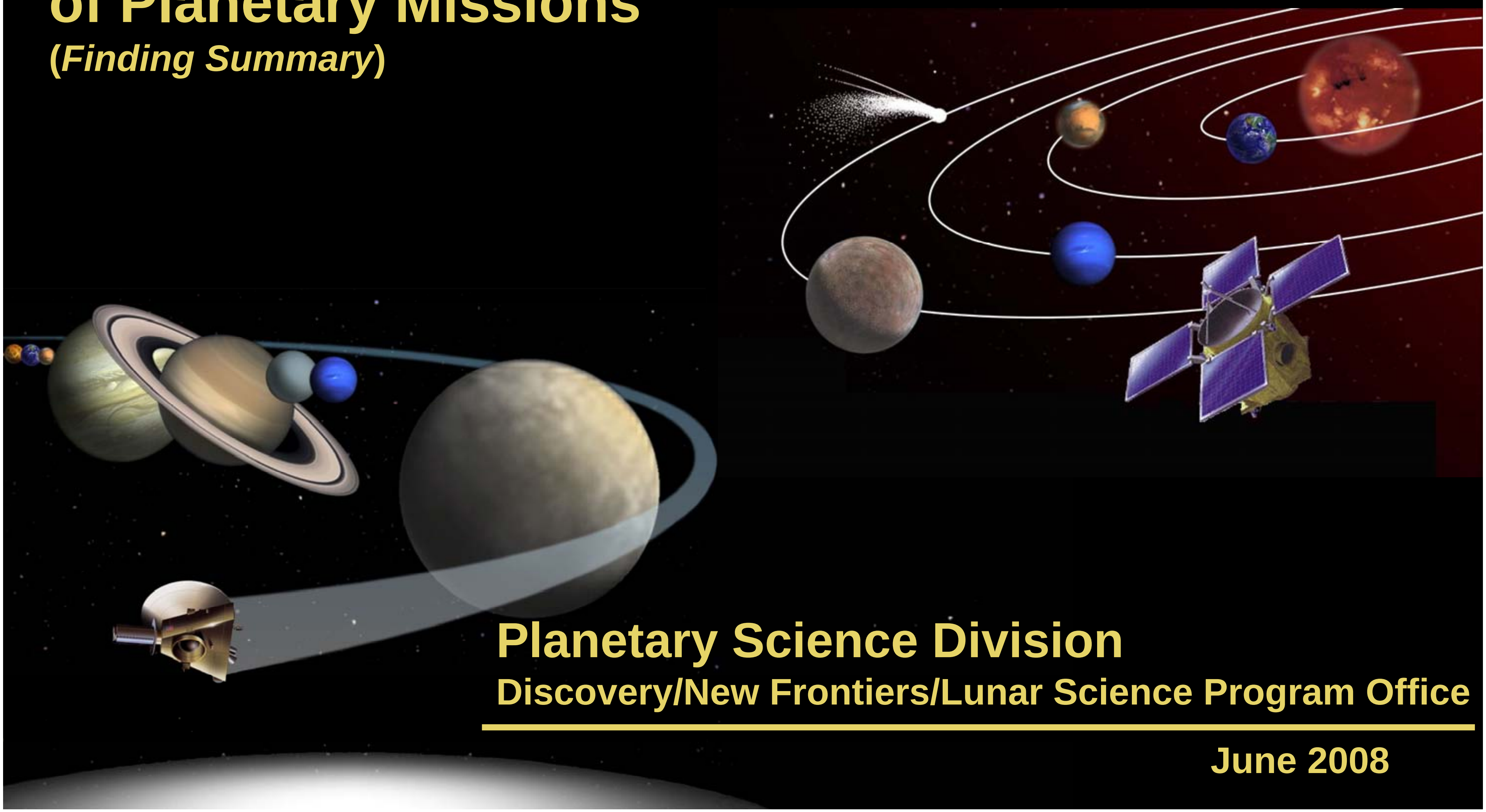
National Aeronautics and Space Administration

# Improving the Life-Cycle Cost Management of Planetary Missions

**(*Finding Summary*)**



## Planetary Science Division

**Discovery/New Frontiers/Lunar Science Program Office**

**June 2008**

# Program Office *Goal*

Discovery

New Frontiers

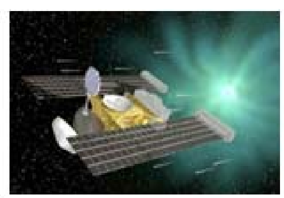
## Goal ……

- **Enhance the probability of mission success of the Projects through independent oversight and insight through all phases of the mission life cycle utilizing a high-powered, effective, and efficient team.**

## Success is……

- **Delivering Mission Science to the PI (meet the Level I requirements)**
- **Ensuring the implementing organization's success in delivering the spacecraft on cost and schedule (meet the launch date and cost cap)**
- **Meeting the Program launch frequency for Science Missions**






