NASA's Physics of the Cosmos and Cosmic Origins Technology Development Program and Technology Needs

Thai Pham

Tech Days 2012

Presentation Objectives

- To inform you about and engage you in the Physics of the Cosmos (PCOS) and Cosmic Origins (COR) Program Offices' technology development program
  - Introduction to the PCOS and COR Program Offices
  - Overview of our technology development activities
  - Present you with opportunities to participate or contribute to our technology development program
    - What our top technology needs are

NASA's Science Goal

Expand scientific understanding of the Earth and the universe in which we live

NASA's Four Scientific Discovery Goals

- Earth Science – Advance Earth System Science to meet the challenges of climate and environmental change.
- Heliophysics – Understand the Sun and its interactions with the Earth and the solar system.
- Planetary Science – Determine the content, origin, and history of the solar system, and the potential for life elsewhere.
- Astrophysics – Discover how the universe works, explore how the universe began and evolved, and search for Earth-like planets.

Astrophysics Has 3 Science Themes

- Physics of the Cosmos (PCOS)
  - How does the universe work? How do matter, energy, space, and time behave under the extraordinary diverse conditions of the cosmos?
- Cosmic Origins (COR)
  - How did we get here? How did the universe originate and evolve to produce the galaxies, stars, and planets we see today?
- Exoplanet Exploration (ExEP)
  - Are we alone? What are the characteristics of planetary systems orbiting other stars, and do they harbor life?

Physics of the Cosmos (PCOS) Program

Program Objective – How does the universe work?

To understand how the universe works starting with the very basic building blocks of our existence - matter, energy, space, and time - and how they behave under the extreme physical conditions that characterize the evolving universe.

The PCOS program incorporates cosmology, high-energy astrophysics, and fundamental physics projects aimed at addressing questions about the nature of complex astrophysical phenomena such as black holes, neutron stars, dark energy, and gravitational waves.

Program Elements

Projects in operations: Chandra, Fermi, Planck, XMM-Newton

Project in development: ST-7

Explorer missions with PCOS Science

- Projects in operation: Suzaku, NuSTAR, Swift and WMAP (in data analysis phase)
- Project in development: Astro-H
- Project in formulation: NICER

PCOS website: pcos.gsfc.nasa.gov

Cosmic Origins (COR) Program

Program Objective – How did we get here?

To understand our cosmic origins, the COR Program strives to discover how the universe originated and evolved to produce the galaxies, stars, and planets we see today. To understand when the first stars in the universe formed, and how they influenced the environments around us.

Program Elements

Projects in operations: Hubble, Herschel, Spitzer, SOFIA (COR science)

Project in development with COR science: JWST

Explorer missions with COR Science

- Project in operation: GALEX, WISE (in data analysis phase)
- Project in formulation: GUSSTO

COR website: cor.gsfc.nasa.gov

Astrophysics Division Technology Funding Sources

NASA's Astrophysics Division funds the development of technology at all levels of maturity.

- The Astronomy and Physics Research and Analysis (APRA) program funds technology development in the earliest phases, from basic research through the first feasibility demonstrations (typically Technology Readiness Level (TRL) 1 through 3.
- The Strategic Astrophysics Technology (SAT) program matures technologies that address the needs of a specific future mission, taking them from the feasibility demonstration to a lab demonstration of a design that meets specific performance requirements (TRL 4 through 6).
- The final maturation stages (TRL 7 through 9) focus on proving the technology's flight-worthiness for a mission-specific application. These stages are addressed by incorporating the technology into a flight project's implementation plan.

Program Technology Management

- The Astrophysics Division invests in technology through several different vehicles, each with its own merit-based review
- These investment decisions are informed by an ongoing discussion with our community through the Program Analysis Groups (PAGs) and through an outreach program that targets both meeting venues and potential providers of specific technologies

The Program Analysis Groups (PAGs)

- There are three PAGs
  - Physics of the Cosmos PAG – PhysPAG
  - Cosmic Origins PAG – COPAG
  - Exoplanet Exploration PAG – ExoPAG
- Each of the three themed PAGs serves as a forum for soliciting and coordinating input and analysis from the scientific community in support of their respective program objectives.
- PAGS are constituted by the NASA Astrophysics Subcommittee and their responsibilities include collecting and summarizing community input with subsequent reporting to NASA via the NASA Advisory Council (NAC)
- All interested scientists and technologists can contribute to the PAG's functions by participating in the PAG meetings and by providing inputs.

