NASA Instrument Cost Model: Version VIII

NICM VIII Training Workshop

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Agenda

- Acknowledgements
- NICM 101
  - Introduction
  - Instrument Data
  - Modeling Methodologies
  - Models
  - JCL
  - Tool Demonstration
- Deeper Dive: NICM VIII Improvements
  - Class-based CERs vs. NICM-E
  - Telescope Cost as a Subsystem & “Telescope Instruments”
  - Improved Cryocooler Estimations

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  - Improved Cryocooler Estimations

NICM Stakeholders

- Sponsor: NASA HQ OCFO/SID/CAD/IPAO
  - Thank you to James Johnson and Charley Hunt for joining today!
- 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

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NICM Team

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What is NICM?

- **NICM is the *NASA* Instrument Cost Model.**
- Cost and Schedule Estimating Tool Suite for NASA Space Flight Instruments, including parametric cost models, cost analogy tools and JCL capabilities.

Who uses NICM?

- Used by all NASA Centers, Contractors, Universities etc.
- Used by Proposal Teams as well as by Proposal Evaluators.
- Over 500 people have attended NICM Training sessions, >= 1 new user every 2 weeks.
  - Your colleagues couldn't make this training session? Have them email NICM@jpl.nasa.gov.

Why NICM?

- **NICM is *the* NASA Instrument Cost Model.**
  - Used by Proposal Evaluators as well as by Proposal Teams.
  - NICM contains Cost Estimating Relationships Based on actual NASA space flight instruments from across the agency.
  - NICM estimates are driven by Objective inputs; no subjective fudge factors.
  - NICM provides two different parametric cost estimating approaches (System and Subsystem levels) as well as several analogy support features.

When is NICM?

- A long time!
- NICM began collecting data in 2004
  - Foreshadowing: You'll notice our CERs are all in FY04. This is why.
  - NICM has collected and normalized data non-stop 2004-present.
  - Newly collected data feeds the updates to the NICM CERs.
- Trying to cram 14 years of NICM history into 7 bullets:
  - NICM I: released in 2006, with each tool in an individual workbook.
  - NICM II-III: a flood of new data pours in after the NICM I release.
  - NICM IV: In-situ instruments added. All tools combined into a single workbook.
  - NICM V: schedule estimating and JCL added.
  - NICM VI: NICM-E capability and Cluster Tool added.
  - NICM VII: Telescope estimating capability added.
  - NICM VIII: You're about to find out!

Where is NICM?

- It’s in an Excel file.
- NICM can be downloaded from www.oncedata.com for NASA users.
- All other users can request a copy at: NICM@jpl.nasa.gov

How (do I use) NICM?

- I'll be demonstrating the tool use for you today.
  - If you are reading this but not sitting in the NICM training right now, please email NICM@jpl.nasa.gov to set up an online demonstration.
- The key to successfully running NICM: Understanding the nature of the instrument data behind the NICM models.

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Instrument Data

- NICM is built off of data of completed instruments.
- To date, NICM has collected data for **545** instruments.
- We are stringent when it comes to the quality, applicability and completeness of the data:
  - **Only 255** of the 545 are normalized and approved for modeling in NICM.
- Interviewing, Analyzing, Normalizing and Reviewing Instrument Data is the heart and main strength of the NICM.

Instrument Data

- The NICM instruments share the following characteristics:
  - All have been built/flown.
  - All have launched 1985 or after.
  - None are 100% foreign built, although some have foreign contributions of known cost.
  - All are space flight instruments (no ground-based or airborne).
  - NICM cost and schedules covers phases B/C/D.
    - Costs and schedules do not cover phases A or E
    - Costs do not include costs for science teams, ground data systems or mission ops.
  - All instruments have been normalized to a single unit's cost where necessary.

Sample of Normalized Database (1 of 2)

Instrument Name	Launch Date	Destination	Inst. Type	Manag. Cost ($K FY04)	Syst. Eng. ($K FY04)	Prod. Assure. ($K FY04)	Int. & Test ($K FY04)	Sensor Cost ($K FY04)	B/C/D Cost ($K FY04)	B/C/D Sched. (months)
ACIS	Jul-99	Earth Orbiting	Optical	3782	20193	3203	3499	59347	94261	72
ACS	Jan-97	Earth Orbiting	Optical	6306	6462	3314	5686	70000	92129	60
AIRS	May-02	Earth Orbiting	Optical	36827	32594	19730	22289	209236	320676	95
GALEX	Apr-03	Earth Orbiting	Optical	815	438	457	2826	18609	23662	62
GLAS	Oct-02	Earth Orbiting	Optical	7717		3689	4825	54035	70266	49
HIRDLS	Jul-04	Earth Orbiting	Optical	29349	4690	4482	5833	39727	84081	58
MISR	Dec-99	Earth Orbiting	Optical	7780	6570	6350	12450	91580	124730	80
MODIS	Dec-99	Earth Orbiting	Optical	27000	37542	13000	96156	102547	276245	60
NICMOS	Feb-97	Earth Orbiting	Optical	5791	5761	2961	13455	39129	67097	84
STIS	Feb-97	Earth Orbiting	Optical	7929	7572	5098	12490	79319	112408	48
TES	Jul-04	Earth Orbiting	Optical	9310	8350	9350	24520	161140	212670	54
TOMS	Jul-96	Earth Orbiting	Optical	6007	7401		5176	12381	30965	40
WFPC1	Apr-90	Earth Orbiting	Optical	8510	16340	9040	18550	106920	159360	141
WFPC2	Dec-93	Earth Orbiting	Optical	11150	14590	6000	23710	77910	137460	108
CRISM	Aug-05	Planetary	Optical	2058	2314	963	1567	21049	30615	42
CTX	Aug-05	Planetary	Optical	540	416		44	4169	5686	40
HiRISE	Aug-05	Planetary	Optical	5640	3383	4096	4744	25398	49843	48
IRAC	Aug-03	Planetary	Optical	5824	2149	828	7878	24726	41405	
ISS	Oct-97	Planetary	Optical	11672	3898	1997	13472	33502	67478	60
MARCI	Aug-05	Planetary	Optical	164	158			1988	2540	35
MCS	Aug-05	Planetary	Optical	865	420	741	3332	8651	14009	40
MICAS	Oct-98	Planetary	Optical	1320	310		1980	6850	10460	36
MOC	Sep-92	Planetary	Optical	3500	2041	1330	3917	17558	32041	72
MOLA	Sep-92	Planetary	Optical	336	4284	1428	672	29000	35720	48
ONC	Aug-05	Planetary	Optical	450	250	350	1400	3180	5660	36
VIMS	Oct-97	Planetary	Optical	5740	3883	2123	3200	20940	38356	72
CPR	Feb-06	Earth Orbiting	Active	1922	1009		7542	68768	79241	66
GFO Alt	Feb-98	Earth Orbiting	Active	5108	2478	2443	3885	21846	35759	38
NSCAT	Aug-96	Earth Orbiting	Active	14270	13800	10110	26890	168750	233820	120
SeaWinds	Dec-02	Earth Orbiting	Active	11270	19690	9810	17010	122320	180100	90
SIR-C	Apr-94	Earth Orbiting	Active	11138	5757	7728	20257	128860	173740	96
SRTM	Feb-00	Earth Orbiting	Active	15353	7788	8361	21311	177463	230275	119
TOPEX ALT	Aug-92	Earth Orbiting	Active	11000	3000	1200	10000	30000	58900	72
Cassini Radar	Oct-97	Planetary	Active	33077	17604	9445	32525	91786	184437	72
Magellan Radar	May-89	Planetary	Active	10917	25978	6148	25553	110326	210587	69
MARSIS	Jun-03	Planetary	Active	2020	1847	1028	2496	12182	19573	44
AMSU-A	May-02	Earth Orbiting	Passive	5578	1769	4207	8446	30001	50001	60
EMLS (MLS)	Jul-04	Earth Orbiting	Passive	8320	1860	15820	10040	122530	158570	90
GFO Radiometer	Feb-98	Earth Orbiting	Passive	1573	692	753	2097	5833	10947	38
JMR	Dec-01	Earth Orbiting	Passive	1307	2550	661	830	10818	16166	51
SSMI	Jun-88	Earth Orbiting	Passive	6253			1670	24460	32383	48
TMR	Aug-92	Earth Orbiting	Passive	1785	3484	903	1134	11950	20606	72
MIRO	Mar-04	Planetary	Passive	2160	650		5150	15040	23000	50