# Background
## *Study Impetus & Research Plan*

Discovery
New Frontiers

"Assess the cost escapes that have occurred on recent DNF missions, and determine what *reasonable* things we can do as a program to either prevent them or manage them better. How are the cost escapes making it through our processes?" - *Program Manager*

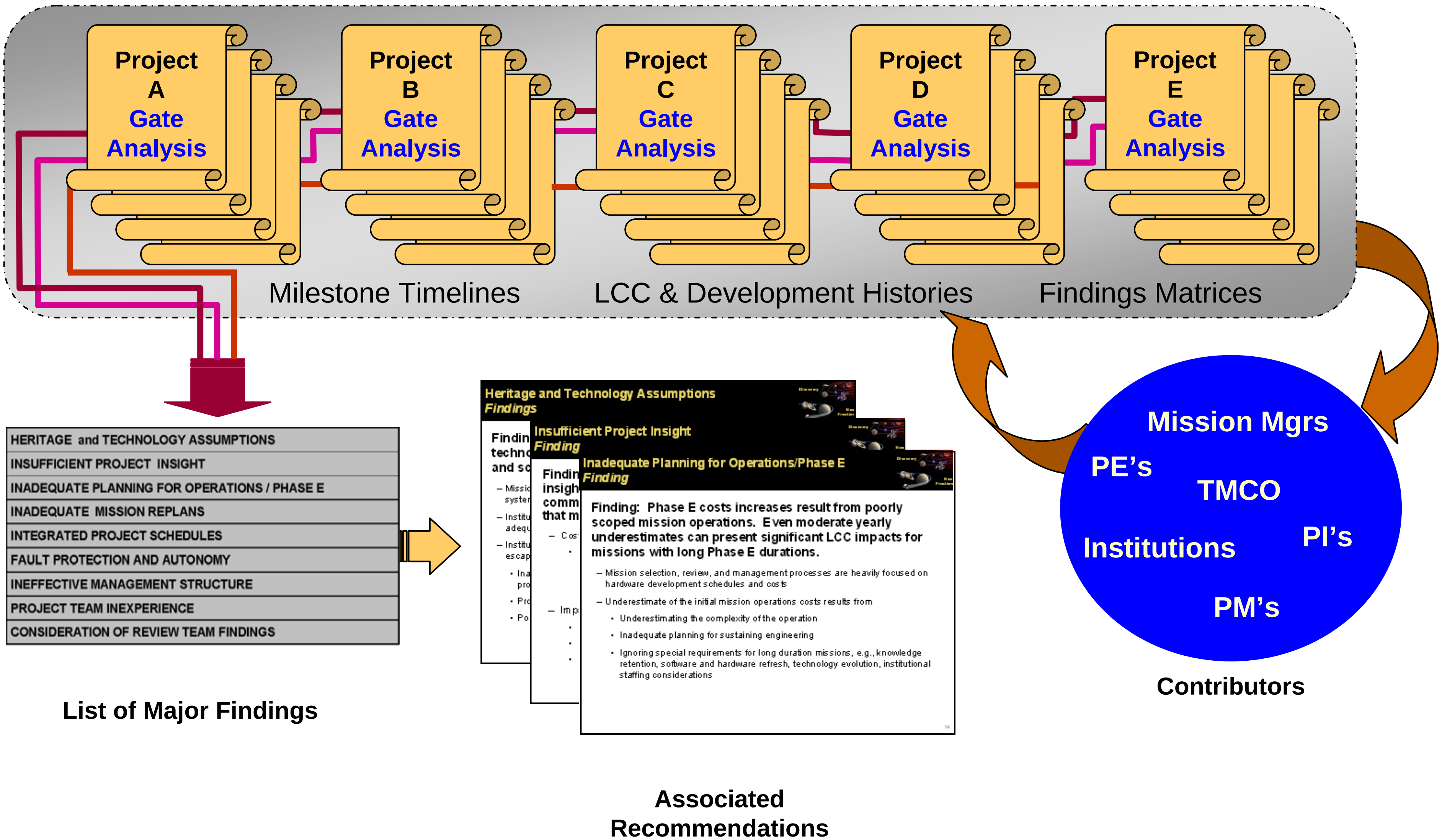
(Reference: Discovery and New Frontiers Program Office (D&NF PO) Risk # DNF-54)

Research Plan:

- ✓ Select candidate missions based on recent cost exceedance history
- ✓ Collect historical data on each mission
- ✓ Establish accepted historical timeline of mission cost increases (phases, major milestones, & decisions affecting)
- ✓ Identify causes affecting cost increases over missions' life cycle

Understand the *why* and *how* of recent cost overruns in order to identify actions for *mitigating* program cost risk

