Jet Propulsion Laboratory
California Institute of Technology

Lessons Learned from Decadal Survey and Probe Study CATEs

Keith Warfield

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DECADAL SURVEY

Survey Data and Best Practices for Survey Studies

Compelling and Feasible

- APD Decadal Success Criteria: APD defines "full success" as delivery to the Decadal Survey Committee of compelling and executable concepts for all four large missions so that science can be adequately prioritized by the Committee.
  - By executable we mean *feasible* with respect to technical, cost, and risk resources outlined in the Study Report

- Compelling and feasible* will be determined by the Decadal Survey Committee prioritizing the concept.

*The Aerospace CATE team will assess cost and risk for the Decadal Survey.

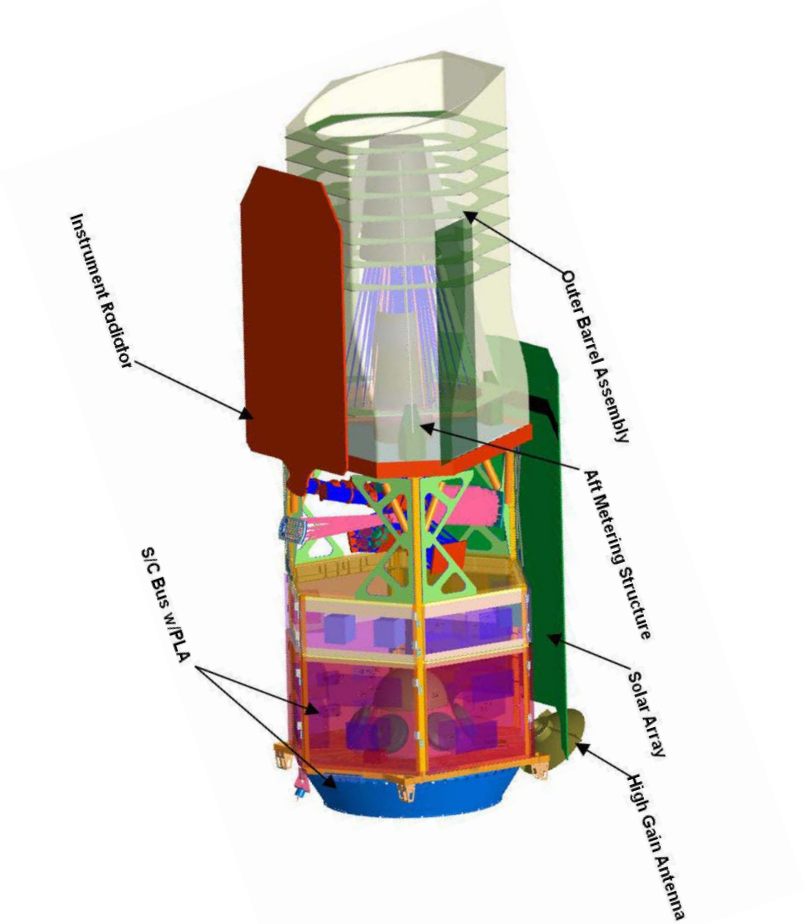
Decadal Survey Data Sources

- The National Academies has released 10 Decadal Surveys since 1964
  - First Decadal was ground-based only
  - Astrophysics has done the most Decadal Surveys (6)
  - Decadal Surveys are now done by all Divisions in SMD
  - All past Decadal Surveys can be downloaded for free from the National Academies
- In 2015 the Academies issued a report on Decadal Survey best practices
  - Report looked to minimize challenges experienced in the last round of surveys
  - Report chartered by SMD
  - http://download.nap.edu/cart/download.cgi?&record_id=21788

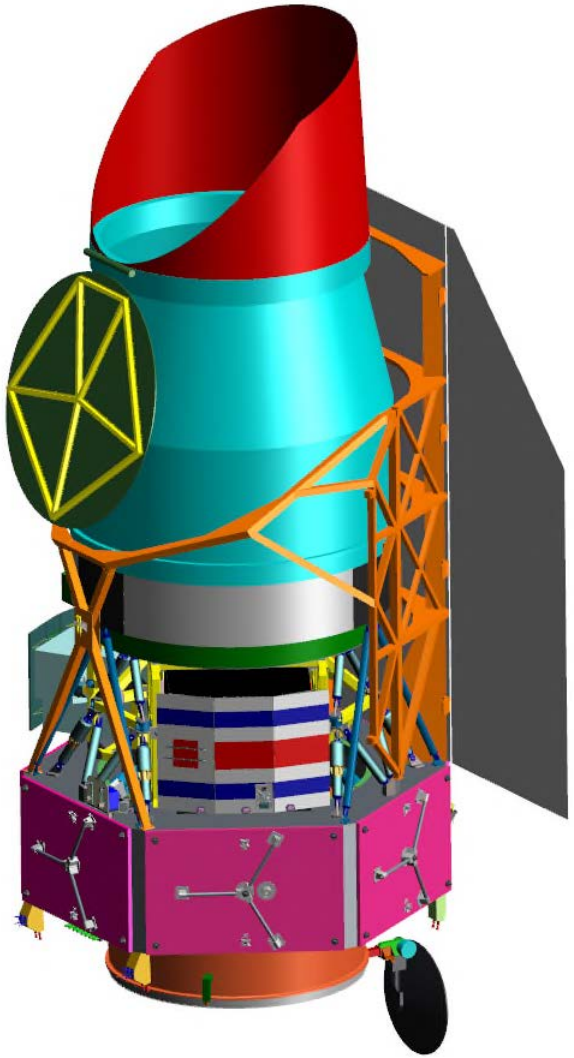
2015 Report – Key Process Findings and Recommendations

- 2015 report discussed how missions are prioritized
  - **Finding balance is key**
    - **Example: balance across the sub-disciplines, between mission and non-mission activities, between new and continued observations, across mission sizes, and between competed and directed missions.**
  - All surveys used science merit, cost and technology readiness as prioritization factors
  - All disciplines must make progress during the decade
- Recommends using "reference missions" to avoid over specifying the mission implementation
- Recommends including all past survey large concepts that have not started
- Surveys should avoid recommending "discipline-disrupting" missions
- Decision Rules and Cost Management
  - Recognizes that science creep on large missions is a major contributor to cost growth.
  - Recommends that the survey clearly state what science must remain to retain consensus priority
    - "It is imperative that survey committees make clear which parts of a performance-driven mission are truly required, and where any compromises or de-scopes might be acceptable."
  - Recommends using decision rules to change or reevaluate survey priorities during the decade
  - Recommends including descope and cancellation triggers in the decision rules

