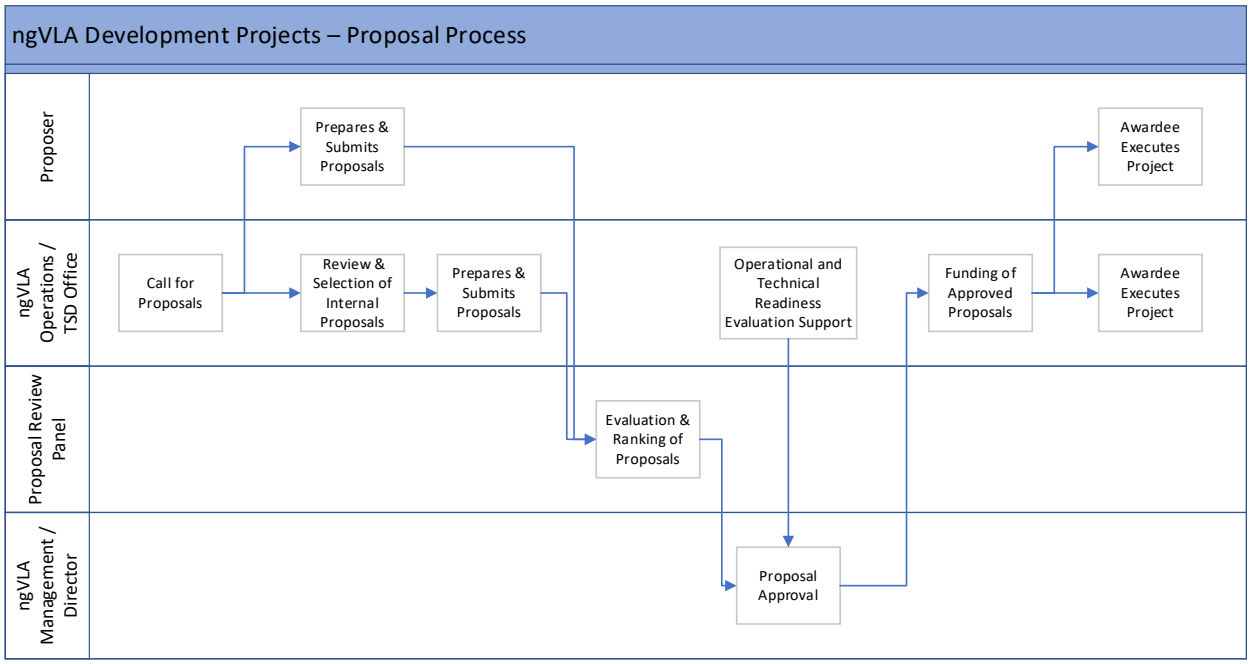


**Figure 3: Proposal process flowchart.**

The Operations Plan will identify the required resources needed to incorporate these new capabilities and other TSD Program deliverables into ngVLA Operations. The roles of various staff within Operations will also be more clearly defined in the Operations Plan, with any conflicts of interest issues resolved.

### 5.2.3 Project Management & Systems Engineering

The management of awarded projects and studies may be supported by personnel in the NRAO Program Management Department. This includes monitoring the project or study status and reporting of this status to the ngVLA Assistant Director. It is assumed that project management processes applied will follow the requisite ngVLA or NRAO requirements [RD01].

Systems engineering processes would be managed by the Systems & Configuration Engineering Group within Engineering Operations, ensuring that standard design and development practices are implemented and that the proposed development project is incorporated into broader efforts to develop and maintain the system. In the context of development projects, these responsibilities extend into Quality Assurance / Product Assurance roles to ensure that the deliverables of the development projects meet relevant quality criteria and are delivered with sufficient documentation and supporting data to enable integration and commissioning activities as well as long-term support.

The Systems Engineering approach on development and LSP projects will adhere to any observatory-level systems engineering standards set by the NRAO Program Management Division to ensure a controlled development process and the delivery of all documentation needed to support the product through its life. The tailored Systems Engineering approach for large projects should be defined in a Systems Engineering Management Plan.

Project management will oversee Development and LSP projects through completion, which may include collecting regular progress reports, ensuring the delivery of required documentation, overseeing product development, conducting necessary reviews, and managing the production, delivery, and acceptance of

project deliverables. For projects whose ultimate deliverable is a new technical capability on the array, project management will be required to develop an integration and commissioning plan jointly with the project team and ngVLA Operations staff.

Key review milestones will include critical review from other Observatory stakeholders such as the Environmental Safety and Security team to ensure that related concerns receive due consideration at all stages of the project lifecycle.

## 5.3 Communication

ngVLA Operations, specifically the TSD Office, is responsible for maintaining a website and any other necessary repositories of information needed to communicate the structure, purpose, processes, and results of the program to internal and external users and other stakeholders. The TSD Office staff are also responsible for developing Call for Proposal documents and announcements that describe the proposal process, schedule, and proposal requirements. The Atacama Large Millimeter/sub-millimeter Array's (ALMA) Call for Proposal Instructions provide a very good template [RD02].