# Study Implementation
## *Study Approach Using Gate Analysis*

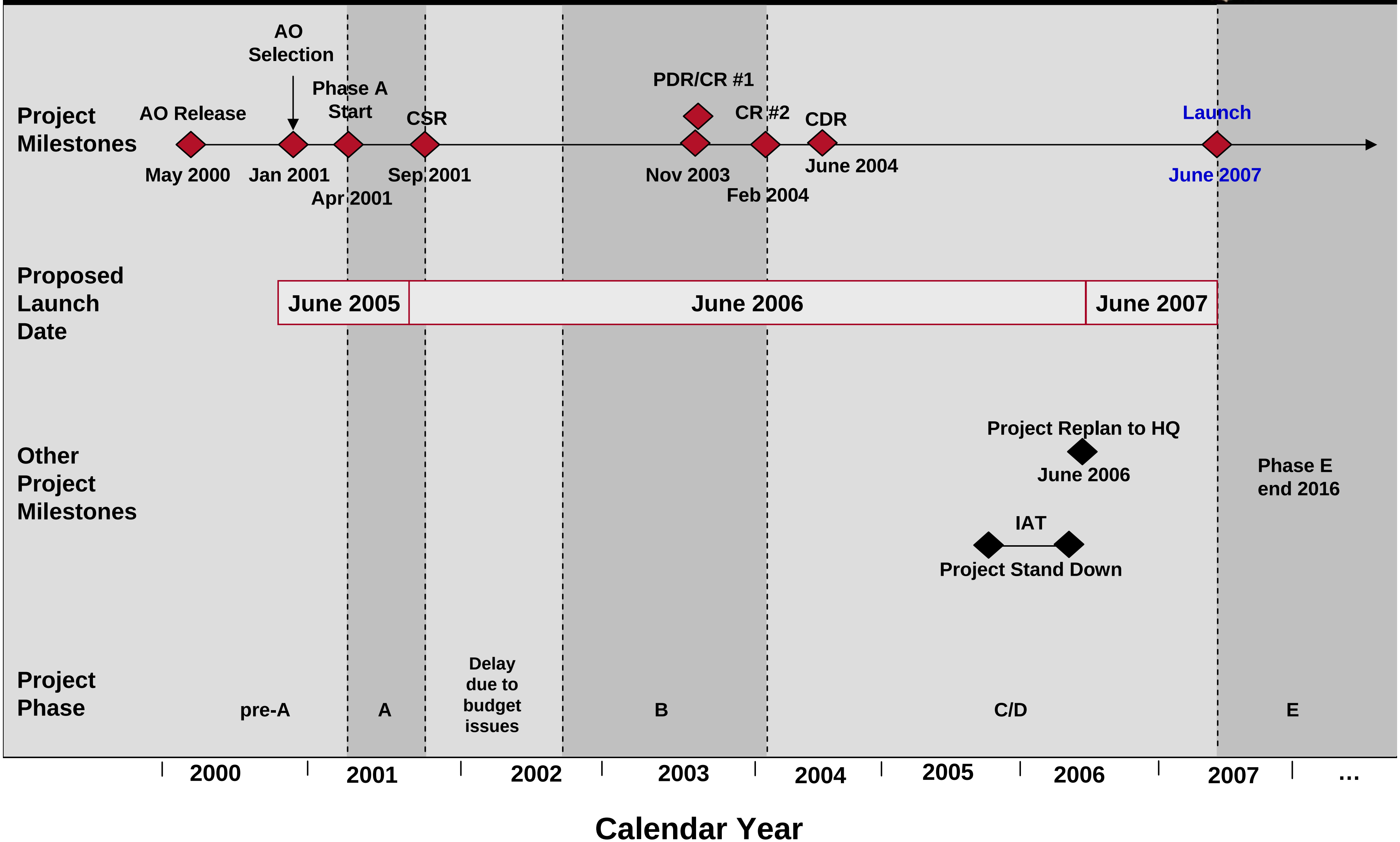


# Study Implementation
## *Issues Affecting Data Collection*

- Collection, analysis, and synthesis of data much more intensive than anticipated
  - Assumptions were made when necessary to correlate across missions, but data still valid for identifying driving issues
- Lack of official/formal program documentation
  - Little traceability to program-level decisions or direction (e.g., official letters, documents)
  - Inconsistent records of year-to-year or life-cycle phased cost commitments and obligations to projects
- Understanding of common program operating principles
  - Institutions (i.e., projects) not clear on *definition of cost cap*

**Difficult to obtain and capture important/key aspects in the life of a mission due to programmatic practices**

# *Mission A*
# *Milestone Timeline*

# Cost History Data Examples

Project didn't enter Phase C/D with 25% reserve. Confirmation Presentation--IAT Report---"Cost reserves for Phase C/D activities appear low at 12% , ..".

Technology -The project was faced with considerable development challenges for qualification of the solar array thermal design, qualification of the phased array RF design, implementation of a new structural composite material design, and the propulsion system titanium tank design.

Longevity Engineering issues. Baseline planning did not address loss or redundancy of key skills in critical areas.

Although the project's early phase B design and trade study efforts evaluated the scope of NIAT recommendations for risk reduction analysis/integration during the development process, the project's implementation of NIAT recommendations were higher than anticipated ($1M).