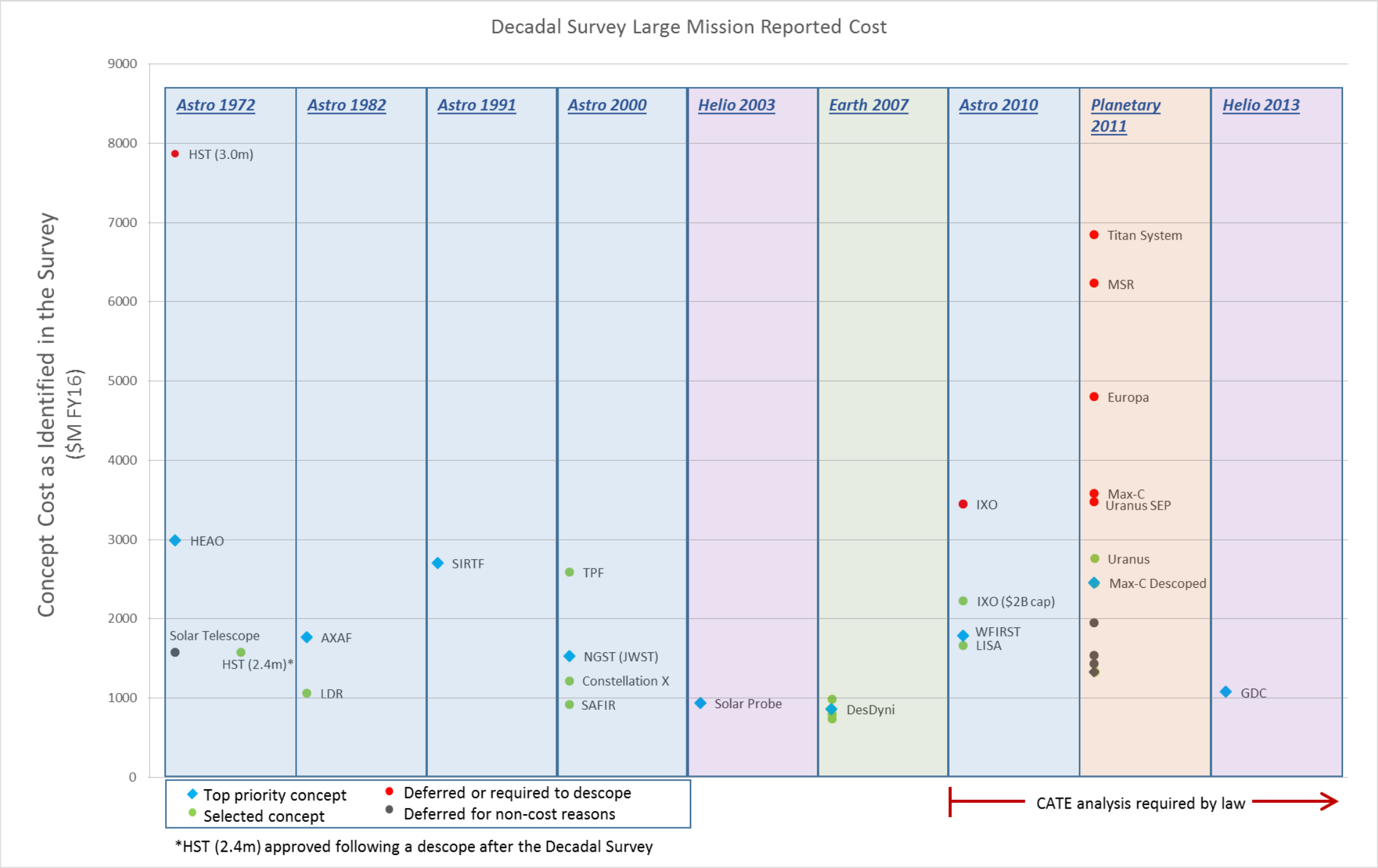
Reference Mission

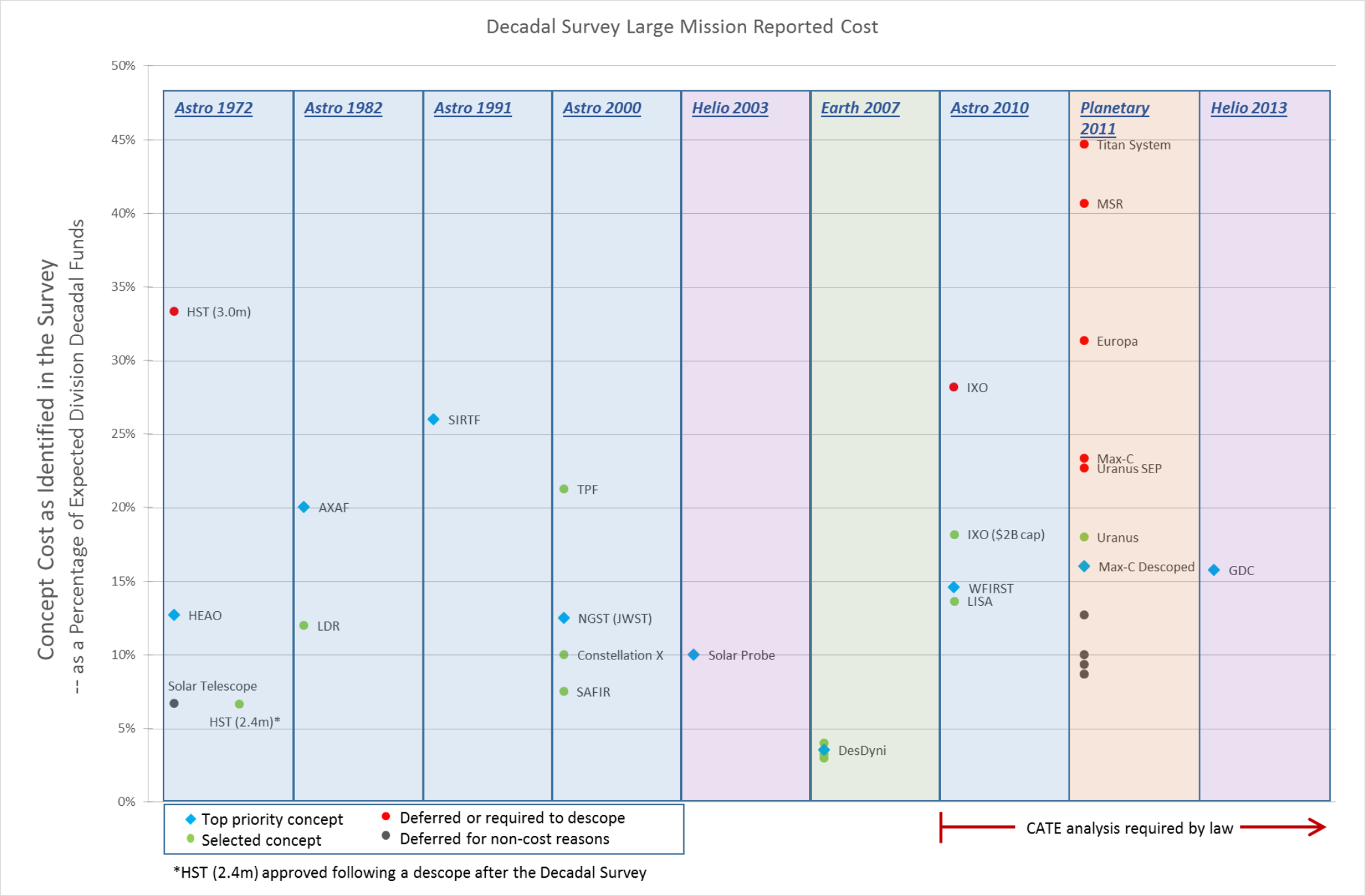


Astro 2010 “Reference Mission”
1.5m JDEM Omega



Current Mission Concept
2.4m WFIRST


Decadal Survey Large Mission Reported Cost
Concept Cost as Identified in the Survey ($M FY16)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Astro 1972
Astro 1982
Astro 1991
Astro 2000
Helio 2003
Earth 2007
Astro 2010
Planetary 2011
Helio 2013
HST (3.0m)
HEAO
Solar Telescope
HST (2.4m)*
AXAF
LDR
SIRTF
TPF
NGST (JWST)
Constellation X
SAFIR
Solar Probe
DesDyni
IXO
IXO ($2B cap)
WFIRST
LISA
Titan System
MSR
Europa
Max-C
Uranus SEP
Uranus
Max-C Descoped
GDC
Top priority concept
Selected concept
Deferred or required to descope
Deferred for non-cost reasons