Illustrative data only, may not match NICM VIII data.

Sample of Normalized Database (1 of 2)

Instrument Name	Mass (kg)	Max Power (W)	TRL	Data Rate (kbps)	# of Bands	# of Channels	Optics/Ant. Mass (kg)	Elec Mass (kg)	Elec Max Power (W)	Wavelength (um)
ACIS	108	155						64		
ACS	341	249		1000	3	3	132	100	144	.115-1.1
AIRS	177	244		1420	12	6	47	38	89	0.4-1.7 & 3.4-15.4
GALEX	135	191	4	25000	2	2	55	23	135	.135-.280
GLAS	307	349	5	550	2	2	119	61	215	1.064 & 0.532
HIRDLS	220	239		65	2	21				6.12-17.76
MISR	148	117		9000	4	9	27	21	15	0.466-0.866
MODIS	229	205		10500	4	36	33	111	202	0.415-14.4
NICMOS	273	150	7	1000	1	3	44	84	150	1.0-2.5
STIS	374	250	8	1000	4	28	181	91	250	.115-1
TES	328	249	5	4700	4		80	29	77	3.2-15.4
TOMS	34	67		0.8	1	6	15	5		0.3086-0.36
WFPC1	292	190	4	1000	48	8	136	51	190	0.115-1.10
WFPC2	281	190	7	1000	48	4	124	51	190	0.115-1.10
CRISM	33	46	5		2	2	9	3	46	0.4-4.05
CTX	3	6	4	20000	1	1	1	0.77	6	0.500-0.800
HiRISE	65	60	6	2400	2	3	15	19	60	0.4-1.0
IRAC	41	56		40	4	4	11	20		3.6, 4.5, 5.8, 8.0
ISS	58	56	6		2	64	14	18		0.2-1.0
MARCI	1	5	7	515	7	2	0.13	0.25	5	
MCS	9	16	4	10	3	9	2	1	16	0.3-50
MICAS	13	17	5	100	3	4	4		12	.08-2.4
MOC	24	21	6	31	1	3	4	12	21	0.4-0.9
MOLA	25	29		0.618	1	1	9	10	10	1
ONC	3	5	7	5	1	1	1	1	4	.45-.60
VIMS	37	26	6	182	2	352	19	12	20	.35-5.10
CPR	261	298	4	20	1	1	42	71	280	3200
GFO Alt	31	72	7	2	1	1	6	24	72	22200
NSCAT	280	240		3	1	2	50	230	240	21000
SeaWinds	202	185		36	1	1	62	141	170	Ku-Band 2.2
SIR-C	1956	7366		180	2	4	1479	477	1741	L: 240000, C: 57000
SRTM	1456	2241		180	1	4	678	608	1976	C: 57000
TOPEX ALT	220	237			2	2	14	206	237	23000-60000
Cassini Radar	46	111		365	1	1	3	43	111	21800
Magellan Radar	170	200		806	1	1	16	154	200	126000
MARSIS	18	39		45	4	2	7	11	39	540000-2300000
AMSU-A	100	110	6	3	15	15			110	13000, 9700, 6000, 6000, 5300
EMLS (MLS)	450	531	7	100	5	26	35	313	531	
GFO Radiometer	22	20	9	0.16	2	2	6	15	20	13600, 8100
JMR	24	31	9	3	3	4	5	13	31	9000, 13000, 16000
SSMI	56	96	7	9 (peak), 3 (ave)	4	7				
TMR	47	26		256	3	4	27	21	26	9000, 13000, 16000
MIRO	20	59	6	2	2		4	14	59	5000, 16000

