NASA Instrument Cost Model: Version VIII Major Improvements

2018 NASA Cost and Schedule Symposium

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Jet Propulsion Laboratory
California Institute of Technology

July 14-16, 2018, Goddard Space Flight Center

NICM Stakeholders

- Sponsor: NASA HQ OCFO/SID/CAD/IPAO
- Legacy Co-Sponsor: JPL Cost Estimation & Pricing Section
- Development Team
  - JPL Systems Modeling, Analysis & Architectures Group
  - JPL Engineering Cost Estimation Group
  - JPL Technical Division Experts
    - Science
    - Communications, Tracking, and Radar
    - Instruments and Science Data Systems
    - Mechanical Systems
  - Last but not least, all of the NASA Centers, Contractors, Universities and others who have built instruments and contribute data to NICM

NICM Team

NICM VIII Team

- Gary Ball
- Luther Beegle
- Justin Boland
- Robert Cesarone
- Mike DiNicola
- Michael Fong
- Hamid Habib-Agahi
- Joe Mrozinski
- Kamrooz Parchamazad
- Al Nash
- Matthew Ramirez
- Michael Saing
- Marc Walch
- Keith Warfield

Agenda

- NICM VIII Major Improvements
  - Mission Class-based CERs vs. NICM-E
  - Telescope Cost as a Subsystem vs. “Telescope Instruments”
  - New Visualizations Features
  - New Cryocooler Cost Estimations

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  - New Cryocooler Cost Estimations

NICM and Mission Class: Introduction

- From 2004 through 2013, NICM collected and normalized data from as many missions as possible.
- Examining the missions that were collected during this period showed that Class B missions were the majority, followed by A and C.
  - This led to 2004-2013 CER's which serviced A and B missions quite well, as well as some, but not all, C class missions.
- While these CER's have evolved and improved over time, they will be referred to herein as the "Traditional NICM CERs"

2004-2013 Mission Class Service Matrix

	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	X	X	✓	✓	X	X	X
D	X	X	X	X	X	N/A*	N/A*

- The green checkmarks indicate where the Traditional NICM CERs serviced well.
- There was not enough C class mission data for Optical, Fields or Microwave instruments to conclude whether or not the Traditional NICM CER's would apply to these instruments.
- Similarly for D class missions.

*Note we found 0 instruments for D class microwave instruments.

NICM-E Introduction

- In 2012-2013, the NICM team received feedback that the NICM CER's were overestimating instrument costs for Explorer Concepts – C class missions.
- We found that we had several instruments on C Class missions that, one-by-one over years of data collection, had been deemed as outliers for the Traditional NICM CERs.
  - Exploring further found that the majority of these instruments flew on Explorer Class missions, but also had the following three criteria in common that separated them from the bulk of the data used in developing the Traditional NICM CERs:
    1. Flew on Class C Missions
    2. Designs had significant inheritance
    3. Were built at Universities

NICM-E Introduction

- These instruments thus formed their own separate family and were used to derive the NICM-E CER.
- In 2014, NICM-E was released as part of NICM VI

  - Trivia: NICM-E was originally named “NICM-Explorer”, but was shortened to NICM-E as two instruments flew on missions that were not technically part of the Explorer Program.

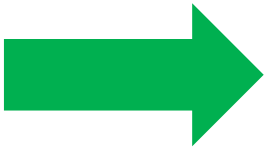
2014-’18 Mission Class Service Matrix

	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	X	X	✓	✓	X	X	X
C: NICM-E	✓	X	✓	X	✓	X	X
D	X	X	X	X	X	N/A	N/A

- The inclusion of NICM-E allowed NICM to service a few more instrument types for Class C missions, but only for those instruments with high inheritance and be university built.
- Note NICM-E did not service D class missions.
- This was an improved service matrix, but we wanted less X’s!

Evolving NICM-E

- Hoping to further improve the Service Matrix, the NICM Team performed new data collection, analysis and CER development, hoping to grow NICM-E's abilities to cover more instrument types.
- Instead, the NICM Team observed that instruments meeting criteria #1 of NICM-E (C Class) alone fall in family with the original NICM-E instrument set.



CONCLUSION:

NICM can drop the #2 and #3 NICM-E criteria and focus on Mission Class alone.

NICM VIII Improved Mission Class Service Matrix

	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	✓	✓	✓	✓	✓	✓	✓
D	✓	✓	✓	X	X	N/A	N/A

- NICM VIII's new CERs deliver the best service matrix to date.
- Newly collected C and D class data showed that we could retire the NICM-E requirements of high inheritance and university build for the new NICM VIII CERs
- Future work: more data needed for Class D Mission Fields and Planetary Particles Instruments.

NICM VII vs. VIII Mission Class Service Matrix

VII

	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	X	X	✓	✓	X	X	X
C: NICM-E	✓	X	✓	X	✓	X	X
D	X	X	X	X	X	N/A	N/A

VIII

	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	✓	✓	✓	✓	✓	✓	✓
D	✓	✓	✓	X	X	N/A	N/A

CONCLUSION: NICM VIII services more Instrument Types and Classes

Mission Class Conclusions

- NICM VIII provides estimates for more instruments types and more mission classes than NICM VII.
- Future estimates that would have relied on NICM-E will get similar results with the new Class-based NICM CERs.
- And instrument type/classes that were left without an estimate before now have a home.

