ExoPlanet Exploration Program

NASA Research Announcement:
Technology Development
for Exoplanet Missions (TDEM)
Technology Milestones

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Peter R. Lawson
Marie B. Levine

Jet Propulsion Laboratory
California Institute of Technology

- One or more technology milestones must be proposed as part of a TDEM proposal

- Milestones are measured steps to verify technology readiness tied to the performance of a specific mission. It can be one or more elements of the "3-legged stool":

  Based on a mission error budget w/ sub-system allocations:

  1. **Demonstrate technology through laboratory experiments to quantified goals traceable to an error budget allocation**

  2. **Validate technology demonstration models & error budget sensitivities**

  3. **Apply validated models to mission analyses and error budget to demonstrate that the on-orbit performance is achieved**

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- Advancement to the next TRL level requires that <u>all</u> 3 steps be satisfied using TRL maturity definitions in NPR 7120.8 Appendix J:
  - Experimental demonstration of the component/subsystem/system technology
  - Model validation of the experimental demonstration, including error budget sensitivities
  - Verification of the mission error budget using the validated models

- A milestone can be any of these 3 steps required to achieve partial TRL advancement and must satisfy at least one of the three criteria:
  - Experimental demonstrations of milestone performance must be stable and repeatable, thereby demonstrating that the result is not spurious or transient;
  - Model must be validated against laboratory results at Milestone levels within specified bounds defined through flight error budget tolerances, thereby establishing that the behavior and its sensitivities are thoroughly understood;
  - Error budgets for the representative mission must be consistent w/ the validated models

- Notes:
  - *The model fidelity and complexity is commensurate with the TRL level, as it is with hardware.*
  - *Demonstrating technology to flight performance levels is not required for TDEM as long as it is explained how the proposed demonstration matures the technology towards a flight goal as part of a longer term technology effort.*

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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 an operational 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.

TPF-C Example:
Starlight Suppression Milestones & TRLs

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Planned Completion Date	Planned Activities	Performance Targets	TRL
Pre-Phase A	Monochromatic starlight suppression	Milestone 1: 10^{-9} contrast, 4 λ/D, laser light (λ=785 nm)	4
Pre-Phase A	Broadband starlight suppression	Milestone 2: 10^{-9} contrast, 4 λ/D, 60 nm bandwidth centered at 800 nm	4
Pre-Phase A	Modeling of testbed	Milestone 3A: Correlation of experimental testbed data and optical models of the testbed at 10^{-9} level	4
Pre-Phase A	Integrated modeling of mission	Milestone 3B: Demonstrate viability of 10^{-10} contrast in flight mission using modeling approach validated against testbed and current mission error budget	4
Phase A	Demonstrate full dark hole using 2 DMs; design/build custom bench and mounts.	1×10^{-9} contrast, full dark hole, 4 λ/D, 100nm bandwidth centered at 675 nm; correlation of experimental testbed data with optical models of the testbed at 1×10^{-9} level	5
Phase B	Experiments with custom bench; install and operate Planet Detection Simulator	1×10^{-10} contrast, full dark hole, 4 λ/D, 100 nm bandwidth centered at 550 nm (or current requirement for planet detection); correlation of experimental testbed data with integrated models of the testbed at 1×10^{-10}	6

Other Milestone examples in TPF-C Technology Plan (2005)
http://planetquest.jpl.nasa.gov/TPF/TPF-CTechPlan.pdf

What needs to be included in the proposal?

- A clear justification of the current TRL of the target technology
  - At a minimum must be at TRL 3 with a proposed advancement to TRL 4.

- An error budget for a representative flight mission with sufficient detail down to the component/sub-system level to quantify the performance goals of the proposed technology demonstration.

- A high-level description and justification of the milestone in the context of how it matures it to flight;
  - enough information that the significance of the milestone is easily understood.