CATE analysis required by law
*HST (2.4m) approved following a descope after the Decadal Survey


Decadal Survey Large Mission Reported Cost
Concept Cost as Identified in the Survey
-- as a Percentage of Expected Division Decadal Funds
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Astro 1972
Astro 1982
Astro 1991
Astro 2000
Helio 2003
Earth 2007
Astro 2010
Planetary 2011
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IXO ($2B cap)
WFIRST
LISA
Titan System
MSR
Europa
Max-C
Uranus SEP
Uranus
Max-C Descoped
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Top priority concept
Selected concept
Deferred or required to descope
Deferred for non-cost reasons
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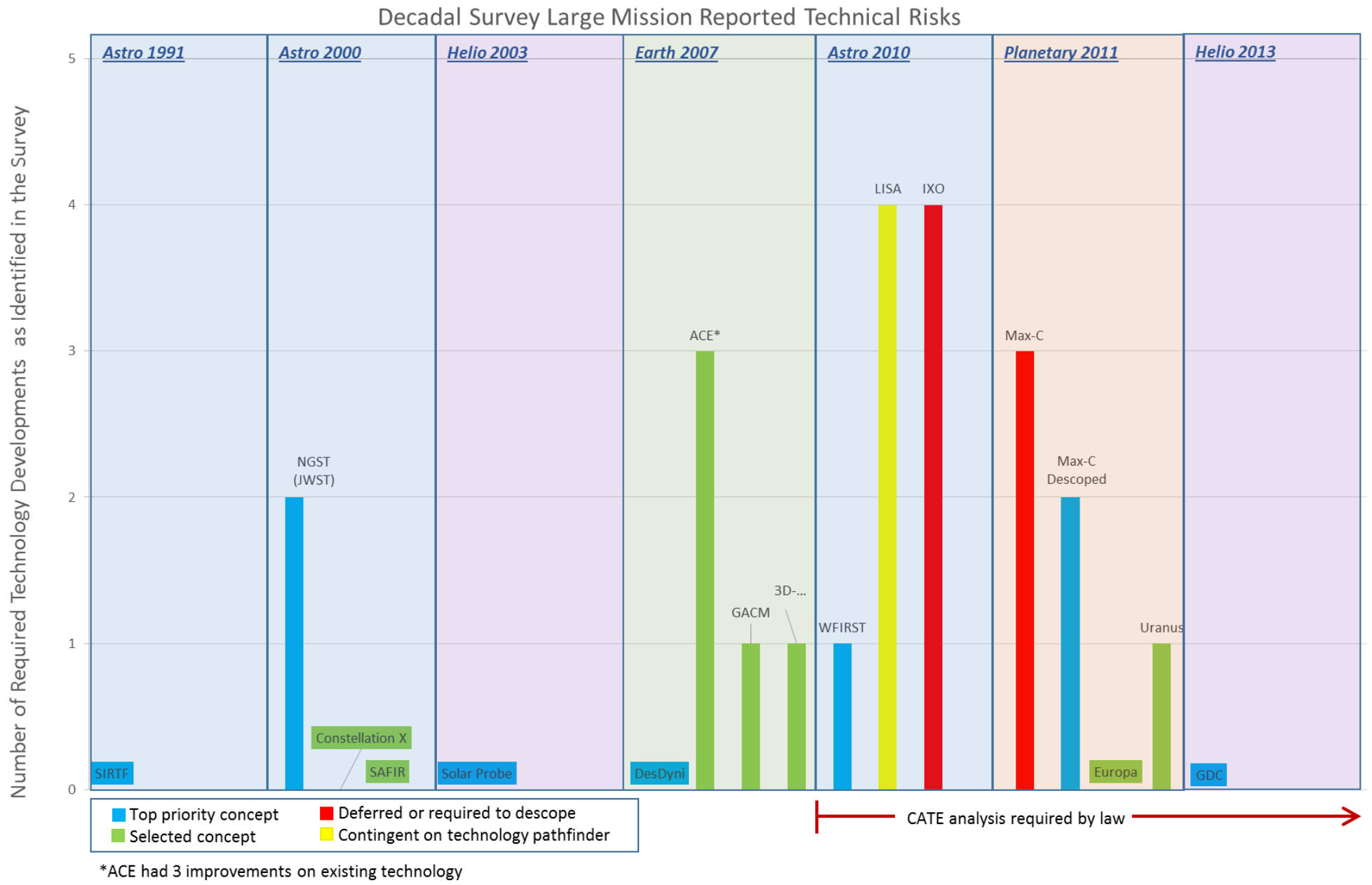