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  - New Visualizations Features
  - New Cryocooler Cost Estimations

Telescope Lingo

Telescope by itself + Backend = Instrument

Telescope Lingo

Telescope by itself + Backend = Instrument

Telescope by itself ≠ Instrument

Telescope Lingo

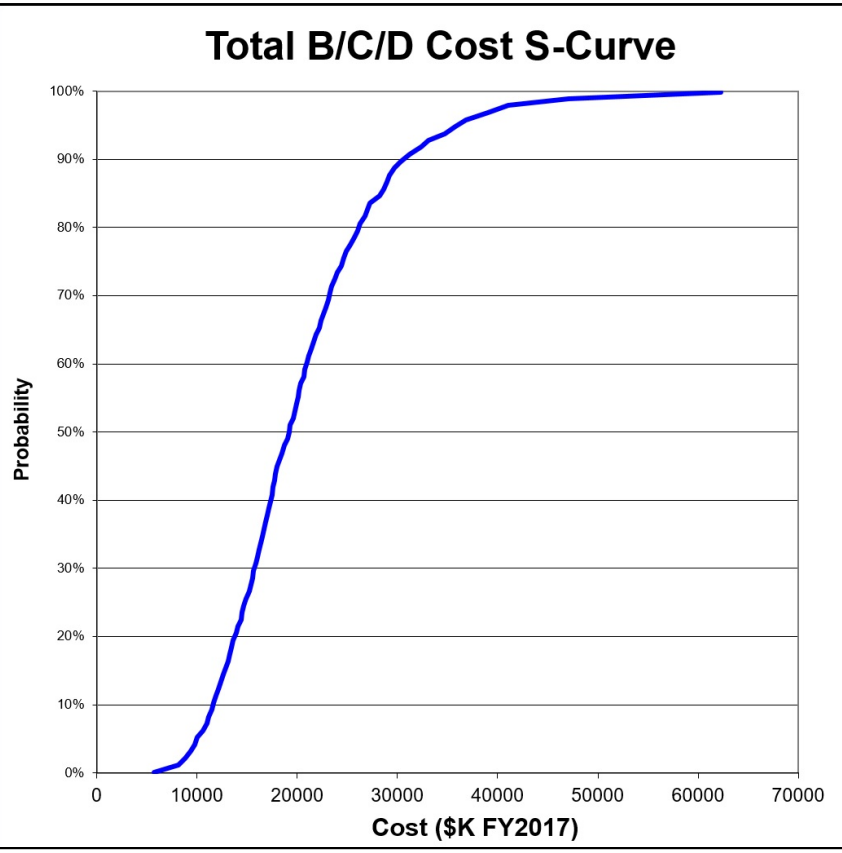
In NICM VII, we treated the Telescope by itself as a SYSTEM

Instrument Name		2017	$K Cost Base Year	
Instrument Type	Remote Sensing			
Remote Sensing Type	Telescope ONLY			
Telescope Type	Infrared			
	Minimum	Most Likely	Maximum	Units
Aperture		30.0		cm
Total B/C/D Cost	$19,190		$23,216	

Go to Search Engine Go to Subsystem

Monte Carlo # Iterations	1,000
Automatic Monte Carlo	On
NICM Help	Off

NICM VII Rev2, February 2016



Telescope Lingo

In NICM VII, we treated the Telescope by itself as a SYSTEM

But wait a minute… in NICM “Systems” are Instruments.

Telescope by itself ≠ Instrument therefore:

Telescope by itself ≠ System

Rather, a telescope by itself is more of a (super) Subsystem.

Telescope by Itself = Subsystem

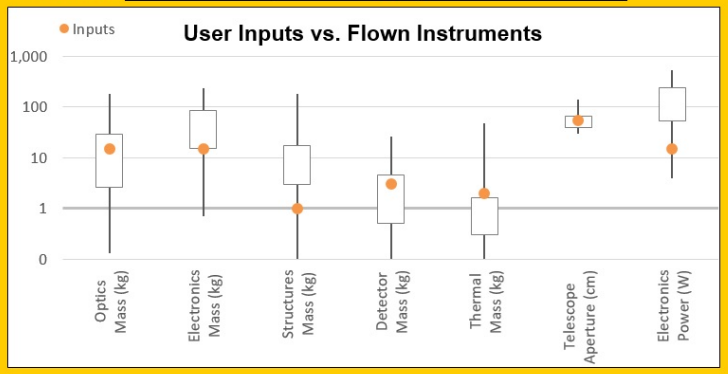
In NICM VIII, we treat the Telescope by itself as a SUBSYSTEM

Inputs

This document has NOT been reviewed for export control. Not for distribution or access to foreign persons.

Instrument Name		Include Telescope?	TRUE
Costs in $K FY	2020	Telescope Type	Infrared
Instrument Type	Optical	Cryocooler?	FALSE
Environment	Earth Orbiting		
		Detector Type	Fields/Ion Detector

Exclude Telescope's Mass & Power	Minimum	Most Likely	Maximum
Optics Mass		15.0 kg	
Telescope Aperture		55.0 cm	
Electronics Mass		15.0 kg	
Structures Mass		1.0 kg	
Detector Mass		3.0 kg	
Thermal Mass		2.0 kg	
Max Power:		15.0 W	