The development costs for the science instruments exceeded original preliminary design estimate by RY$ 18M, during Phase C/D.  Primary problems were attributable to the Ball Aerospace instrument.

During this same Phase C/D period, the project experienced cost growth. The project had not revalidated their vendor quotes since the CSR cost estimate.

# Cost History Data Examples


**Project experienced several stops and starts. Completed Phase A by Sept 2001 but 9/11 national disaster delayed Phase B into 2002.**

**Three different Project Managers during Phase A through Phase C/D due…..**

**Center project management didn't assume "prime contractor" role. Contractor never had prime contractor responsibility.**

**Contractor had no system level, planetary project implementation experience. Project experienced significant Contractor cost overruns.**

**The project proposal assumed a high-level of propulsion system hardware inheritance from another mission. Phase B study should have derived that assumption was not valid. Phase C/D experienced significant cost overruns.**

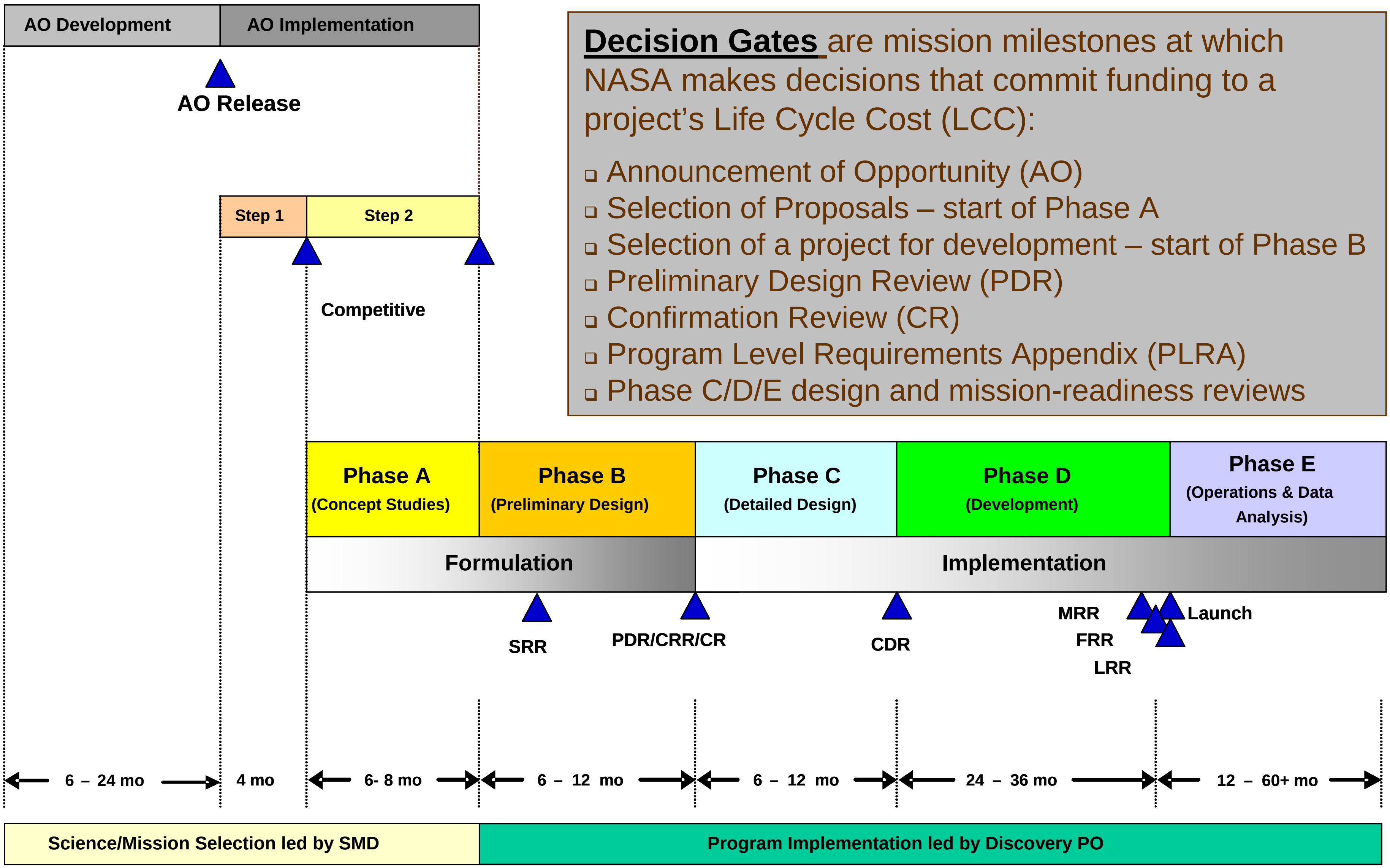
**Independent assessment teams at PDR and CDR of project indicated high probability that project was under funded.**