Decadal Survey Large Mission Reported Technical Risks
Number of Required Technology Developments as Identified in the Survey
0
1
2
3
4
5
Astro 1991
Astro 2000
Helio 2003
Earth 2007
Astro 2010
Planetary 2011
Helio 2013
SIRTF
NGST (JWST)
Constellation X
SAFIR
Solar Probe
DesDyni
ACE*
GACM
3D-...
WFIRST
LISA
IXO
Max-C
Max-C Descoped
Europa
Uranus
GDC
Top priority concept
Selected concept
Deferred or required to descope
Contingent on technology pathfinder
CATE analysis required by law
*ACE had 3 improvements on existing technology

Congressional Requirements on the Decadal Survey

From the NASA Appropriations Act of 2008:

SEC. 1104. NATIONAL ACADEMIES DECADAL SURVEYS.

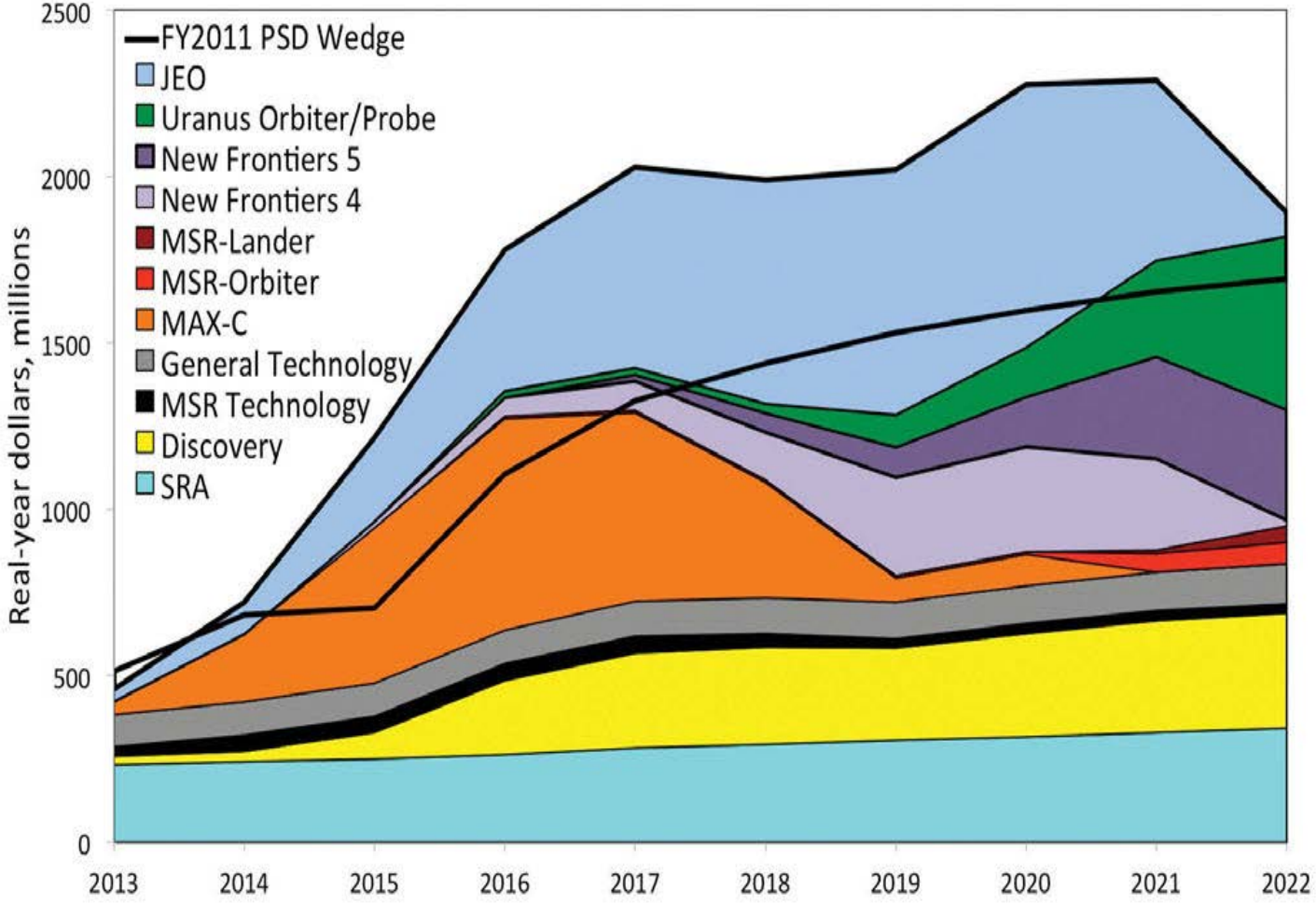
(a) In General.—The Administrator shall enter into agreements on a periodic basis with the National Academies for independent assessments, also known as ***decadal surveys***, to take stock of the status and opportunities for Earth and space science discipline fields and Aeronautics research and to recommend priorities for research and programmatic areas over the next decade.

(b) Independent Cost Estimates.—The agreements described in subsection(a) shall include ***independent estimates of the life cycle costs and technical readiness*** of missions assessed in the decadal surveys whenever possible.

(c) Reexamination.—The Administrator shall request that each National Academies decadal survey committee identify any conditions or events, such as significant cost growth or scientific or technological advances, that would warrant NASA asking the National Academies to reexamine the priorities that the decadal survey had established.