Monte Carlo # Iterations:	1000
Automatic Monte Carlo	On
NICM Help	Off

Copy Inputs to Search Engine | Copy Inputs to System Tool

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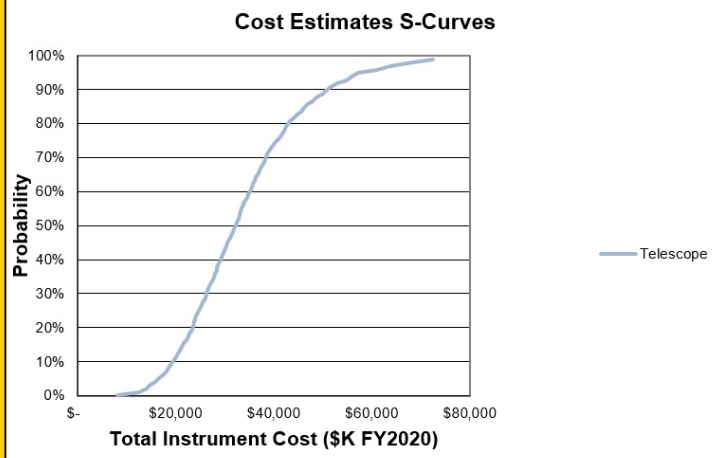
Model Cost Estimates

Probability	S-curve	30%	50%	70%
Total Instrument	Off	$49,444	$65,739	$86,619
Management	Off	$3,485	$5,216	$7,247
Sys. Engrg.	Off	$3,575	$5,252	$7,422
Prod. Assurance	Off	$2,112	$3,032	$4,400
I & T	Off	$4,618	$6,744	$10,054
Total Sensor	Off	$35,654	$45,495	$57,497
Optics	Off	$4,348	$5,913	$8,304
Telescope	On	$26,270	$32,175	$38,446
Electronics	Off	$2,597	$3,656	$5,063
Mech/Structures	Off	$407	$643	$980
Detectors	Off	$1,015	$1,543	$2,353
Thermal/Fluid	Off	$602	$885	$1,285
Software	Off	$414	$681	$1,067

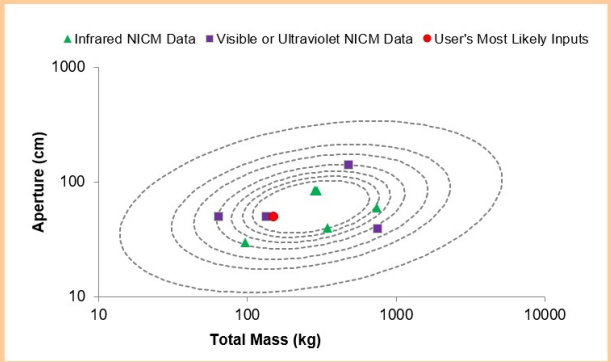


Telescope + Backend = Instrument

And, in the NICM VIII System Tool, we now provide an estimate for a “Telescope Instrument” rather than just a Telescope by itself.

Instrument Name	
$K Cost Base Year	2020
Instrument Type	Remote Sensing
Environment	Planetary
Mission Class	A
Remote Sensing Type	Optical
Instrument Includes Telescope?	TRUE
Telescope Aperture Bin	>= 30 cm
Telescope Type	Visible or Ultraviolet

	Minimum	Most Likely	Maximum	Units
Total Mass		150.0		kg
Aperture		50.0		cm



X-axis	Total Mass (kg)
Y-axis	Aperture (cm)
Monte Carlo # Iterations	1,000
Automatic Monte Carlo	On
NICM Help	On

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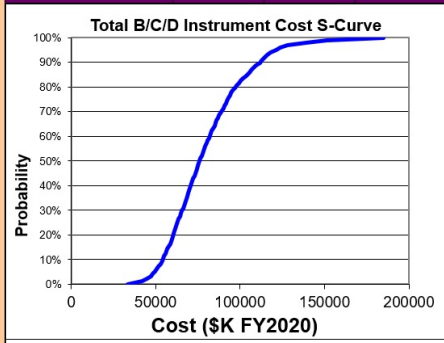
NICM VIII July 2018

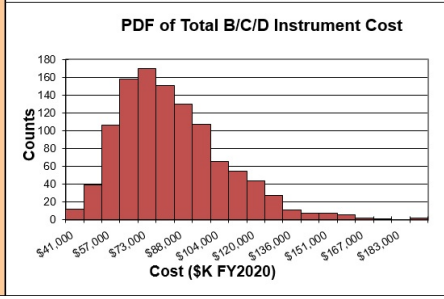
Model Cost Estimates

Probability	30%	50%	70%
Total Instrument	$65,760	$76,091	$88,933

Analogy Cost Estimates

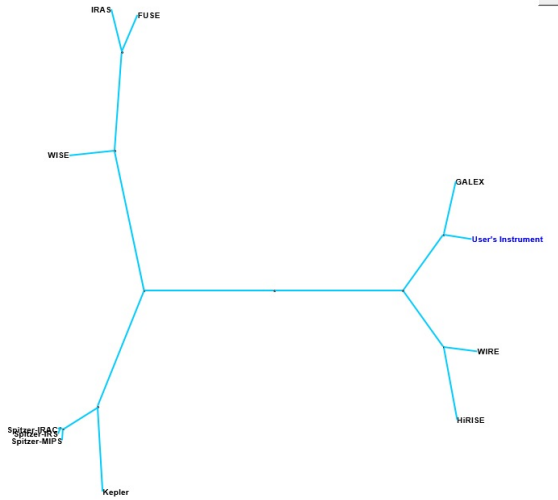
	Total Cost	Mission Class	Total Mass (kg)	Aperture (cm)	Telescope Type	Home Page
GALEX	$41,356	B	135	50	Visible or Ultraviolet	Home Page
WISE	$78,970	C	346	40	Infrared	
HiRISE	$50,602	B	64	50	Visible or Ultraviolet	Home Page
Spitzer-MIPS	$130,262	A	283	85	Infrared	Home Page
WIRE	$35,576	C	97	30	Infrared	