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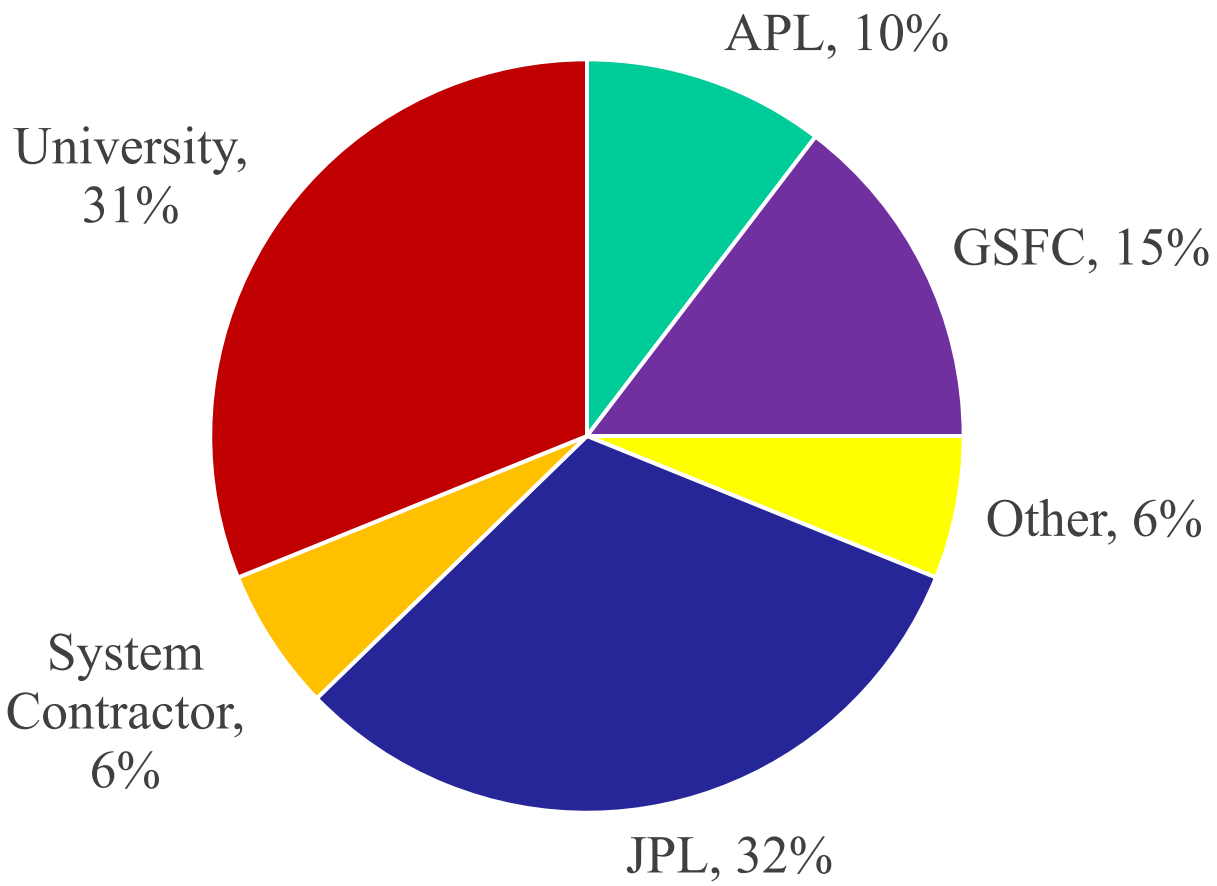
Data by Instrument Lead Organizations



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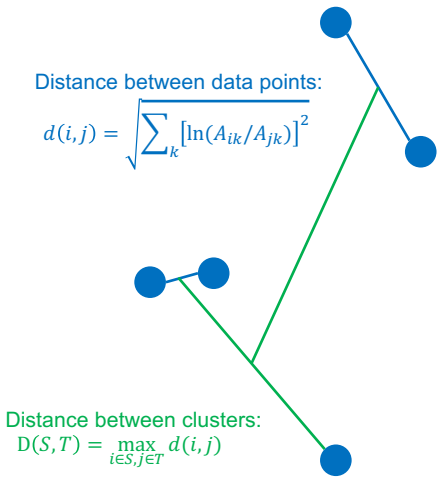
Modeling Methodology

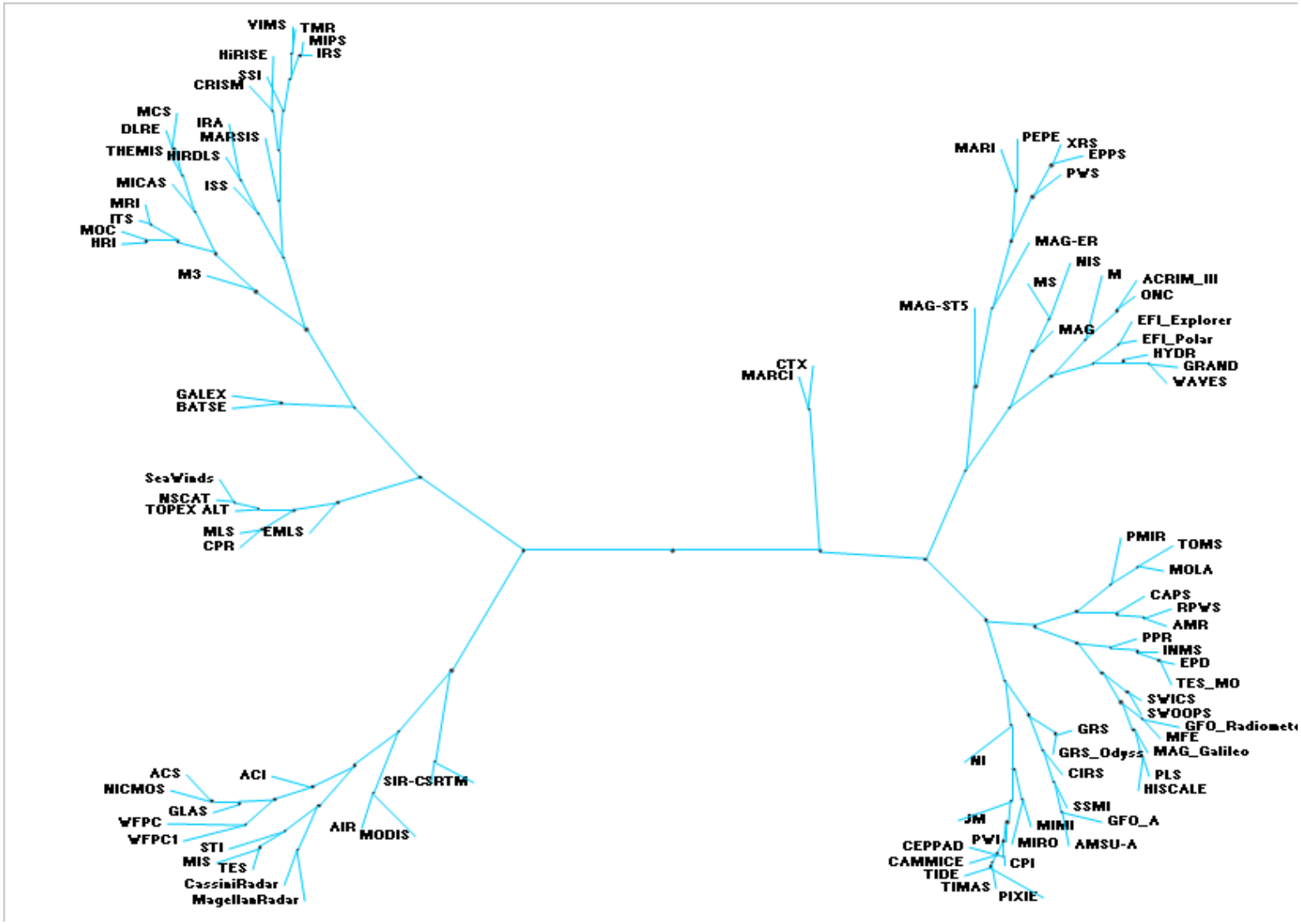
- Cluster Analysis
  - Identifies Instrument Groupings from Attribute Values
  - Assesses Consistency of Groups with Instrument Types
- Principal Components Analysis
  - Standard Data Mining Technique that
    - Finds Potential Cost Drivers from Instrument Attributes
    - Identifies Instrument Data Outliers – Revisit data with technical experts
    - Finds separation in the data (i.e. clustering)
    - Addresses multi-collinearity in data for regression analysis
- Bootstrap Cross Validation
  - *Bootstrap*: Process for generating meaningful statistics without assuming asymptotic normality.
  - *Cross Validation*: Partitioning of data set into training and testing sets. Out-of-sample validation.
  - Bootstrap technique also used to perform statistical tests for regression analysis.