## 5.4 Program Cadence

Annual calls for studies and projects in capability development and hardware and software development will first occur in 2036, two years after the transition to full operations. Calls for LSP submissions will first occur twice during Early Science operations and every two years during full operations.

Early Science LSPs are expected to be smaller in scope, given that the full array capabilities will not be available. That said, the first round of LSPs executed during Early Science will provide a mechanism for the community to contribute to ngVLA commissioning efforts, placing ngVLA data into public use as early as possible. Having access to such data early on will additionally help build the ngVLA user community and aid with the scientific and technical preparation of future PI-led proposals.

The overall cadence and funding level of the TSD Program calls is summarized in Table 1.

| Funding Period | Capability Dev. Projects Awards | Hardware or Software Dev. Studies/Projects Awards | Dev. Funding per Year (2023 USD) | Legacy Science Project Awards | Legacy Science Funding per Year (2023 USD) | Total Funding per Year (2023 USD) |
| --- | --- | --- | --- | --- | --- | --- |
| Early Science 1 (2028–2031) | - | - | - | 1–3 | $1.2M | **$3.6M** |
| Early Science 2 (2031–2033) | - | - | - | 1–3 | $1.2M | **$3.6M** |
| 2034 | - | - | - | 1–2 | $3.6M | **$3.6M** |
| 2035 | - | - | - | - | $3.6M | **$3.6M** |
| 2036 | 2–5 | 2–5 / 1–2 | $6M | 1–2 | $3.6M | **$9.6M** |
| 2037 | 2–5 | 2–5 / 1–2 | $6M | - | $3.6M | **$9.6M** |
| 2038 | 2–5 | 2–5 / 1–2 | $6M | 1–2 | $3.6M | **$9.6M** |
| 2039–2053 | 2–5 | 2–5 / 1–2 | $6–12M | 1–2 biennially | $3.6M | **$9.6–15.6M** |

**Table 1: ngVLA Development Program funding and cadence.**

### 5.5 Funding

The ngVLA Operations budget directly funds the ngVLA TSD Office. Per [AD01], the LSP anticipates funding needs of approximately $3.6M (2023, USD) per year to support multiple individual projects. The Development Program will require an additional $6M-$12M (2023, USD) per year, based on fluctuating technical and scientific needs. Consequently, a total of at least $9.6M (2023, USD) is needed per year to fund the TSD Office Programs (Table 1).

We note that the proposed level of funding will not accommodate major overhauls or computing infrastructure refresh cycles, the latter of which is budgeted for in operations. Major array development overhauls larger than the outlined budget may be partially or fully addressed through other funding programs.

The recommended TSD Office funding should be further refined as the ngVLA project continues through the design phase of the project lifecycle. The preliminary and final technical baselines can inform cost estimates for hypothetical upgrades such as commensal observing systems, as well as notional obsolescence remediation projects, and may form a useful basis for sizing the TSD Program. Additionally, descoped or deferred aspects of the construction project may drive early development priorities and program funding needs.

## 6 International Development Plans

While the ngVLA will be operated as a facility of the NRAO, international partners and/or domestic institutions may participate in the direct operation and maintenance of the facility. Examples of such contributions might include operating a repair center for a partner-provided component, hosting a remote software development team, and contributing to the time allocation process. Financial contributions made by partners to cover a fraction of ngVLA operations will inherently include the same fractional contribution to the TSD Program.

In addition to these routine operations contributions, international partners may have interests in providing self-funded extended services to their local user communities, such as additional support with proposal preparation and data analysis. Partners may also wish to participate in the facility scientific and technical development, or administer program awards.

The ngVLA TSD Programs will be operated on similar principles to ‘Open Skies’ observing, with awards based on merit-based criteria established by independent review committees. Such a program should be inherently extensible to include the international ngVLA community through participation in these review committees. Alternatively, parallel processes may be necessary to meet stakeholder needs.

Direct international and institutional partner participation in ngVLA Science Advisory Committee is strongly favored and central to establishing a common consensus of priorities and a shared development roadmap, even if TSD funds are separately allocated and managed. The facility development partnership model will be further detailed in future versions of this document, as the associated partnership arrangements mature.

# 7 Abbreviations and Acronyms

| Acronym | Description |
| --- | --- |
| AD | Applicable Document |
| ALMA | Atacama Large Millimeter/sub-millimeter Array |
| IPT | Integrated Product Team |
| LSP | Legacy Science Program |
| ngVLA | Next Generation VLA |
| NRAO | National Radio Astronomy Observatory |
| PI | Principal Investigator |
| RD | Reference Document |
| SAC | Science Advisory Council |
| SEMP | Systems Engineering Management Plan |
| TAC | Technical Advisory Council |
| TSD | Technical and Scientific Development |

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