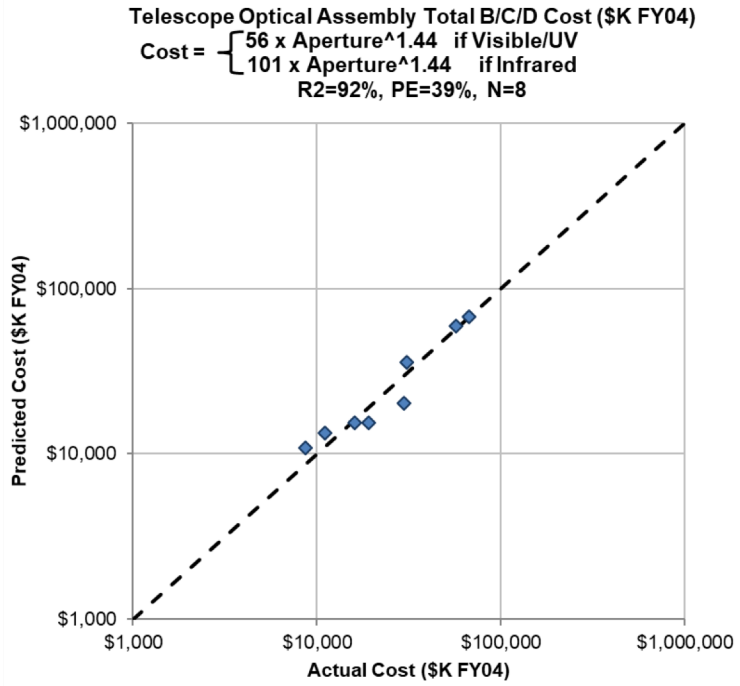
Cluster Tree

Rotate Branches



The “New” Telescope Subsystem CER

Is just the old NICM VII System Model’s “Telescope Only” CER moved from one tool to the other.



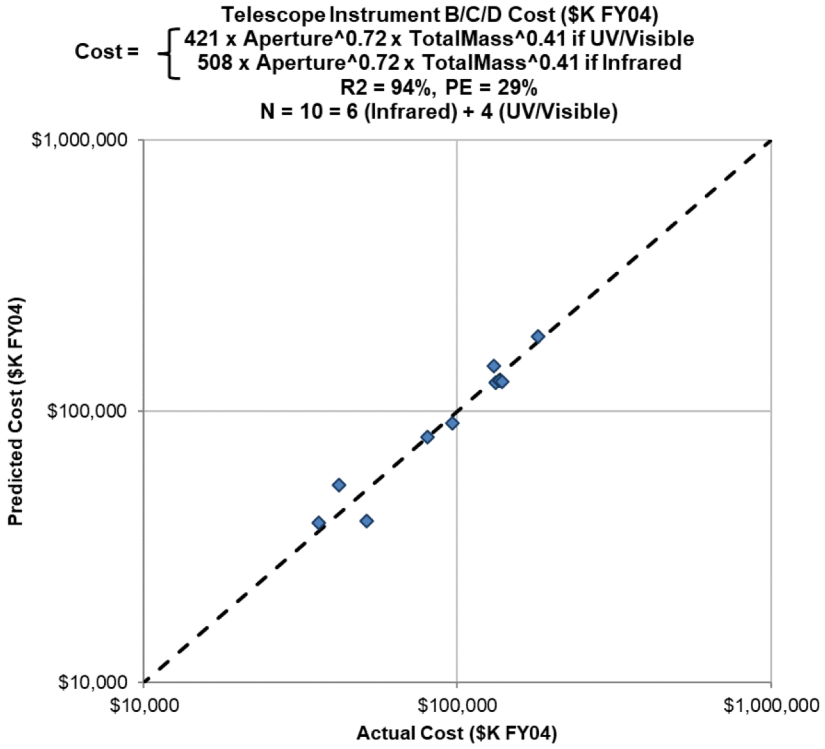
Alternative form of equation:

Cost = 56 $\text{Aperture}^{1.44}$ $\text{Exp}\{IR\}^{0.58}$

where IR = 1 if Telescope captures IR wavelengths; 0 if Telescope captures UV/Visible wavelengths

The New “Telescope Instrument” CER

Did not exist in NICM VII and thus is truly new for NICM VIII



Alternative form of equation:
Cost = 421 Aperture0.72 TotalMass0.41 Exp{IR}0.19
where IR = 1 if Telescope captures IR wavelengths; 0 if Telescope captures UV/Visible wavelengths

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Box and Whisker Plots

Allow the user to see their inputs relative to the CER data.

Inputs

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Instrument Name		Include Telescope?	TRUE
Costs in $K FY	2020	Telescope Type	Infrared
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Environment	Earth Orbiting		
		Detector Type	Fields/Ion Detector

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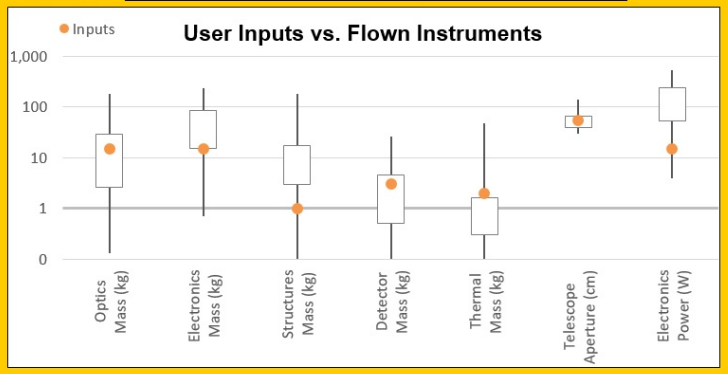