Cluster Analysis

- Cluster Analysis
  - Defines the similarity between instruments by differences in the instrument attribute values.
  - Develops groups of similar instruments based on *distances* (i.e. dissimilarities) between instruments.
- Euclidean Distance Metric (*d* in figure to right):
  - $\mathbf{A}_{ik}$ is the value of attribute k for instrument i.
  - Gives "distance" between instruments
  - A table of distances is created between all pairs of instruments
- Distance table is then input to general clustering algorithm to generate groupings
  - Complete Clustering: uses the function *D* in the figure to calculate distance between clusters
- Output results are displayed in an unrooted tree.



Cluster Analysis: Remote Sensing Instruments



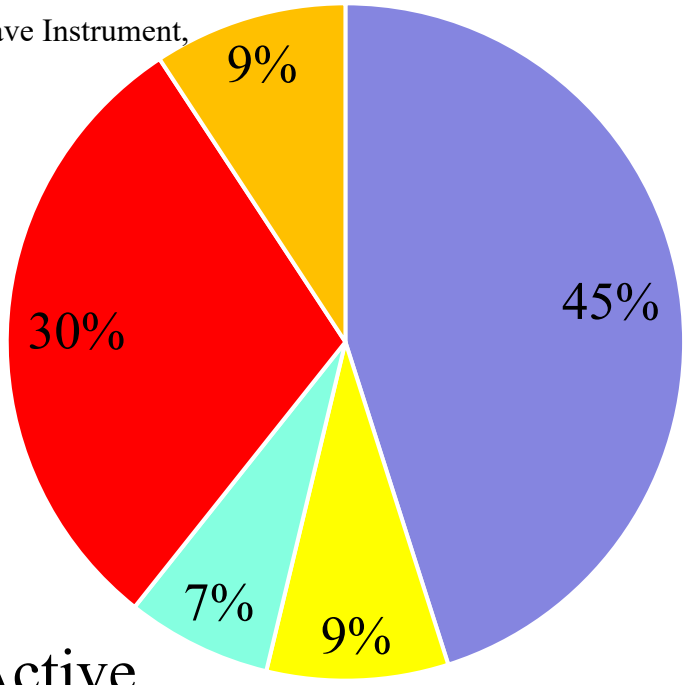
Remote Sensing Instruments Types

Fields:

- Magnetometer,
- Magnetic Field Instrument,
- Electric Field Instrument,
- Plasma Wave Instrument,
- ….etc.

Particles:

- Particle Detector,
- Gamma Ray Spectrometer,
- X-Ray Imager,
- Magnetospheric Imaging Instrument,
- Plasma Spectrometer,
- ….etc.



Optical:

- Camera,
- Spectrometer,
- Infrared Sounder,
- Laser Altimeter,
- Photometer,
- ….etc.