**PI and Project Manager expended project reserves ($25M) in the first year of Phase C/D, attempting to satisfy/meet the launch date -- not a restricted launch window. In second year of phase C/D, the Project experienced significant cost overruns.**

# Background
## *Generic Mission Development Process*


**<u>Decision Gates</u>** are mission milestones at which NASA makes decisions that commit funding to a project's Life Cycle Cost (LCC):

- Announcement of Opportunity (AO)
- Selection of Proposals – start of Phase A
- Selection of a project for development – start of Phase B
- Preliminary Design Review (PDR)
- Confirmation Review (CR)
- Program Level Requirements Appendix (PLRA)
- Phase C/D/E design and mission-readiness reviews



# Process


**Project A Mission Findings from Gate Analysis of Project Development Lifecycle**

| | Recommended Steps Distributed by Phase of Life Cycle | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | AO | AO / Phase A | PDR | | Phase C/D | | All Phases | |
| Phase/Milestone/Mechanism<br>Mission Event | AO Period Step 1 - Selection | Phase A CSR (AO Step 2) | Phase B - PDR | CR Period | Phase C - CDR | Phase D (Dev./ATLO) | Periodic Reporting | Notes |
| Explanation of the finding/event that increased mission life cycle cost. Include timeframe that finding affected LCC of the mission.<br>"When did it hit the fan?" | Progressing through the development life cycle (AO thru' launch +phase E/ops), consider what steps/actions/methods/approaches could have been taken to better mitigate and control the *mission event?*<br>Goal: produce a specific recommendation that leads to better control and management of project cost growth through the life cycle (AO - phase E). | | | | | | | Include *specific (i.e., finding based) and concrete recommendations for each mission event.*<br>*"What should I do the next time this event occurs in a project's development cycle?"* |
| **9) Sustaining Engineering Underestimate**<br><br>Prior to launch, it was determined that the mission baseline costs did not include provision for Spacecraft or instrument engineering support during Phase E. | | Project should provide FTE estimate by WBS engineering skill area for Phase E.<br><br>TMCO should review adequacy by skill area. | | SRB should independently evaluate Phase E staffing levels for adequacy.<br><br>Staffing level summary should be presented in CR presentation. | | Engineering staffing support readiness should be addressed in ORR, along with longevity planning preparation. | | |
| **10) Longevity Engineering issues**<br><br>Baseline planning for the Mission did not address loss or redundancy of key skills in critical areas. Example, departure of Lead System engineer created a significant gap in knowledge, or the need for propulsion system engineer backup. This presented a risk to completion of the mission, which required staffing to mitigate/ | TMCO should specifically check this area for long duration flights. | CSR should require submittal of summary longevity plan.<br><br>TMCO should evaluate longevity plan and cost estimate, including staffing approach. | | SRB should evaluate project longevity plan and costs.<br><br>A page on longevity planning and staffing should be presented in the CR. | | ORR should address longevity preparedness | | |

# Study Implementation
## *Major Observations*


| |
|---|
| **Inability of Project & Program to perform credible estimates early in development** |
| **Poor Program Documentation** |
| **Risk Transition at Phase B** |
| **Upper Stage Certification** |
| **Nuclear Power Sources** |

# Study Implementation
## *Major Findings*

| |
|---|
| HERITAGE and TECHNOLOGY ASSUMPTIONS |
| INSUFFICIENT PROJECT INSIGHT |
| INADEQUATE PLANNING FOR OPERATIONS / PHASE E |
| INADEQUATE MISSION REPLANS |
| INTEGRATED PROJECT SCHEDULES |
| FAULT PROTECTION AND AUTONOMY |
| INEFFECTIVE MANAGEMENT STRUCTURE |
| PROJECT TEAM INEXPERIENCE |
| CONSIDERATION OF REVIEW TEAM FINDINGS |

# Observations

**<u>Inability of Project & Program to perform credible estimates early in development:</u>** Optimistic estimates during Phase A lead to cost and schedule growth in Phases C/D.

- Although, the aerospace industry has produced spacecraft systems for more than 30 years, the early LCC estimates continue to be inaccurate.
- The relative immaturity of mission designs in the early development phases affects the ability to accurately forecast/check the project LCC estimates.
- Cost modeling tools are improving, but are still heavily driven by key assumptions and knowledge of the mission
- Optimistic key assumptions which don’t come true (heritage, SW simulation facilities, personnel sharing & multi-tasking, Fault Protection SW, contactor experience, etc…)
- Competitive pressures????

# Observations

**<u>Poor Program Documentation:</u>** Program needs to be diligent in documenting decisions and Project direction

- Significant Programmatic direction to a Project should be documented by the PO or PSD in a NASA memorandum
- Project Budget adjustments should be documented in the Program Budget Report, including documentation of PPBE feedback to projects.
- Significant Project meeting decisions should be documented in official minutes (DPMC, Program Control Board, etc…) which are sent to key program and project attendees.