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NICM VIII July 2018

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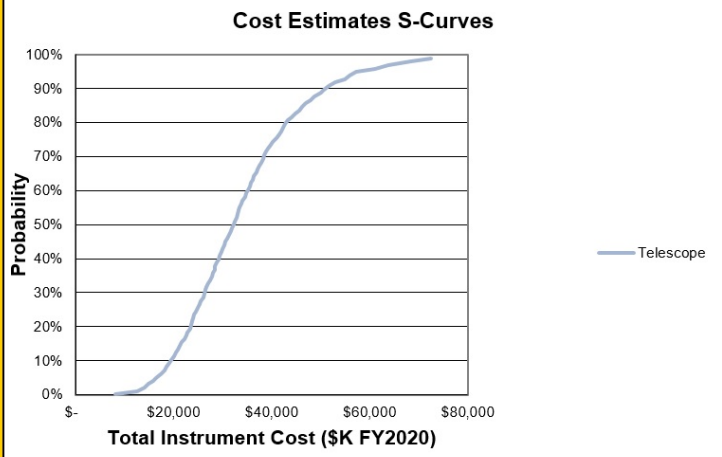

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s Mass & Power	Minimum	Most Likely	Maximum
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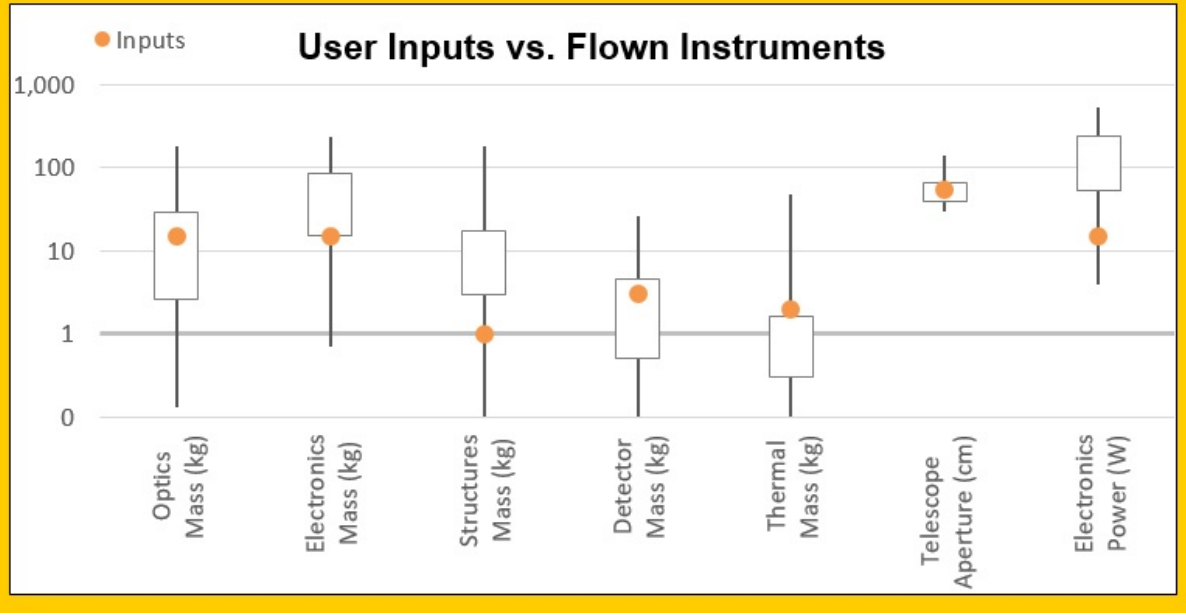
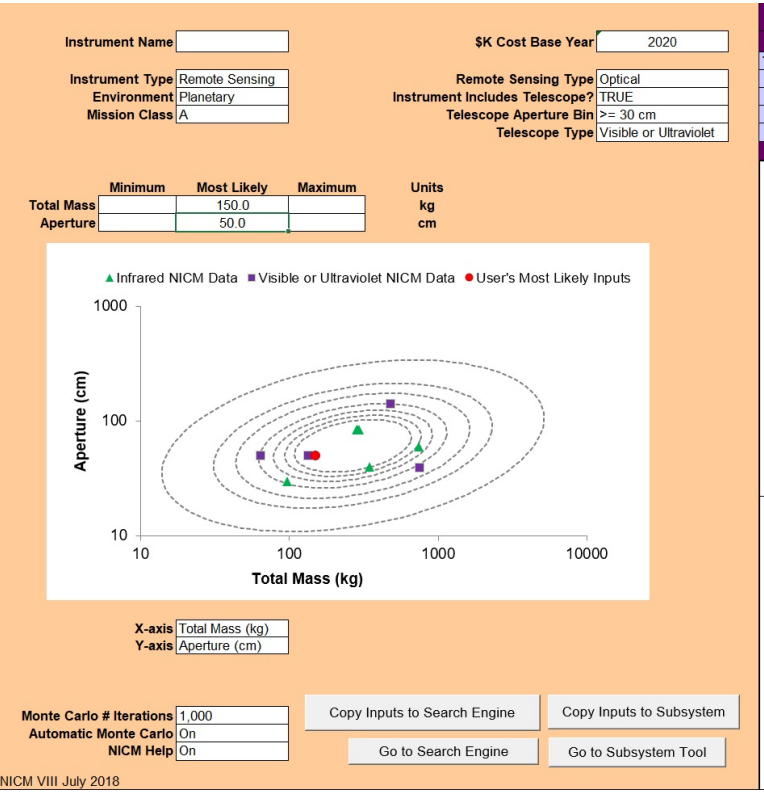


Probability Ellipses for Inputs

Probability around the mean ellipses added to the 2D input plot: at the 50, 60, 70, 80, 90, 95 and 99 percentages.