2015 Report – CATE Findings and Recommendations

- CATE develops cost and risk estimates for all major mission concepts in the survey
  - The estimates are spread over the decade and used to evaluate portfolio options by the survey committee
- CATE is considered a *best practice* and is viewed as highly successful
  - "…without a technical and cost risk metric relative science value between missions cannot be properly judged."
- Recommended a two-step CATE process
  - Cost box criteria for initial round
  - Detailed estimate for final round



Observations about the Decadal Survey Process

- The Decadal Survey has always prioritized only missions that appear to leave money for other astrophysics communities
  - "A successful federal research program must also be balanced. There is a tradeoff between investing in the development and construction of ambitious new telescopes and supporting broad-ranging observational and theoretical research that optimizes the return from operating facilities. The goal of the committee, consistent with its charge, has been to maximize the science return for a given budget." – Astro2010
- All past missions prioritized by the Decadal Survey were thought to be under $3B*

  *$FY16, cost to NASA.
- It's a new mission start or technology money, but not both
  - Missions prioritized for a start (without required precursor missions or descopes) have always been seen as having 3 or less technologies to develop.
  - For a new mission start "we must use the tools we have".
- The Decadal Survey has deferred extremely compelling mission concepts in the past
  - Examples: 3m Hubble (Astro 1972), Lunar Telescope (Astro 1991), 4m Theia and New Worlds concepts (Astro 2010), Mars Sample Return (Planetary 2011)
  - Compelling is not enough…cost and technology readiness must be part of the design process

THE CATE

Compelling and Feasible

- APD Decadal Success Criteria: APD defines "full success" as delivery to the Decadal Survey Committee of compelling and executable concepts for all four large missions so that science can be adequately prioritized by the Committee.
  - By executable we mean *feasible* with respect to technical, cost, and risk resources outlined in the Study Report

- Compelling and feasible* will be determined by the Decadal Survey Committee prioritizing the concept.

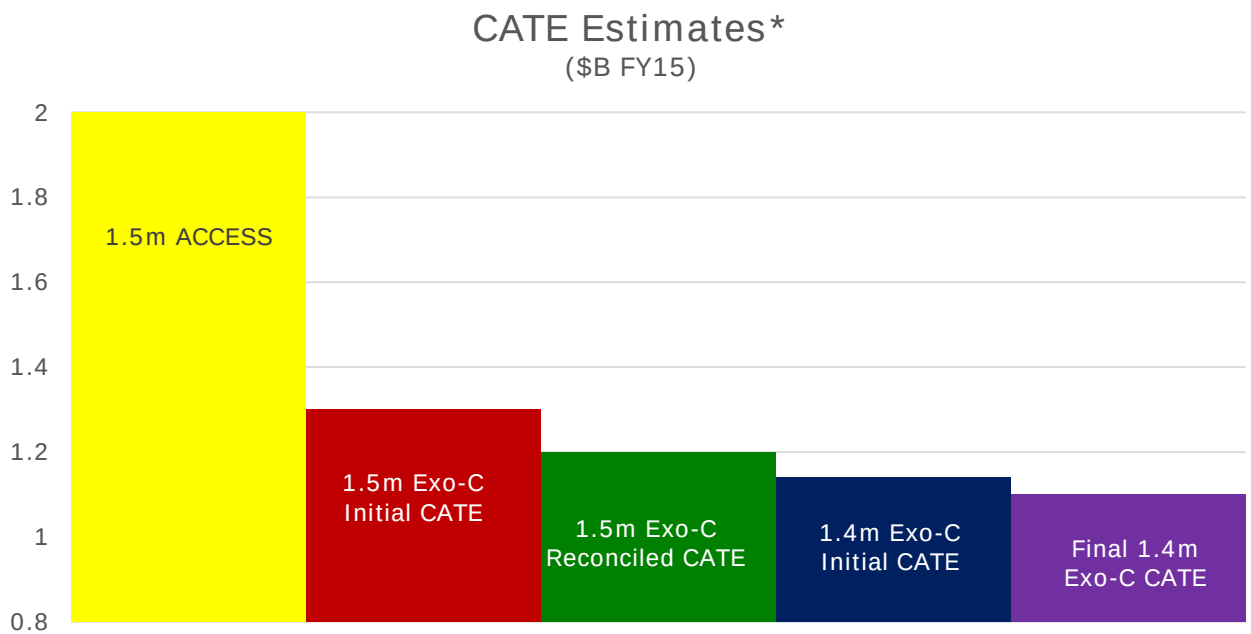
*The Aerospace CATE team will assess cost and risk for the Decadal Survey.

The CATE

- What is the CATE and why are we doing it?
  - A cost and technical assessment of Decadal Survey concepts is required by law
  - To meet this requirement, the National Academies solicited independent cost evaluation process proposals and selected the Aerospace Corporation's Cost and Technical Evaluation (CATE) process as the best approach.
  - The Academies have only ever used the Aerospace CATE to meet this requirement
  - Used for the Astro2010 Decadal Survey and every Survey since
  - Frequently used on large mission gate reviews such as on Mars2020, Europa and WFIRST

CATEs are now a regular feature of Decadal Surveys and Flagship mission formulation

Lessons Learned: Exo-C CATE Estimate Progress



* All designs used off-axis telescopes and Hybrid Lyot Coronagraphs

- $150M came from arguing about CATE analogues and methods
- Most of the improvement came from making better design choices
  - ***The largest factor in getting a lower cost from the Academies in the Decadal will be containing the scope of the concept***

The STDT will need to trade performance against cost and risk at all times

Lessons Learned: CATE Process

- Uses historic data and objective models in a subjective process
  - Unlikely to miss costs
  - Results may not agree with our expectations
- The need to go through the CATE process sets the depth of study design detail
  - CATE uses an input form that requires many design details and parameters
  - ***Important: Missing/insufficient information will be seen as holes in the design and will result in higher cost and risk estimates***
  - Best results come from interacting with CATE team to clarify design details
- Probe CATE process allowed for reconciliation with concept estimate
  - Not done in ASTRO2010 but should be done in 2020 to avoid cost/risk estimates based on misinterpreted information

Lessons Learned: CATE Estimate

- CATE presumes optimism in the evaluated estimate
- CATE is concerned about consistency with earlier CATE estimates
- CATE estimate is driven by Spacecraft, Payload and Threat estimates
  - Heavy use of wrap factors amplifies changes in spacecraft and payload
  - We were unable to successfully challenge the "Threat" estimate