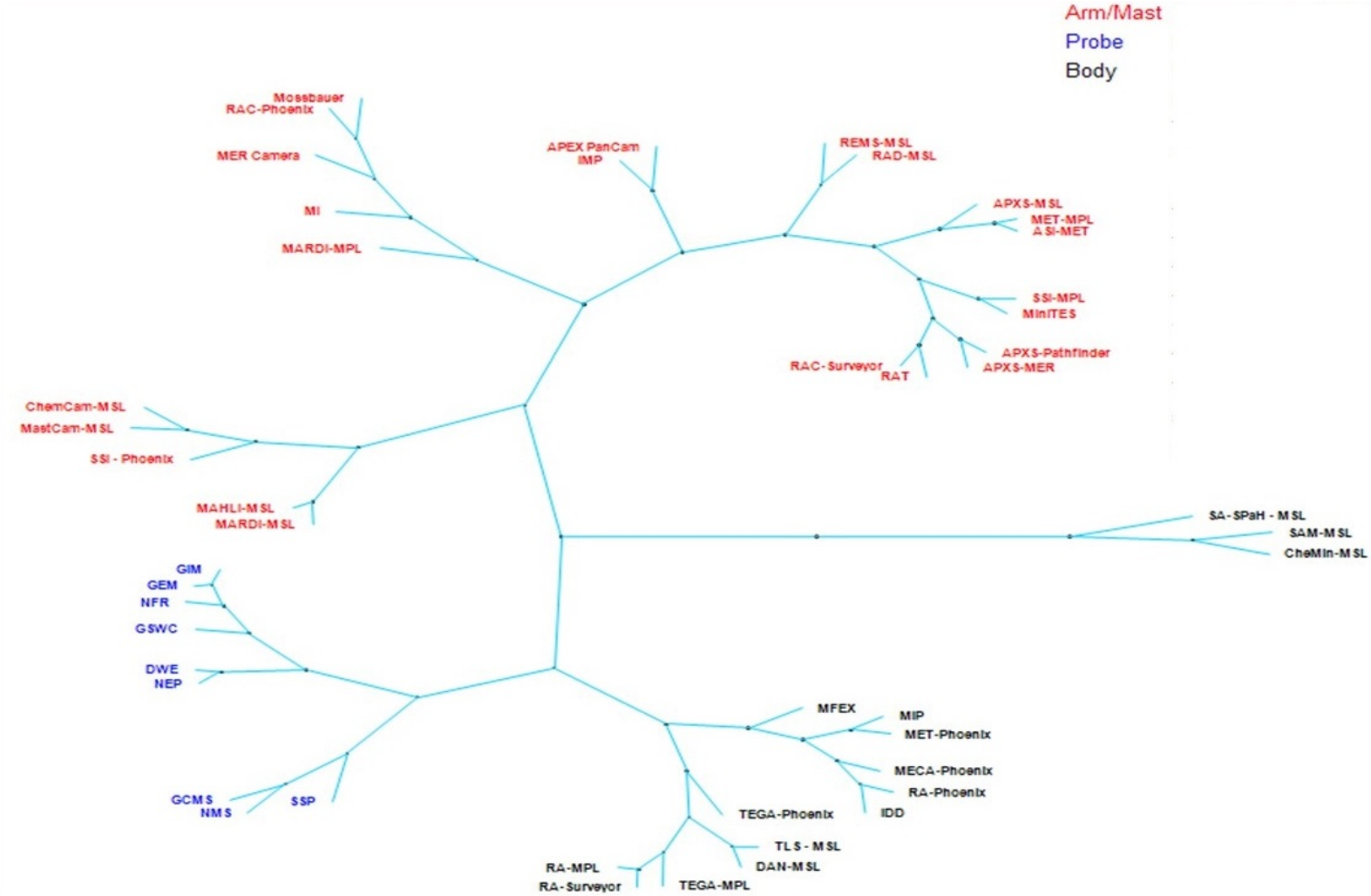
Active Microwave:

- Radar,
- Altimeter,
- Scatterometer,
- …etc.

Passive Microwave:

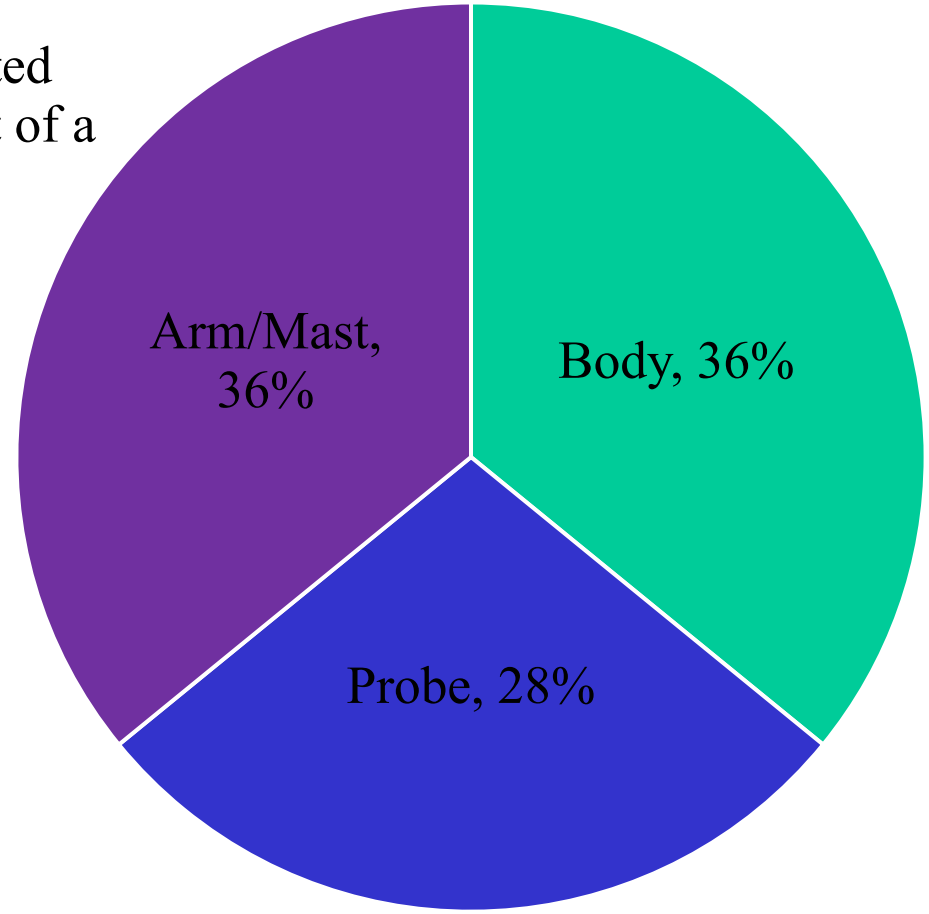
- Microwave Radiometer,
- Microwave Imager,
- Microwave Limb Sounder,
- …etc.

Cluster Analysis: In-Situ Instruments



In-Situ Instrument Mounting Types

• Instruments located on the arm or mast of a rover or lander.



Instruments located on:

• Rover Body

• Lander Body

• Instruments located on Atmospheric Probes

Instruments by Top Level Bins

- NICM is built off of data of completed instruments.
- Collected data for **545** instruments*
- **255** of the **545** have normalized and approved for modeling in NICM
    - **194** Remote Sensing Instruments
    - **41** In-Situ Instruments
    - **9** Cryocoolers
    - **8** Telescopes

Principal Components Analysis (PCA)

- What if we could somehow look at all variables at once and determine how they are correlated?
  - Specifically, which variables are correlated with cost?
- What if we could identify combinations of variables that explain the most variation in the data
  - This could help us develop a regression relationship.
- What if we saw the data projected onto the primary sources of variation in the data?
  - This is another way to see how our data might be clustering
  - Different than the previous clustering technique because it factors in correlation.

These are some of the many benefits of PCA.