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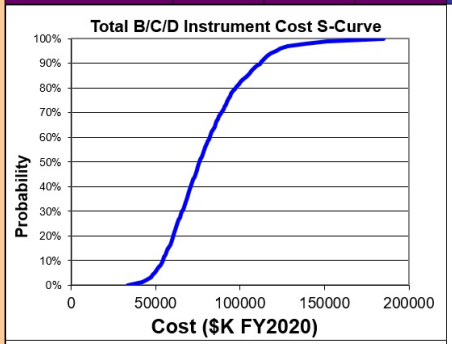
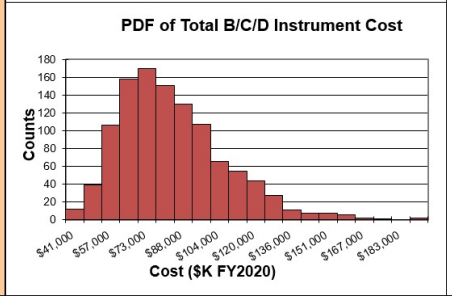
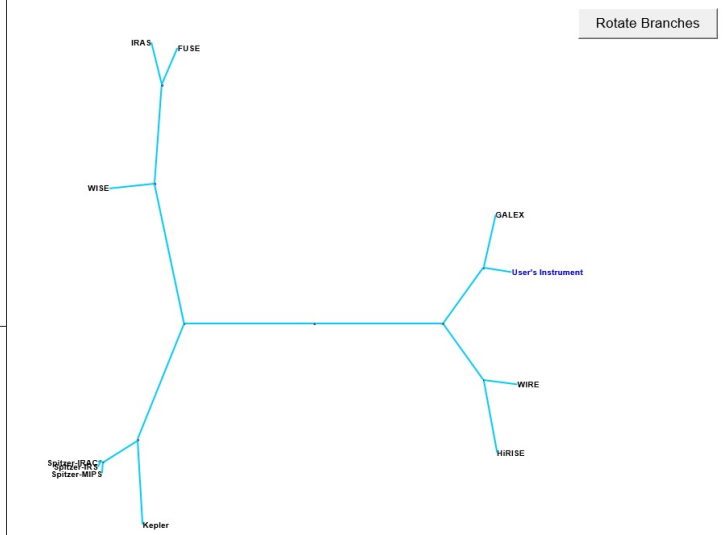




Cluster Tree



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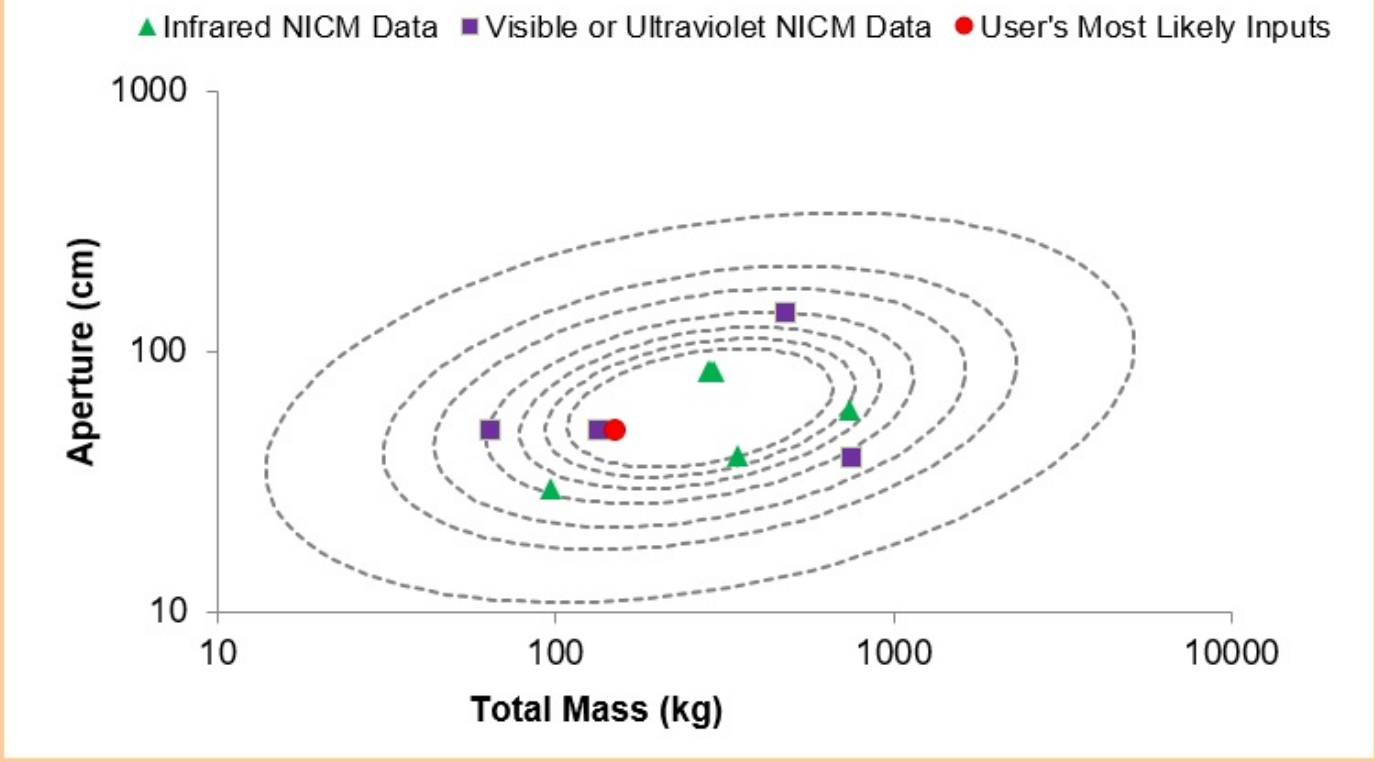
Probability around the mean ellipses added to the 2D input plot: at the 50, 60, 70, 80, 90, 95 and 99 percentages.