Example Cost Estimate Table

Notional Results

WBS Element	Project Estimate	CATE Estimate	Basis of Aerospace Estimate
Phase A	$ 44	$ 44	Pass-through
Mission PM/SE/MA	$ 45	$ 98	Wrap factors from analogous projects
Instruments	$ 251	$ 308	Instrument models and analogies
Spacecraft	$ 174	$ 243	Bus models and analogies
Pre-launch Ground and Science	$ 98	$ 92	Wrap factors from analogous projects
Phase E Costs and EPO	$ 160	$ 183	MO costs from analogous projects. DA passed-through.
Total Reserves	$ 220	$ 250	70th Percentile from cost risk Analysis
Launch Vehicle/Services	$ 161	$ 154	Cost for proposed LV
Total Mission Cost Without Threats	**$ 1,137**	**$ 1,373**	
Schedule Threats		$ 32	Potential slip from ISE multiplied by project burn rates
Mass and Power Cont. Threats		$ 48	Cost re-estimated using Aerospace contingencies
LV Threats		$ -	Cost difference to move to larger LV
Total Mission Cost With Threats	**$ 1,137**	**$ 1,453**	

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Project X Top Technical Risks and Concerns

Project X Technical Risk Rating is Medium

- **Medium new development, mostly in the engineering implementation**
  - *Increase in detector array size*
  - *Migration from FPGAs to ASICs*
  - *Modernization of heritage instrument control unit*
- **Mass margins and power margins are aggressive and launch mass margin is very sensitive to changes in dry mass**
  - *Concept design is closer than recommended to Atlas V 551 capacity limit and the system is very sensitive to changes in mass*
  - *Several mass liens against concept design*
- **Time critical mission operations contributes to medium operational risk**
  - *Fault management for autonomous mode requires further definition*
  - *Sampling operations and hardware need further definition*

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CATE Technical Risk Assessment

- CATE identifies key risks to achieving required performance
  - Highlight significant deviations from current state of the art performance
  - Trace performance risk to science mission impact
  - Evaluate potential of planned risk mitigation efforts
- Overall risk color rating (blue, green, yellow, orange or red) is usually tied to the overall number of risks
- CATE technical risks closely mapped to Probe Study technology development areas
  - Added a few technology items not on the Probe lists
  - Can also draw on insufficient resource margins or programmatic assumptions (e.g., assumed foreign suppliers/partners) as a risk source

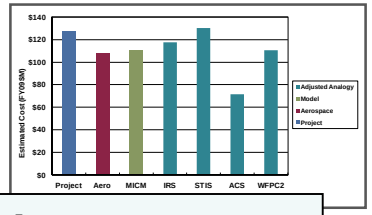
Observations about the CATE

- The CATE does not care about “compelling”…its all cost and risk for them.
  - No scientists are on the CATE.
- Only the CATE’s cost and risk estimates matter.
  - We need to replicate their methods for our trade evaluations.
- The CATE process is data driven. The CATE will respond to data-based arguments. The CATE does not respond to opinion-based arguments.
- Early and ongoing conversations helped us understand the CATE team and their methods.
  - Generalists, often without depth in critical design areas but able to call in specialists to help.
- Interim estimates and early interaction with the CATE helped us strengthen weak points. in our design and reduced CATE concerns.
- It is easier to get the CATE to not make a mistake than it is to get them to correct a mistake once they make one.
  - Make your strongest case for a low cost before the CATE turns in an estimate.
  - Work suspected estimate process problems early and quietly.