PAGs serve as the voice of the science community

PCOS and COR's Technology Management Program

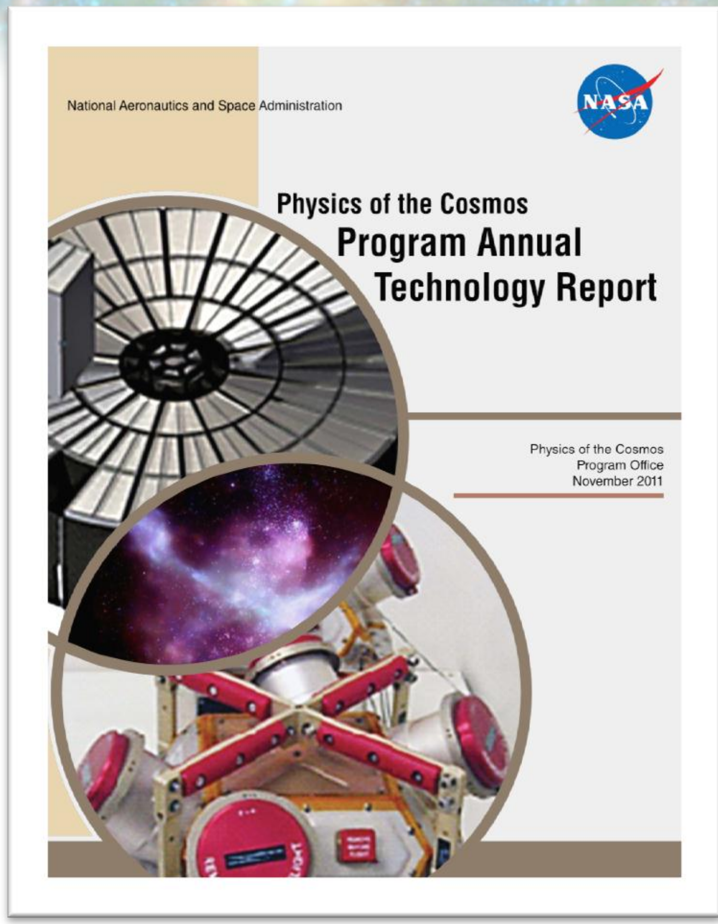
- The community identifies technology needs each summer by working with the PAG or through direct individual submission via the Program Office's web sites.
- The Program's Technology Management Board (TMB) prioritizes these needs based on a published set of criteria that includes assessments of scientific priorities, benefits and impacts, timeliness, and effectiveness.
- These priorities are published each year in the Program Annual Technology Report (PATR), along with the development status of technologies that were funded the previous year.
- The program references these priorities and the PATR over the following year as the calls for technology proposals are generated and investment decisions made.
- Comment from the community is invited at every stage, and specific technology needs input is requested at the start of the summer to begin the prioritization cycle again.

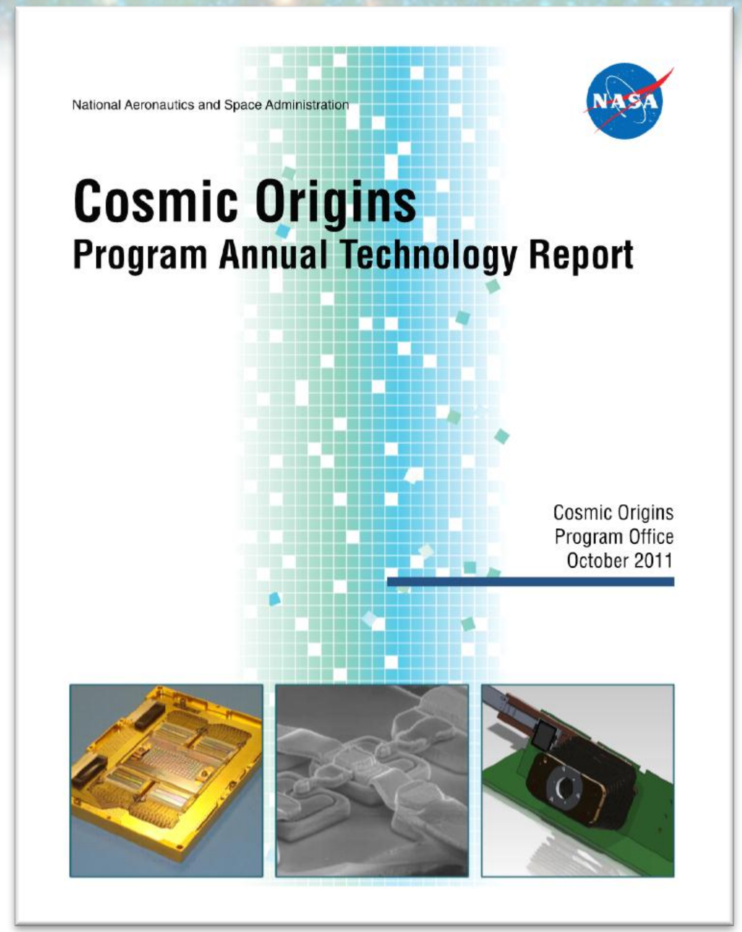
The Program Annual Technology Report (PATR)