**<u>Risk Transition at Phase B:</u>** The Program and Projects were not tracking or mitigating risks and issues identified in the Phase A competitive review process (Phase A Step 2)

# Observations

**<u>Upper Stage Certification:</u>** The processes and standards of the Spacecraft team are not setup to perform flight certification of a launch stage. Procurement of the 3rd stage should be performed by the Launch Vehicle provider.

**<u>Nuclear Power Sources:</u>** Nuclear compliance processing for RTGs can become a significant hidden cost for both the Spacecraft and the Launch Vehicle teams. Cost estimates and reserves to process nuclear power sources should be evaluated in detail.

# Heritage and Technology Assumptions
## *Findings*


**<u>Finding</u>: Optimistic hardware/software inheritance and technology readiness assumptions cause significant cost and schedule growth in Phases C/D.**

– Missions frequently assume the use of heritage and advanced technology systems in their proposals to reduce the overall mission risk and cost.

– Institutional inheritance and technology readiness processes appear to adequately prevent technical issues from impacting mission operational success

– Institutional inheritance and technology readiness processes allow cost/schedule escapes to occur which impact phase C/D.

- Inadequate understanding of the heritage system's performance within the proposed project design
- Project personnel with insufficient experience with the heritage system
- Poor scoping of impacts to implement a new technology for space flight

# Insufficient Project Insight
## *Findings*


**<u>Finding:</u> Insufficient project management and technical insight into contractor performance results in poor communications, schedule delays, and technical problems that manifest as cost over-runs.**

- Cost overruns resulted from insufficient oversight/insight in many areas
  - Specifications, processes, and procedures that did not meet institutional standards
    - Organization “cultural” differences
    - Insufficient flow down of requirements
- Impacts
  - Rework, retest, and waivers to hardware and software
  - Hardware mishaps
  - Additional personnel to perform the appropriate level of insight is added to correct issues


**<u>Finding:</u> Phase E costs increases result from poorly scoped mission operations. Even moderate yearly underestimates can present significant LCC impacts for missions with long Phase E durations.**

- Mission selection, review, and management processes are heavily focused on hardware development schedules and costs
- Underestimate of the initial mission operations costs results from
  - Underestimating the complexity of the operation
  - Inadequate planning for sustaining engineering
  - Ignoring special requirements for long duration missions, e.g., knowledge retention, software and hardware refresh, technology evolution, institutional staffing considerations

# Inadequate Mission Replans
## *Findings*


**<u>Finding:</u> The impact of significant changes to mission scope, schedule, or funding profiles were not sufficiently understood, resulting in unexpected cost increases and schedule delays.**

- Failure of the projects to do a thorough impact assessment and replan, and the Program to confirm it, resulted in later mission cost and schedule surprises
- Program-driven changes include
  - Scope additions such as NIAT requirements (for risk reduction)
  - Program funding constraints/Full cost requirements
- Project-driven changes include
  - Launch delays due to hardware development issues/costs
  - Deferral of Phase C/D work (software and ground segment hardware) into Phase E
- Program- and Project-driven changes, regardless of lifecycle timeframe, often result in underestimates of the effects (i.e., duration and complexity) on the operations phase
  - Replans during development tend to concentrate on Phase C/D, so impacts to operations receive limited analysis and review

# Integrated Project Schedules
## *Findings*


**<u>Finding:</u>  The lack of a comprehensive, integrated Project schedule results in uncoordinated activities, inefficiencies in resource management, and increased costs**

- EVM is ineffective without a valid, comprehensive Integrated Master Schedule
- Integrated Master Schedule inadequacies include
  - Missing critical milestones and major events resulting in underestimated resources, and insufficient data for tracking performance
  - Missing logical relationships (interdependencies), or unidentified or incomplete critical paths, resulting in underestimated resources, schedule delays, and poor decision making
  - Multiple separate, uncoordinated schedules resulting in incomplete data for tracking performance, missing logical relationships, and unidentified critical paths

# Fault Protection and Autonomy
## *Findings*

**<u>Finding</u>: Missions underestimate the time and effort required to complete fault protection and autonomy (FPA).**

- Underestimation of FPA complexity results from difficulties
  - defining appropriate autonomy requirements and the proper level of fault protection- (i.e. system design vs. autonomy)
  - estimating test requirements, including hardware simulation facilities (test beds)
  - estimating required resources
- FPA requirements tend to be defined late in the development cycle compounding the cost or schedule impacts
- Impacts vary from schedule delays, to cost overruns, to launch delay

# Ineffective Management Structure
## *Findings*


**<u>Finding</u>: Ineffective management structure and unclear roles and responsibilities resulted in cost and schedule impacts to missions**

- Primarily occurred within Projects involving multiple organizations.
- The management structure issues directly compounded the effects of other embedded project issues (e.g., heritage and technology problems, cost control, prime contractor inexperience, etc)
- Problem areas included
  - Inconsistent Project Reporting and Decision-Making
  - Unclear lines of Technical Authority
  - Unconnected Systems Engineering across multiple organizations
  - Unclear responsibility for System Integration