THE CATE

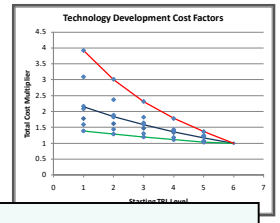
Process, Models and Data

CATE Cost Estimating Process



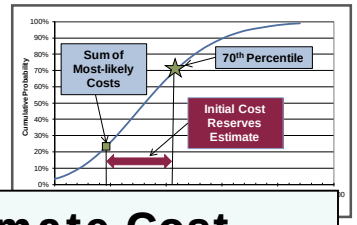
Estimate Instruments & Spacecraft

Multiple analogies and models



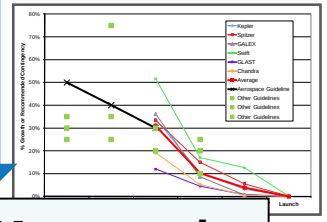
Estimate Other Elements

Based on historical data



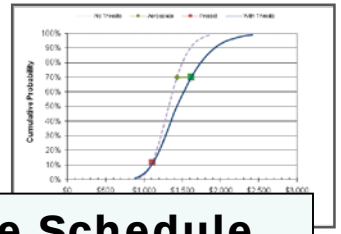
Estimate Cost Reserves

Based on probabilistic cost risk analysis



Estimate Mass and Power Contingency Threat

Re-run estimate with Aerospace contingencies



Estimate Schedule Threat

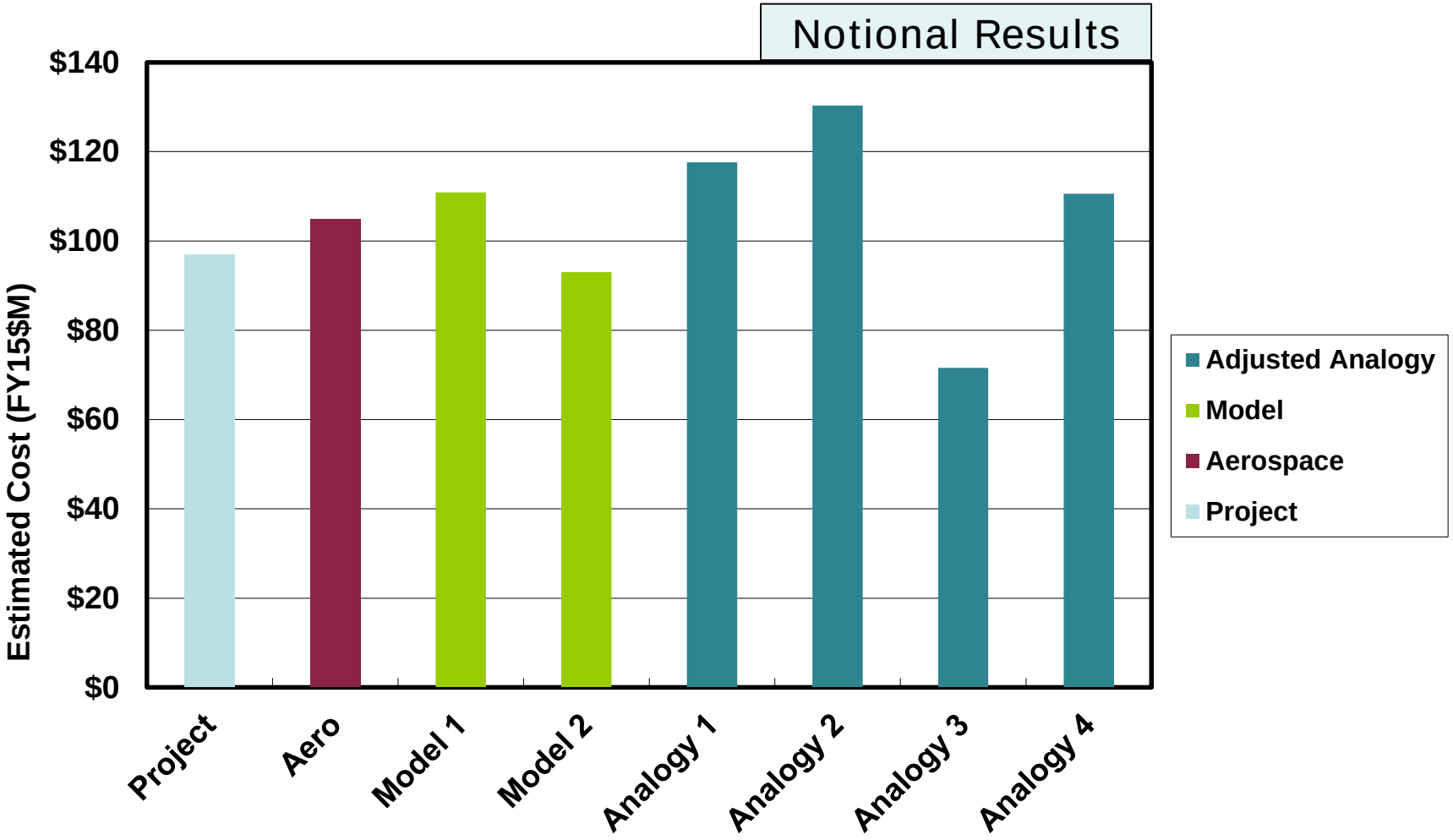
Based on ISE results and project burn rates

WBS Element	Project Estimate	Aerospace Estimate	Basis of Aerospace Estimate
Phase A	$ 44	$ 44	Pass-through
Mission PM/SE/MA	$ 45	$ 98	Wrap factors from Kepler, Spitzer, Chandra, JWST, LRO, GLAST
Instruments	$ 251	$ 308	MICM, analogies (Spitzer, Kepler, WISE, IRS, STIS, ACS, WFPC2)
Spacecraft	$ 174	$ 243	NAFCOM, analogies to Kepler, Spitzer, SDO, LRO
Pre-launch Ground and Science	$ 98	$ 92	Wrap factors from Spitzer, Chandra, and JWST
Phase E Costs and EPO	$ 160	$ 183	MO costs from HST, Spitzer, Chandra. DA passed-through.
Total Reserves	$ 172	$ 309	70th Percentile from cost risk Analysis
Launch Vehicle/Services	$ 161	$ 154	Atlas 511 assumed. Costs from Flagship Mission Studies
Total Mission Cost Without Threats	**$ 1,105**	**$ 1,432**	
Schedule Threats		$ 82	9 months at project burn rates
Mass and Power Cont. Threats		$ 76	Additional 288 kg and 186 Watts