- The resources, general approach, and schedule that will be used to attain the milestone

References and Examples

- Technology Readiness Levels as defined in NASA Procedural Requirements NPR 7120.8
  - http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_0008_&page_name=AppendixJ

- TPF-C Technology Plan & Milestone Reports
  - http://planetquest.jpl.nasa.gov/TPF-C/tpf-C_index.cfm

- TPF-I Technology Milestone Whitepapers & Reports
  - http://planetquest.jpl.nasa.gov/TPF-I/tpf_currentStatus.cfm

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- Milestone Whitepaper
  - A detailed document describing the goal of the milestone demonstration and the criteria by which it will be met
  - It is the contract that describes the work to be undertaken
  - Signed by the PI, the Exoplanet Program representative, and NASA HQ

- Lawson will guide you through the process on behalf of the Exoplanet Program
  - Assist in editing the Whitepaper, if appropriate
  - Coordinate the date of the review with the independent panel
  - Moderate the review on behalf of the PI
  - Track issues to be resolved
  - Negotiate changes and coordinate the signing of the final draft

- Milestones will be reviewed and approved by an independent board appointed by NASA HQ (EIRB) and select members of the ExEP Program.

Typical Milestone Whitepaper Table of Contents

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1. Objective

2. Introduction

   i. Testbed and/or model description

   ii. Definition of demonstration goals and traceability to flight mission error budget allocation

   iii. Differences between flight and lab demos and/or models

3. Milestone Procedure

   i. Definitions

   ii. Measurement / analysis approach, including:

   - assumptions, calibration of test/modeling errors, …

   iii. Validation methodology

4. Milestone Criteria

5. Certification Process

6. References

(Example) Milestone Success Criteria

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- Define the
  - Wavelength and minimum bandwidth to be used
  - Performance metric (i.e. starlight rejection)
  - Threshold performance required for success
    - Maximum mean value calculated over an angular region, or as a function of time for a given period
  - Duration of the tests or time-series of data
    - Each time series will be n-hours or more
  - Number of repetitions of the experiment
    - Typically three repetitions
  - The time between experiments
    - Typically 48 hours
- For model validation, provide model fidelity goals based on error budget tolerances

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- Lawson will schedule a review by telecon about 1 ½ or 2 months in advance of the anticipated date
    - www.doodle.com

- The PI will send a draft whitepaper to the independent panel ~2 weeks prior to the review

- The panel will compile a bulleted or numbered list of detailed comments in a single Word document and email it for consideration of the PI about 3 days prior to the review

- The PI will send his responses to the panel just prior to the telecon; the Word document itself is edited and returned.

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- The telecon will last about 1.5 – 2.0 hours. Most issues will already have been resolved by the previous exchanges.
  - The list of comments and responses will be read through.
  - Most discussions will simply be to clarify the issues and concerns
  - Changes to the text will be negotiated and noted

- About 2 or 3 weeks after the review, a revised draft will be sent to the panel, along with the edited Word document noting where the changes have occurred.

- If the panel is in agreement (by email) that all issues have been resolved, the panel will recommend that the document be signed, and the signature page will be circulated.

The Milestone Report and Review

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- The Milestone Report is almost a carbon copy of the Whitepaper, repeating all that content but now also including
  - Laboratory and/or Modeling Results
    - Show all the required experimental / analysis data
    - The criteria are stepped through and shown to be met
  - Conclusion
    - Because all the criteria have been met, the milestone has now been demonstrated

- The Report review process is essentially the same as the Whitepaper review

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- Make it easy for the review panel to help you.

- Provide a detailed and clear description of the milestone experiment and its relevance to flight
  - Include a diagram of the experimental layout and components. Provide photographs if possible.

- Explain the path forward to future milestones and the overall technology plan or roadmap

- Provide background material and references from the refereed literature

- Make absolutely sure the success criteria are unambiguous and not needlessly restrictive

- Do your **utmost** to resolve all major issues and/or misunderstandings *prior* to the date of the telecon

Exoplanet Program Point of Contact

ExoPlanet Exploration Program

For questions concerning technology milestones contact:

Dr. Peter Lawson

Jet Propulsion Laboratory

4800 Oak Grove Drive

Pasadena, CA 91109

Telephone: (818) 354-0747

Email: Peter.R.Lawson@jpl.nasa.gov