# Project Team Inexperience
## *Findings*


**<u>Finding:</u> Teams with major players with limited experience in planetary mission development are a major contributor to program management issues resulting in cost over-runs**

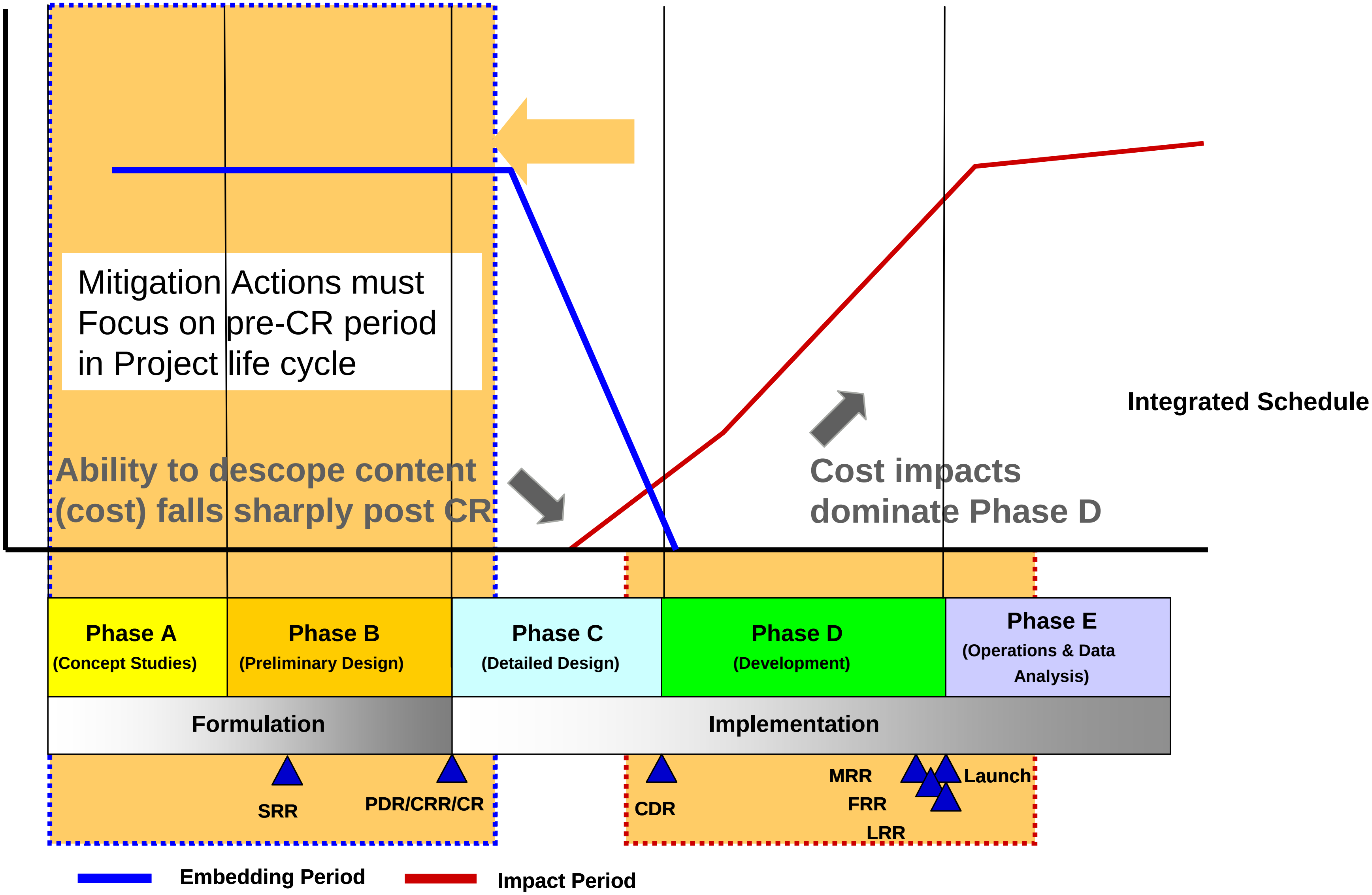
- Inexperience was manifested in many ways
  - Complex or poorly-defined management structure, roles and responsibilities, and communications
  - Inadequate development schedules and implementation of performance measuring techniques
  - Inadequate performance oversight and configuration management: institute to prime and prime to subs
  - Inaccurate cost estimates, inadequate cost control and management of reserves
- The “System” needs to operate differently to reduce risk, when bringing a new player into the planetary field

# Consideration of Review Team Findings
## *Findings*

**<u>Finding</u>: NASA commissions senior-level expert review panels, yet does not always address (mitigate or refute) the panel’s conclusions and recommendations**