Integrate Results & Level Across Concepts

Cross-check with CoBRA

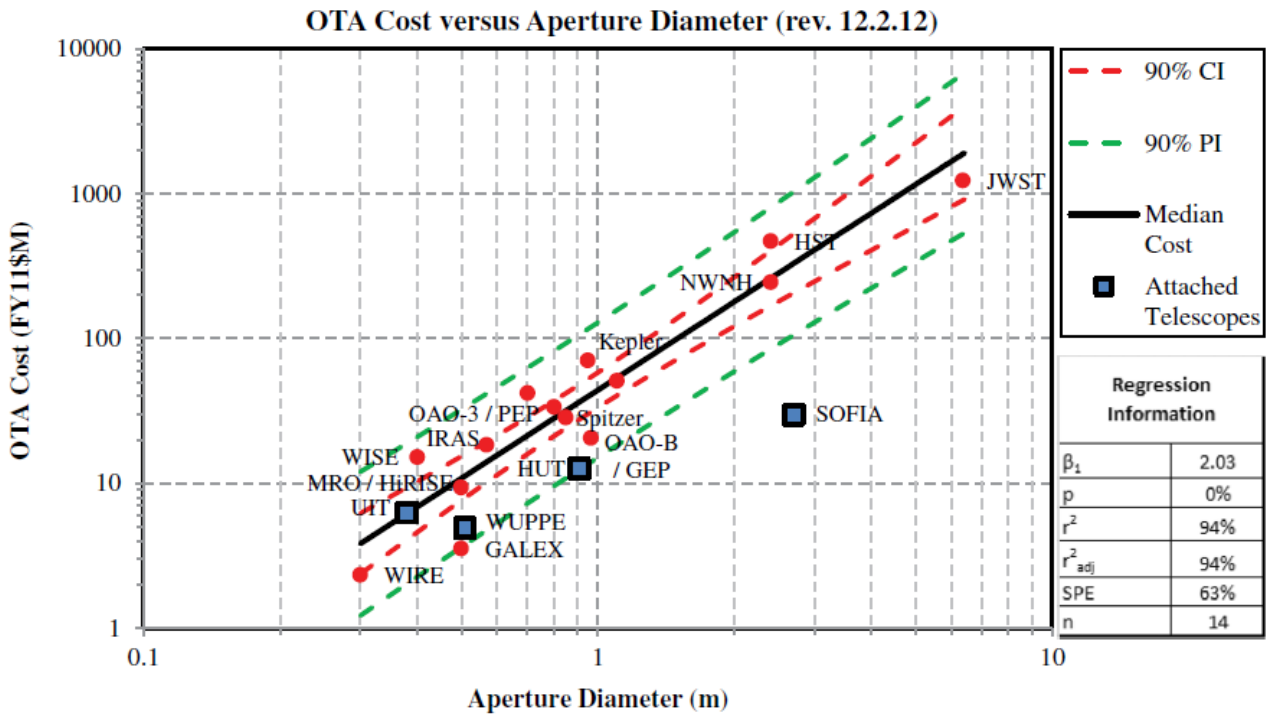
Example Hardware Estimate Results

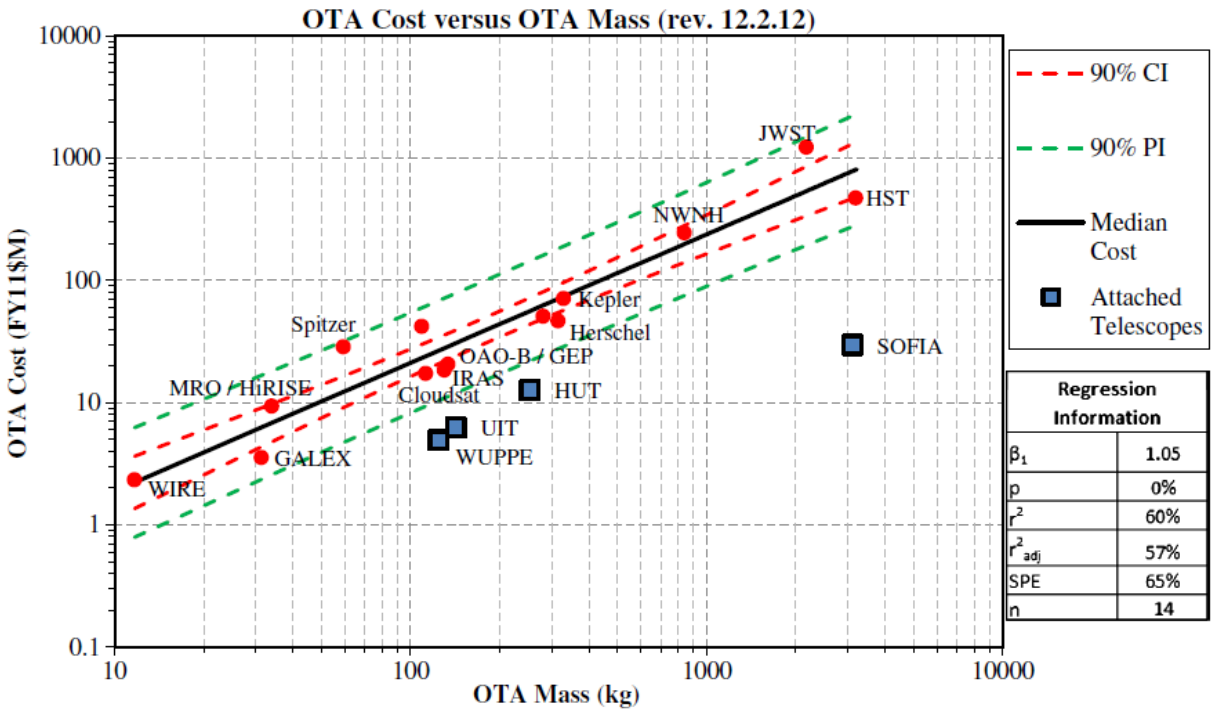


CATE Models and Analogue Data

- **Instruments and spacecraft buses**
  - Multiple analogies are used for each element
    - Analogue costs and technical descriptions taken from NASA CADRe, NICM and internal Aerospace sources
    - Analogies chosen based on similarity to proposed instrument and by supplier
  - Multiple cost models are also used for each element
    - Instruments - MICM, NICM
    - Spacecraft - NAFCOM, SSCM
    - NICM, MICM and SSCM used on Probe studies. PRICE-H used for starshade

Stahl Telescope Model





Stahl, et.al., “Update to Single-variable Parametric Cost Models for Space Telescopes”, 2013

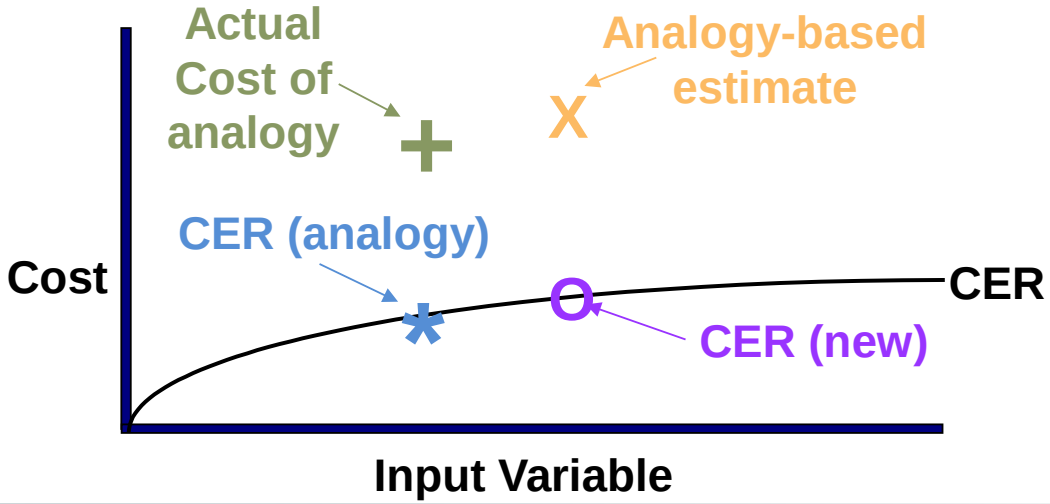
- Model data is current and independent parameters are objective
- Model is publicly available
- Primary model used by CATE on Probe studies

Analogy-Based Estimate Process

Ties the Estimated Cost to Historical Actuals

- Analogy-based estimates use historical items as the basis for an estimate
  - Technical and programmatic differences often require adjustment to the historical costs
  - Every historical program has "unique" aspects that affected the cost, but should not affect the cost of a new element
    - Using multiple analogies can potentially average out the impacts of these unique aspects

Analogy-based Estimate = Actual cost of analogy x CER (new) / CER (analogy)



AEROSPACE

Example Cost Estimate Table

ExoPlanet Exploration Program

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