	Minimum	Most Likely	Maximum	Units
Total Mass		150.0		kg
Aperture		50.0		cm



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  - New Visualizations Features
  - **New Cryocooler Cost Estimations**

Cryocoolers: NICM VII Equation

- NICM VII applies the following equation to estimate the cost of a New Cryocooler Development:

$$\text{Cryocooler Cost (FY04 \$K)} = \mathbf{40{,}099} \times \text{LowTemp}^{-0.15}$$

where "LowTemp" is the lowest temperature (in Kelvin) that the instrument needs to be cooled to by the cryocooler.

- **Note that large coefficient in front of the equation.**

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where “LowTemp” is the lowest temperature (in Kelvin) that the instrument needs to be cooled to by the cryocooler.

- **This equation was built off of data from new and unique cooler designs requiring significant development.**

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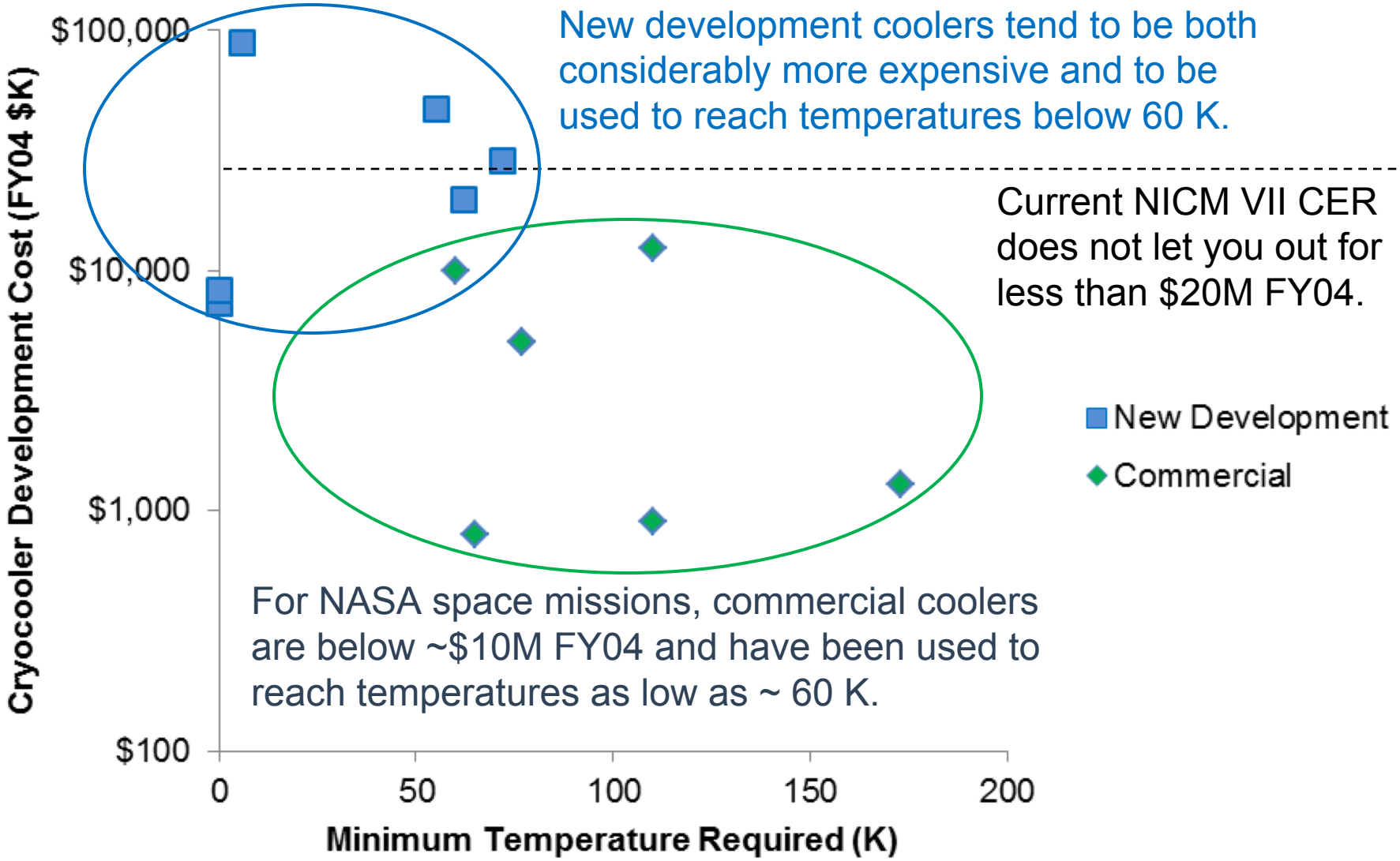
- **However, many present applications are utilizing commercially available cyrocooler solutions, which enable significant cost savings.**

Commercial vs. New Development



Note: Dewars not shown on graph.