Bootstrap Cross Validation

- Explanation of ".632" Bootstrap Cross-validation
  - Apply the following procedure for each CER (& associated dataset)
    - Sample *with replacement* from the dataset (using sample size same as dataset)
    - Fit regression model to trial sample selection
    - Predict cost with model for instruments in original dataset that were not selected by trial sampling for testing
    - Repeat above steps 999 times, saving cost deltas for each instrument tested
    - Calculate average model variance (= cost delta^2) for all 999 trials. Average with *apparent error* of original regression. This approximates the prediction error of the original CER.

Instrument

#	Trial #1	Trial #2	…	Trial #999
1	//	//	…	$\Delta_{1,999}$
2	/	$\Delta_{2,2}$	…	//
3	/	/	…	$\Delta_{3,999}$
4	$\Delta_{4,1}$	/	…	/
5	//	//	…	///
6	/	/	…	/
7	$\Delta_{7,1}$	$\Delta_{7,2}$	…	$\Delta_{7,999}$
8	/	/	…	/
9	//	/	…	//
10	$\Delta_{10,1}$	/	…	$\Delta_{10,999}$

$$\sigma^2_{(BCV)} = (\Sigma_i\ (\Sigma_t \Delta^2_{i,t}/\mathbf{N}_i)/|\#\mathbf{I}|$$

$$\sigma^2_{(\text{“632”})} = 0.368\ \sigma^2_{(app)} + 0.632\ \sigma^2_{(BCV)}$$

N_i = # of times the instrument was used for testing

#I = Total number of instruments

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Model Overview

- NICM contains the following modeling types:
  - Cost Estimating Relationships (CERs).
  - Schedule Estimating Relationships (SERs).
- The CERs exist at two different levels:
  - The instrument System or Total Level.
  - The instrument Subsystem and Wrap Level.
- The SERs exist at the System Level only.

Defining a few Terms

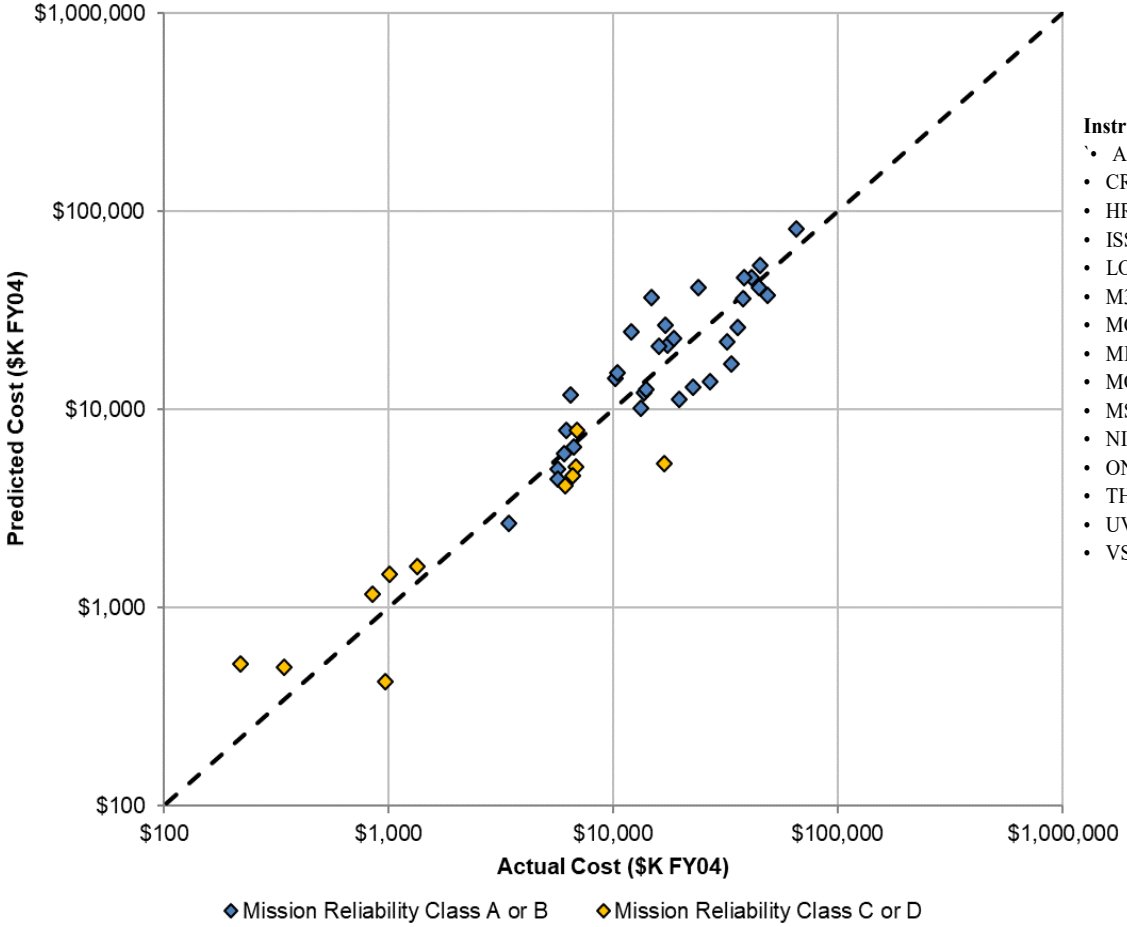
- NICM Destinations:
  - Earth Orbiting: A mission in a geocentric orbit.
  - Planetary: Everybody else.
- Telescope Lingo:
  - Telescope Optical Assembly (TOA), or “Telescope” for short.
    - This is just the front end, it does not include the backend detectors.
    - In other words, a “Telescope” is NOT an instrument, as it can produce no science without a backend.
  - Telescope Instrument: In the context of NICM, this is an instrument which includes both the TOA and a backend detector.
    - A “Telescope Instrument” is an instrument.