- The PATR is an annual report that describes the state of the Program's technology development activities.
  - Summarizes the Program's technology development status for the prior year
  - Assesses the Program's technology needs with respect to current portfolio of planned missions and scientific themes in the Program
  - Provides a prioritized list of technology needs for the coming year

- Updates annually and timed to support annual planning processes.

The Inaugural PCOS and COR PATRs





The PCOS and COR PATRs can be viewed and downloaded from their respective websites: pcos.gsfc.nasa.gov and cor.gsfc.nasa.gov

Each Technology Need Is Evaluated Using a Rigorous Set of Prioritization Criteria

Physics of the Cosmos Program

Cosmic Origins Program

Technology Needs Prioritization Criteria (7/19/12)

					Score Meaning				
#	**Criterion**	**Weight**	**Score (0-4)**	**Weighted Score**	**General Description/Question**	**4**	**3**	**2**	**1**	**0**
1	Scientific Ranking of Applicable Mission Concept	4	4	16	Scientific priority as determined by the Decadal Review, other community-based review, other peer review, or programmatic assessment. Captures the importance of the mission concept which will benefit from the technology.	Highest ranking	Medium rank	Low rank	Not ranked by the Decadal	No clear applicable mission concept
2	Overall Relevance to Applicable Mission Concept	4	4	16	Impact of the technology on the applicable mission concept. Captures the overall importance of the technology to the mission concept.	Critical key enabling technology - required to meet mission concept goals	Highly desirable technology - reduces need for critical resources and/or required to meet secondary mission concept goals	Desirable - offers significant benefits but not required for mission success	Minor implementation improvements	No implementation improvement
3	Scope of Applicability	3								own applicable mission pt
4	Time To Anticipated Need	3								ticipated need
5	Scientific Impact to Applicable Mission Concept	2								entific improvements
6	Implementation Impact to Applicable Mission Concept	2								plementation improvements
7	Schedule Impact to Applicable Mission Concept	2	4	8	Impact of the technology on the schedule of the applicable mission concept. How much does this technology simplify the implementation to bring in the schedule?	Technology is likely to drive the applicable mission schedule.	Technology is likely to drive the schedule for a major subsystem/ component of the applicable mission concept	Technology is likely to drive the schedule for a minor applicable mission concept component	Technology is less likely to be a factor for the schedule of the applicable mission concept	Technology will not be a factor for the schedule of the applicable mission concept
8	Risk Reduction to Applicable Mission Concept	2	4	8	Ability of the technology to reduce risks by providing an alternate path for a high risk technology that is part of the applicable misssion concept.	Technology is a direct alternative to a key technology envisioned for the applicable mission concept. No other known alternate technologies	Technology is a direct alternative to a key technology envisioned for the applicable mission concept. At least one other known alternate technology	Technology is a direct alternative to a secondary technology envisioned. No other known alternate technologies	Technology is a direct alternative to a secondary technology envisioned. At least one other known alternate technology	No risk benefits or technology is already part of the applicable mission concept
9	Definition of Required Technology	1	4	4	How well defined is the required technology? Is there a clear description of what is sought?	Exquisitely defined	Well defined, but some vagueness	Well defined, but some conflicting goals not clarified	Not well defined, lacking in clarity	Poorly defined, not clear at all what is being described
10	Other Sources of Funding	1	4	4	Are there other sources of funding to mature this technology? If funding is expected to be available from other sources, this will lower the prioritization.	No, the Program is the only viable source of funding.	Interest from other sources can be developed during the development time of the technology	Interest from other sources is likely during the development time of the technology	Moderate investments (relative to the potential level for a NASA investment) in the technology are already being made by other programs, agencies, or countries.	Major investments (relative to the potential level for a NASA investment) in the technology are already being made by other programs, agencies, or countries.
11	Availability of Providers	1	4	4	Are there credible providers/developers of this technology? Where providers are scarce, there may be a compelling need to maintain continuity for the technology in the event there are no replacement technologies.	Potential providers/developers have insufficient capabilities to meet applicable mission concept needs.	Potential providers/developers have uncertain capability relative to applicable mission concept needs.	Single competent and credible provider/developer known	Two competent and credible providers/developers known	Multiple competent and credible providers/developers known