- In many instances, issues identified, but not addressed, significantly affected a Project’s cost and schedule and the Program’s budget.
- There was little evidence indicating a consistent approach to responding to the findings and recommendations of an Independent Review Team (IRT) or Independent Assessment Team (IAT)
  - Disposition of findings and recommendations was not documented
  - Follow through risks, budget adjustments, or threats were not created

# *High Level Summary of the Findings*
# *Timing of the Embedding and Impacts*



# Improving LCC Management
## *Gate Analysis Summary*

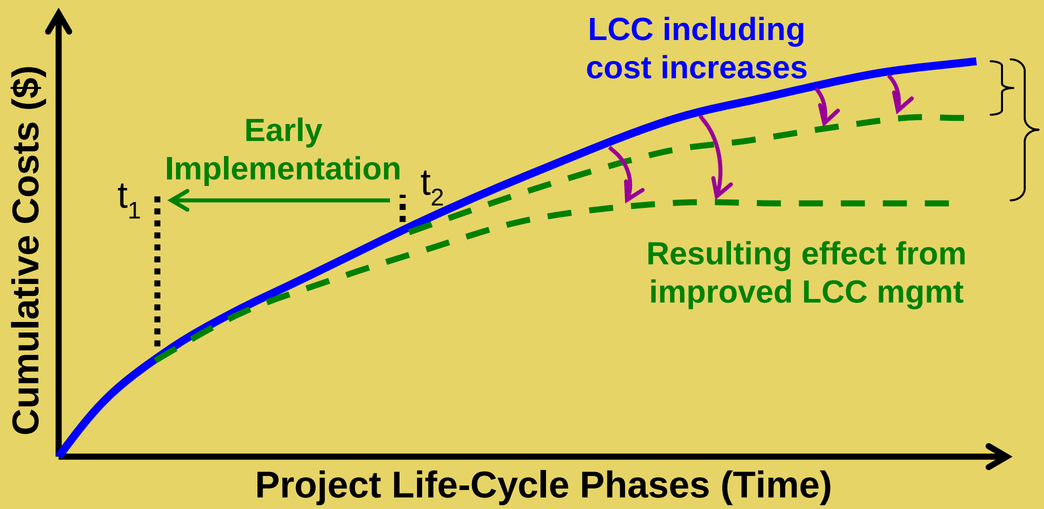

**Summary**

- ❑ Assessed five recent missions for LCC increases and causes
- ❑ Used “gate analysis” to identify findings & form recommendations
- ❑ Identified common themes (i.e., cross-cutting) from aggregated findings

- ❑ Implementation of improvements in process (some are easy…some are very complex and require further study)
  - ❑ Opportunity to infuse specific lessons learned
  - ❑ Positive impact on mission LCC management norms

**Notional Effect of Improved LCC Mgmt:**

Potential for better LCC control due to the early implementation of recommendations and process improvements.



# Acronyms

| | |
|---|---|
| AO | Announcement of Opportunity |
| AR | Acceptance Review |
| ARR | ATLO Readiness Review |
| ATLO | Assembly, Test, and Launch Operations |
| CDR | Critical design Review |
| CR | Confirmation Review |
| CRR | Confirmation Readiness Review |
| CSR | Concept Study Report |
| D&NF PO | Discovery and New Frontiers Program Office |
| DOE | Department of Energy |
| DPI | Deputy Principle Investigator |
| EM | Engineering Model |
| EVM | Earned Value Management |
| FPP | Flight Practices and Procedures |
| FRR | Flight Readiness Review |
| FTE | Full-Time Equivalent |
| FY | Fiscal Year |
| IAT | Independent Assessment Team |
| ICE | Independent Cost Estimate |
| IRT | Independent Review Team |
| LCC | Life-Cycle Costs |
| LRR | Launch Readiness Review |
| LV | Launch Vehicle |
| MM | Mission Manager |
| MOA | Memorandum of Agreement |
| MRR | Mission Readiness Review |
| PBR | Project Budget Report |
| PCA | Program Commitment Agreement |
| PDR | Preliminary Design Review |
| PDS | Planetary Data System |
| PI | Principle Investigator |
| PLRA | Program Level Requirements Appendix (to the Program Plan) |
| PM | Project Manager |
| PO | Program Office |
| PSD | Planetary Science Division |
| RTG | Radioisotope Thermoelectric Generator |
| RM | Resource Manager |
| RY | Real Year |
| SMD | Science Mission Directorate |
| SRB | Standing Review Board |
| SRR | Systems Requirements Review |
| TMCO | Technical, Management, Cost, and Other |
| WBS | Work Breakdown Structure |

# Graphics

Cover page: Discovery and New Frontiers Program Graphics

Page 1: Various Discovery and New Frontiers Mission graphics

Page 3: Pictorial of Review Process

Page 5: Example of a study developed Mission Milestone Timeline

Page 8: Notional graphic of Generic Mission Development phases and milestones

Page 24: Concept of the timing of findings and their impacts to the mission cost/schedule

Page 25: Notional graphic to depict how reductions or elimination of systemic findings can vary the mission cost profile LCC