Cryocoolers: Background

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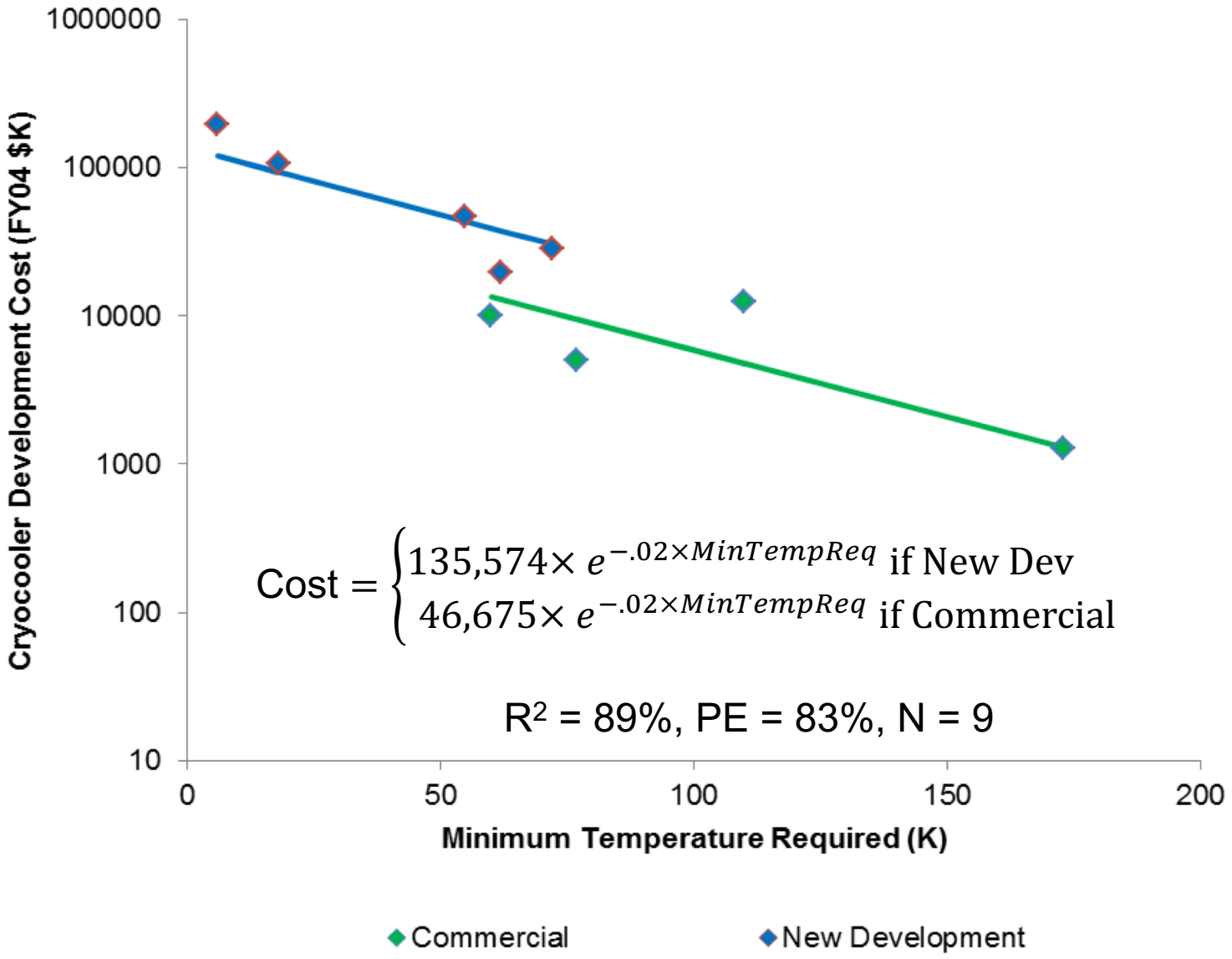
where “LowTemp” is the lowest temperature (in Kelvin) that the instrument needs to be cooled to by the cryocooler.

- **The new NICM VIII Cryocooler CER allows estimates of cost for both new designs and those leveraging commercial solutions.**

Cryocooler CER



NICM VII vs. NICM VIII Cryocooler CERs

Costs in $K FY04

- NICM VII: New Cryocoolers Only

$$\text{Cryocooler Cost} = 40{,}099 \times \text{LowTemp}^{-0.15}$$

- NICM VIII: New Cryocoolers *and* Commercial

$$\text{Cryocooler Cost} = \begin{cases} 135{,}574 \times e^{-.02 \times MinTempReq} & \text{if New Dev} \\ 46{,}675 \times e^{-.02 \times MinTempReq} & \text{if Commercial} \end{cases}$$

The new NICM VIII Cryocooler CER allows estimates of cost for both new designs and those leveraging commercial solutions.

Sneak Peek: Future Work Already Underway

- Research for NICM IX has already begun
  - Further improvements expected to the Schedule Estimating Relationships, such as Mission Class based SERs.
  - Exploring the role of Class in the Subsystem CERs and Wraps.
  - Exploring splitting the Detector CERs into further subcategories.
  - Explore data imputation methods to utilize incomplete data.
  - Explore override capabilities when vender quotes used.
  - Upgrade Search Engine to allow “Or” and other searches.
  - Add hyperlinks from plots to NICM Instrument Sheets.
  - And more!

Training and Download

- Email NICM@jpl.nasa.gov to RSVP for the next Live or WebEx training opportunity
- NICM can be downloaded from www.oncedata.com for NASA users.
- All other users can request a copy at: NICM@jpl.nasa.gov

Questions?

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   - NASA Instrument Cost Model (NICM), 2014 International Cost Estimation and Analysis Association (ICEAA) Professional Development & Training Workshop, Denver Colorado , June 2014, H. Habib-Agahi, J. Mrozinski, G. Fox.
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