Technology prioritization metric contains 11 criteria and addresses science/mission priorities, benefits and impacts, timeliness and effectiveness

The PCOS Technology Needs Priority From 2011 PATR (top 3 of 5 priorities)

Priority	Technology	Science
1	X-ray calorimeter: central array (~1,000 pixels): 2.5 eV FWHM at 6 keV; extended array: 10 eV FWHM at 6 keV.	X-ray
	Telescope: Classical optical design. Surface roughness <lambda/30, backscatter/straylight. Athermal design with temp gradient dimensional stability: pm/sqrt(Hz) and µm lifetime, angular stability <8nrad	Gravitational Wave
	Laser: 10 yr life, 2W, low noise, fast frequency and power actuators	Gravitational Wave
	lightweight, replicated x-ray optics. Lightweight precision structure	X-ray
2	High resolution gratings (transmission or reflection)	X-ray
	High-throughput, light, low-cost, cold, mm-wave telescope operating at low backgrounds	Inflation
	Large format (1,000-10,000 pixels) arrays of CMB polarimeters with noise below the CMB photon noise and excellent control of systematics	Inflation
	Phasemeter: Quadrant photodetector: low noise. ADC: 10 yr life, low noise (amplitude and timing). Alignment sensing, optical truss interferometer, refocus mechanism	Gravitational Wave
	µN thrusters: 10 yr. life, low contam, low thrust noise. Not formation flying.	Gravitational Wave
3	Cryocoolers for detectors and other instrument HW	X-ray
	Low CTE materials	Gravitational Wave
	Passive Spitzer design plus cooling to 100 mK	Inflation
	Anti-reflection coatings	Inflation

PCOS Priority 1
Optics related technology needs

- Stable, low stray light telescopes for gravitational wave detection

  Athermal telescope designs have to be developed to meet stability and alignment requirements. Materials have to be tested for creep at the pm/nrad level. Study ways to predict and reduce the effects of back scatter on the interferometry.

- Long life lasers for future gravitational wave mission

  2W laser in a linear polarized, single frequency, single spatial mode. It requires fast actuators (BW > 10kHz) for intensity and frequency stabilization to enable laser phase locking and relative intensity noise of <10-6/rtHz. Shot noise limited at 1mW laser power above 2 MHz, and 10 year lifetime.

- Lightweight replicated X-ray optics

  Requirement for perfectly aligned primary-secondary mirror pair are 3.3-6.6 arc-sec HPD for 5-10 arc-sec HPD mission, respectively. Manufacturability requirements drive fabrication yield and fabrication time per mirror segment.

PCOS Priority 2
Optics related technology needs

- High resolution X-ray gratings
  - High ruling density off-plane (OP) reflective and critical angle transmission (CAT) x-ray gratings for dispersive x-ray spectroscopy. Gratings with resolving power lambda/delta-lambda > 3000 over wavelengths of 1.2 to 5 nm.

- High throughput, cold mm-wave telescope operating at low background for future inflation probe missions
  - High-throughput telescope and optical elements with controlled polarization properties are required; possible use of active polarization modulation using optical elements.

- Phasemeter system for gravitational wave measurement
  - The phasemeter measures the phase of laser beat signals with ucycl/rtHz sensitivity. It is the main interferometry signal for LISA. The phasemeter consists of a fast photo receiver which detects the beat signal, an ADC which digitizes the laser beat signal, and a digital signal processing board which processes the digitized signal.

The COR Technology Needs Priority From 2011 PATR

COR Technology Needs Prioritization	
High QE, large format UV detectors	**Priority 1.** Contains technology activities that the Board has determined to be of the highest interest to the Cosmic Origins program and recommends that they should be invested in first, when funding is available
Photon counting UV large-format detectors	
UV coatings	
Ultralow-noise Far-IR direct detectors	
Large, low-cost, light-weight precision mirrors for Ultra-Stable Large Aperture UV/Optical Telescopes	**Priority 2:** Contains technology activities that the Board feels are worthy of pursuit and would be invested in, if funding allows
Deployable light-weight precision mirrors for future Very Large Aperture UV/Optical Telescopes	
Large format, low noise Far-IR direct detectors	
Sub-Kelvin Coolers	
Photon counting Optical/IR detector arrays	**Priority 3:** Contains technologies that are deemed to be supportive of COR objectives but, for various reasons, do not warrant investment at the present, although they could be invested in, if significant additional funding is available
Large, cryogenic far-IR telescopes	
Very large format, low noise Optical/IR detector arrays	
Interferometry for far-IR telescopes	

COR Priorities 1 & 2
Optics related technology needs

- Priority 1
  - UV Coatings – highly reflective and highly uniform with wide bandpasses UV coatings are required to support the next generation of UV missions, allows multiple reflections, extended bandpasses, and accommodate combined UV and high-contrast exoplanet imaging objectives.
- Priority 2
  - Large low cost, light-weight precision mirrors for ultra-stable large aperture UV optical telescopes
  - Deployable light-weight precision mirrors for future very large aperture UV optical telescopes

    Future UV/Optical telescopes will require increasingly large apertures to answer the questions raised by HST, JWST, Planck and Herschel and to complement ground-based telescopes. Requires technologies that provide high degree of thermal and dynamic stability, and wave front sensing and control.

How You Can Participate and Contribute

- Contribute and engage with your science community!
- Visit the PCOS and/or COR website for more information
- Subscribe to the PCOS and/or COR mailing list and receive news and announcements to stay informed
- Attend PAG meetings (in person or by phone)
- Participate in PAG activities
- Contribute to technology needs list development or submit need(s) directly to the Program
- Propose to SAT proposal calls
- Feel free to contact us if you have questions

pcos.gsfc.nasa.gov

cor.gsfc.nasa.gov

Conclusion

- PCOS and COR Program Offices seek input on technology needs each June from the PhysPAG and COPAG, respectively, and the general science and research community
- Technology needs prioritization is determined by the Program TMB, using a stringent set of prioritization criteria that includes the Decadal Survey priority
- Program technology needs priorities are published each October in the PATR. This information:
  – Informs the call for SAT proposals
  – Informs technology developers of the Program needs
  – Guides the selection of technology awards to be aligned with program goals
- Contribute and engage with your science community
  – Submit your technology needs
  – Participate in PAG meetings and activities
  – Be informed of the program needs – consult the PATR
  – Propose your innovation

Thank you!

Backup

2011 Targeted PCOS Technology Awards

Proposed Work	PI	Institution
X-ray Mission Mirrors: Develop glass mirror segment fabrication and mounting techniques toward demonstration of TRL 5	W. Zhang	Goddard Space Flight Center
X-ray Mission Micro-calorimeter: Develop 32 x 32 arrays that incorporate Athena "pitch" and 3 X 16 readout for demonstration of TRL 5	C. Kilbourne	Goddard Space Flight Center
Gravitational Wave Mission Telescope: Establish telescope design that meets pathlength stability and wavefront error requirements for NGO; demonstrate optical and scattered light performance for telescope.	J. Livas	Goddard Space Flight Center
Gravitational Wave Mission Phasemeter: Design and demonstrate modifications to phasemeter that support relaxation of LISA's requirements on laser noise, orbital parameters, and received optical power; Assemble and test analog signal chain pre-amp board	W. Klipstein	Jet Propulsion Laboratory

Targeted COR Technology Awards

Proposal Title	PI	Institution	Area
Heterodyne Technology For SOFIA	Paul Goldsmith	JPL	*Far-IR Detectors*
Far-Infrared Large-Format Array Detectors	Harvey Moseley	GSFC	*Far-IR Detectors*

2011 PCOS SAT Awards

Title	PI	Institution
Development of Fabrication Process for Critical-Angle X-ray Transmission Gratings	M. Schattenburg	Massachusetts Institute of Technology
Antenna-Coupled Superconducting Detectors for Cosmic Microwave Background Polarimetry	J. Bock	Jet Propulsion Laboratory
Directly-Deposited Blocking Filters for Imaging X-ray Detectors: Technology Development for the International X-ray Observatory	M. Bautz	Massachusetts Institute of Technology
Off-plane Grating Arrays for Future Missions	R. McEntaffer	University of Iowa
Development of moderate angular resolution full shell electroplated metal grazing incidence x-ray optics	P. Reid	Smithsonian Astrophysical Observatory

2011 COR SAT Awards

Title	PI	Institution
Advanced UVOIR Mirror Technology Development for Very Large Space Telescopes	Phillip Stahl	Marshall Space Flight Center
High performance cross-strip micro- channel plate detector systems for spaceflight experiments	John Vallerga	UC Berkeley
Enhanced MgF2 & LiF Overcoated Al Mirrors for FUV Space Astronomy	Manuel Quijada	Goddard Space Flight Center

Prioritizing PCOS and COR Technology Needs

- A prioritization process has been put in place that will
  - Inform the call for SAT proposals
  - Inform technology developers of the program needs
  - Guide the selection of technology awards to be aligned with program goals
- PCOS and COR TMBs are in the process of prioritizing the 2012 technology needs inputs based on established criteria
- Needs priorities and investment recommendation will be published in the Program Annual Technology Report (PATR)
- This process improves the transparency and relevance of technology investments, provides the community a voice in the process, ensures open competition for funding, and leverages the technology investments of external organizations by defining a need and a customer

Technology Management: Merit Based Processes

All technology funding allocated through a merit-based process

- A Program Technology Management Board is established to review/vet community input, define needs and priorities, recommend allocations, and concur at achievement milestones (see next chart)
- In all cases, technology needs are identified working closely with the broad community (PAG, SAGs, workshops, working groups)
- Program Technology
  - Traditional open call released by NASA HQ as an AO (e.g., ROSES, APRA, SAT)
  - Program Director serves as selecting official
- Unique infrastructure
  - Targeted call for proposals released by NASA HQ or Program Office
  - Program Director serves as selecting official (or equivalent)
- Mission-specific technology (tied to study or project office)
  - Managed according to vetted TDP, with RFPs and strategic partnerships managed by the study or project office

NASA TRL Per NPR 7120.8 Appendix J (1 of 4)

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experimental results validating predictions of key parameters.

NASA TRL Per NPR 7120.8 Appendix J (2 of 4)

TRL	Definition	Hardware Description	Software Description	Exit Criteria
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in a relevant environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.

30

NASA TRL Per NPR 7120.8 Appendix J (3 of 4)

TRL	Definition	Hardware Description	Software Description	Exit Criteria
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

NASA TRL Per NPR 7120.8 Terminologies (4 of 4)

Proof of Concept: Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.

Breadboard: A low fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.

Brassboard: A medium fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.

Proto-type Unit: The proto-type unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment

Engineering Unit: A high fidelity unit that demonstrates critical aspects of the engineering processes involved in the development of the operational unit. Engineering test units are intended to closely resemble the final product (hardware/software) to the maximum extent possible and are built and tested so as to establish confidence that the design will function in the expected environments. In some cases, the engineering unit will become the final product, assuming proper traceability has been exercised over the components and hardware handling.

Mission Configuration: The final architecture/system design of the product that will be used in the operational environment. If the product is a subsystem/component, then it is embedded in the actual system in the actual configuration used in operation.

Laboratory Environment: An environment that does not address in any manner the environment to be encountered by the system, subsystem, or component (hardware or software) during its intended operation. Tests in a laboratory environment are solely for the purpose of demonstrating the underlying principles of technical performance (functions), without respect to the impact of environment.

Relevant Environment: Not all systems, subsystems, and/or components need to be operated in the operational environment in order to satisfactorily address performance margin requirements. Consequently, the relevant environment is the specific subset of the operational environment that is required to demonstrate critical "at risk" aspects of the final product performance in an operational environment. It is an environment that focuses specifically on "stressing" the technology advance in question.

Operational Environment: The environment in which the final product will be operated. In the case of space flight hardware/software, it is space. In the case of ground-based or airborne systems that are not directed toward space flight, it will be the environments defined by the scope of operations. For software, the environment will be defined by the operational platform.