Optical Planetary CER

Optical (Planetary) Instrument Total B/C/D Cost (FY04 $K)

$$\text{Cost} = \begin{cases} 355 \times \text{TotalMass}^{0.44} \times \text{TotalMaxPwr}^{0.49} \times \text{DsgnLife}^{0.35} & \text{if Mission Class A or B} \\ 134 \times \text{TotalMass}^{0.44} \times \text{TotalMaxPwr}^{0.49} \times \text{DsgnLife}^{0.35} & \text{if Mission Class C or D} \end{cases}$$

R2=89%, PE=48%, N=43



Instruments used in the development of the Optical (Planetary) Instrument CER:

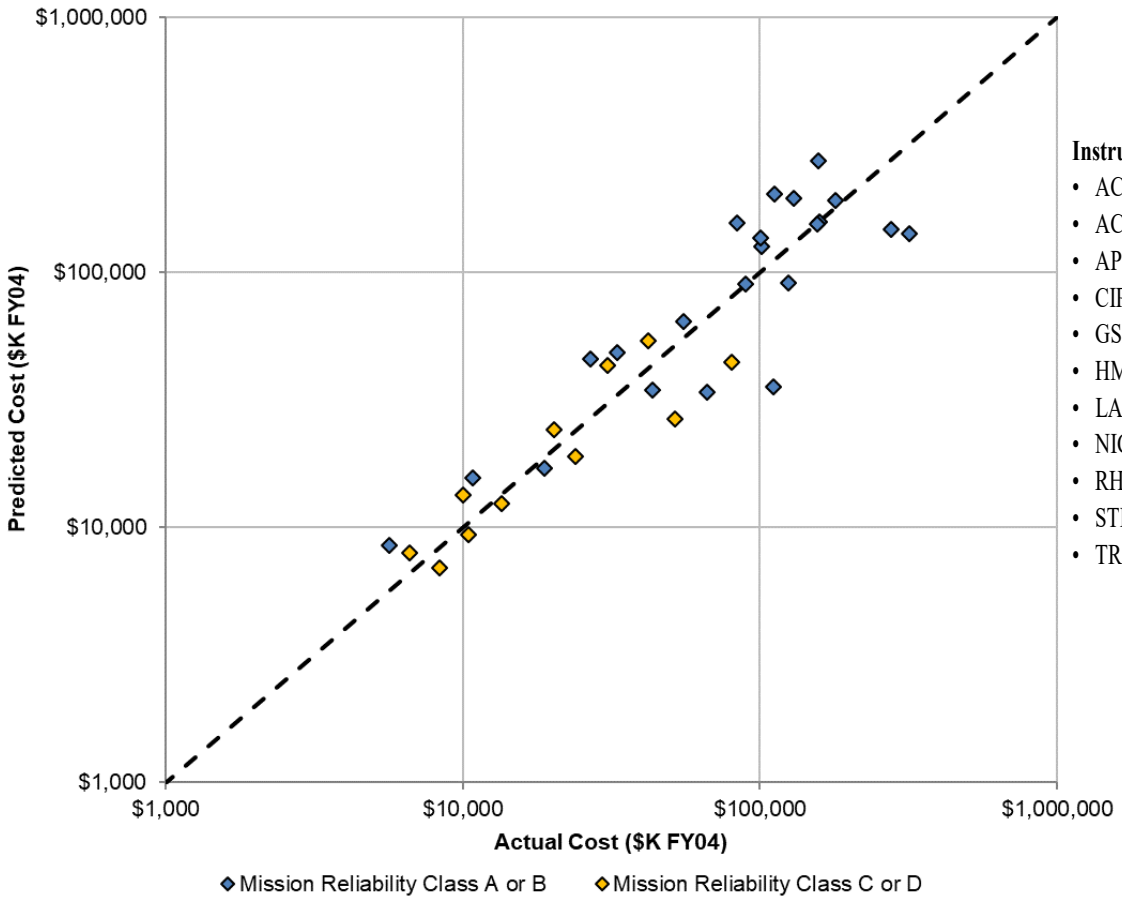
- ALICE_Rosetta
- CRISP
- HRI_Deep_Impact
- ISS
- LOLA
- M3
- MCS
- MIPS
- MOC-MO
- MSI
- NIS
- ONC
- THEMIS
- UVS - Juno
- VSP
- CFI
- CTX
- IRAC
- ITS
- LORRI
- MARCI
- MDIS
- MIR
- MOLA-MO
- NavCam
- NLR
- PMIRR
- TLP
- VIMS
- CIRS
- DLRE
- IRS
- JunoCam
- LROC
- MASCS
- MICAS
- MLA
- MRI
- NIR
- NSP
- TES_MO
- UVIS
- VIS_LCROSS

Optical Earth Orbiting CER

Optical (Earth Orbiting) Instrument Total B/C/D Cost (FY04 $K)

$$\text{Cost} = \begin{cases} 817 \times \text{TotalMass}^{0.46} \times \text{TotalMaxPwr}^{0.51} & \text{if Mission Class A or B} \\ 341 \times \text{TotalMass}^{0.46} \times \text{TotalMaxPwr}^{0.51} & \text{if Mission Class C or D} \end{cases}$$

R2=85%, PE=48%, N=33



Instruments used in the development of the Optical (Earth Orbiting) Instrument CER:

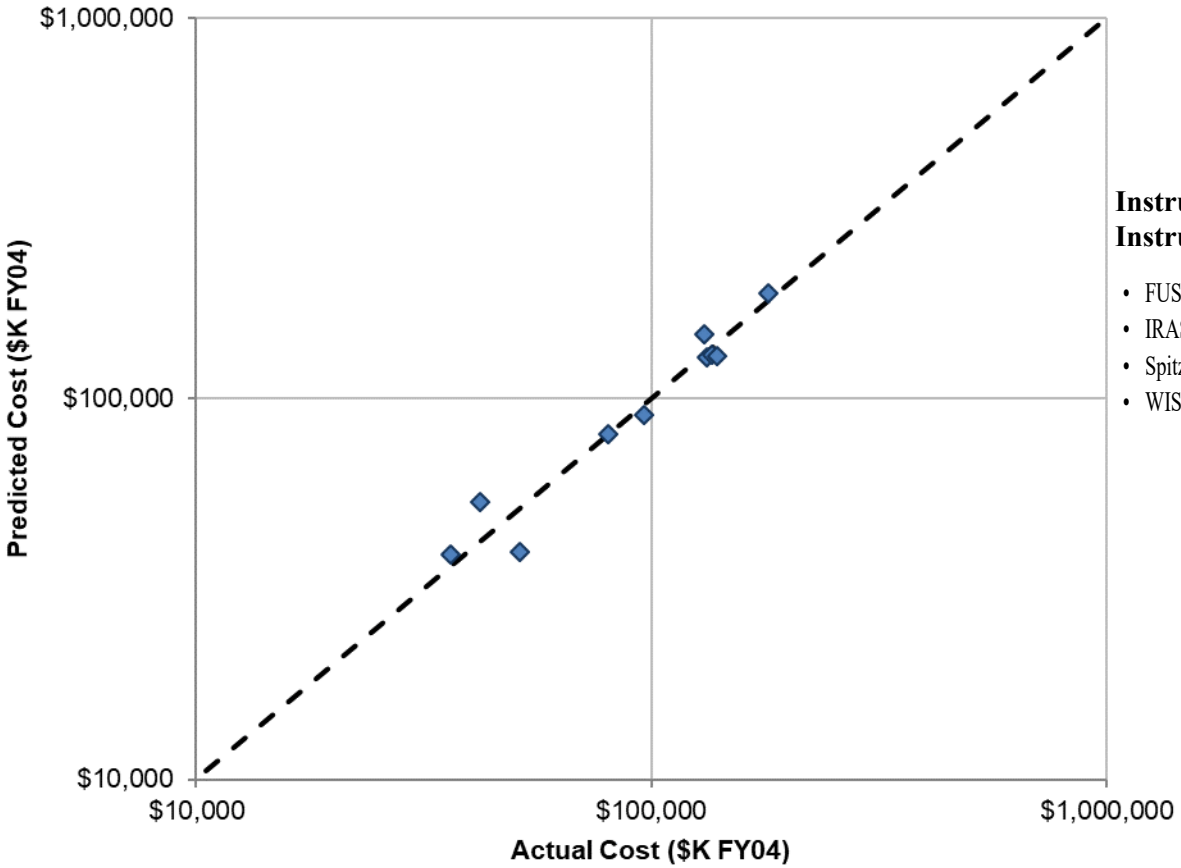
- ACIS
- ACS
- APS-Glory
- CIPS
- GSPEC-OCO
- HMI
- LAC
- NICMOS
- RHESSI
- STIS
- TRACE
- ACRIM II
- AIA
- CERES
- EVE
- GUVI
- HRC
- MISR
- NuStar
- SABER
- TES_Aura
- WFPC1
- ACRIM III
- AIRS
- CHIPS
- FUV
- HIRDLS
- IRIS
- MODIS
- OLI
- SOFIE
- TOMS
- WFPC2

Telescope Instrument CER

Telescope Instrument Total B/C/D Cost (FY04 $K)

$$\text{Cost} = \begin{cases} 421 \times \text{PrimMirrorDiam}^{0.72} \times \text{TotalMass}^{0.41} & \text{if UV/Visible} \\ 508 \times \text{PrimMirrorDiam}^{0.72} \times \text{TotalMass}^{0.41} & \text{if Infrared} \end{cases}$$

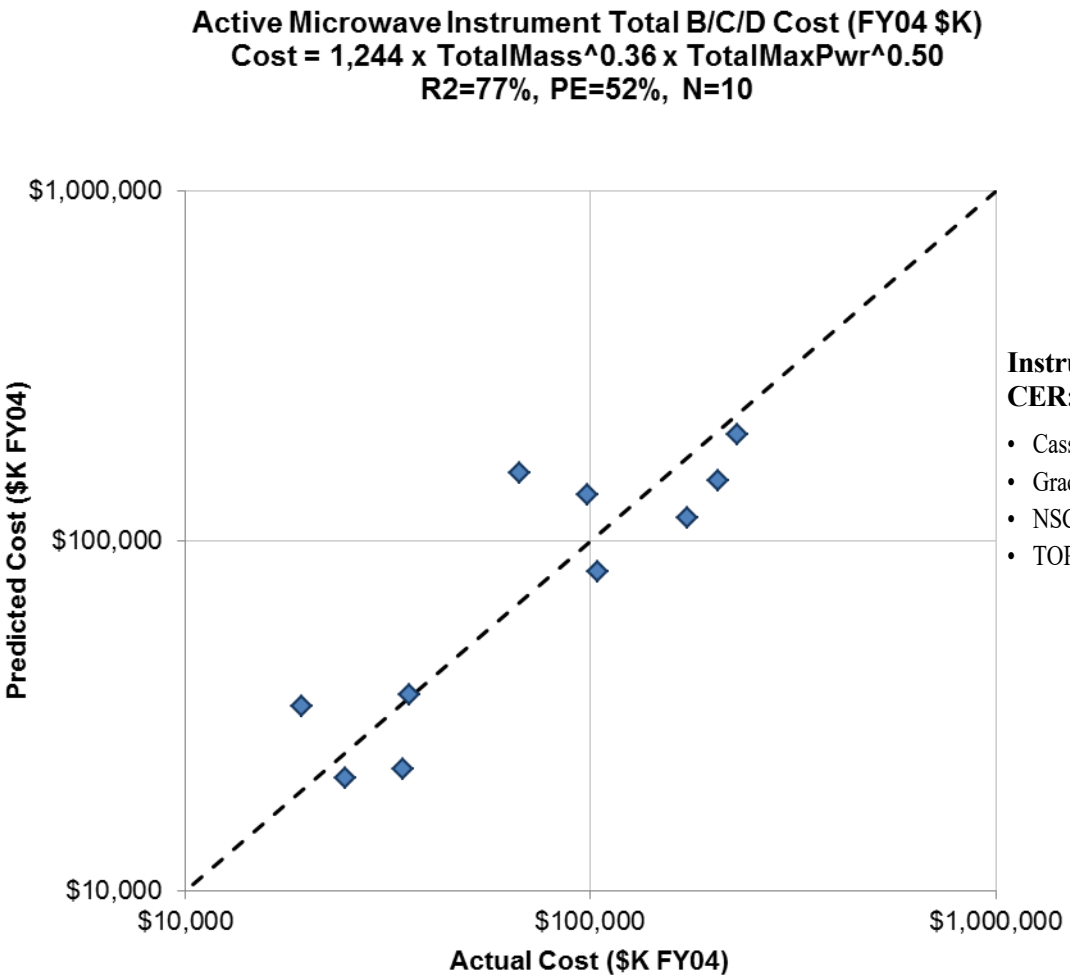
R2=94%, PE=29%, N=10



Instruments used in the development of the Telescope Instrument CER:

- FUSE
- IRAS
- Spitzer-IRS
- WISE
- GALEX
- Kepler
- Spitzer-MIPS
- HiRISE
- Spitzer-IRAC
- WIRE

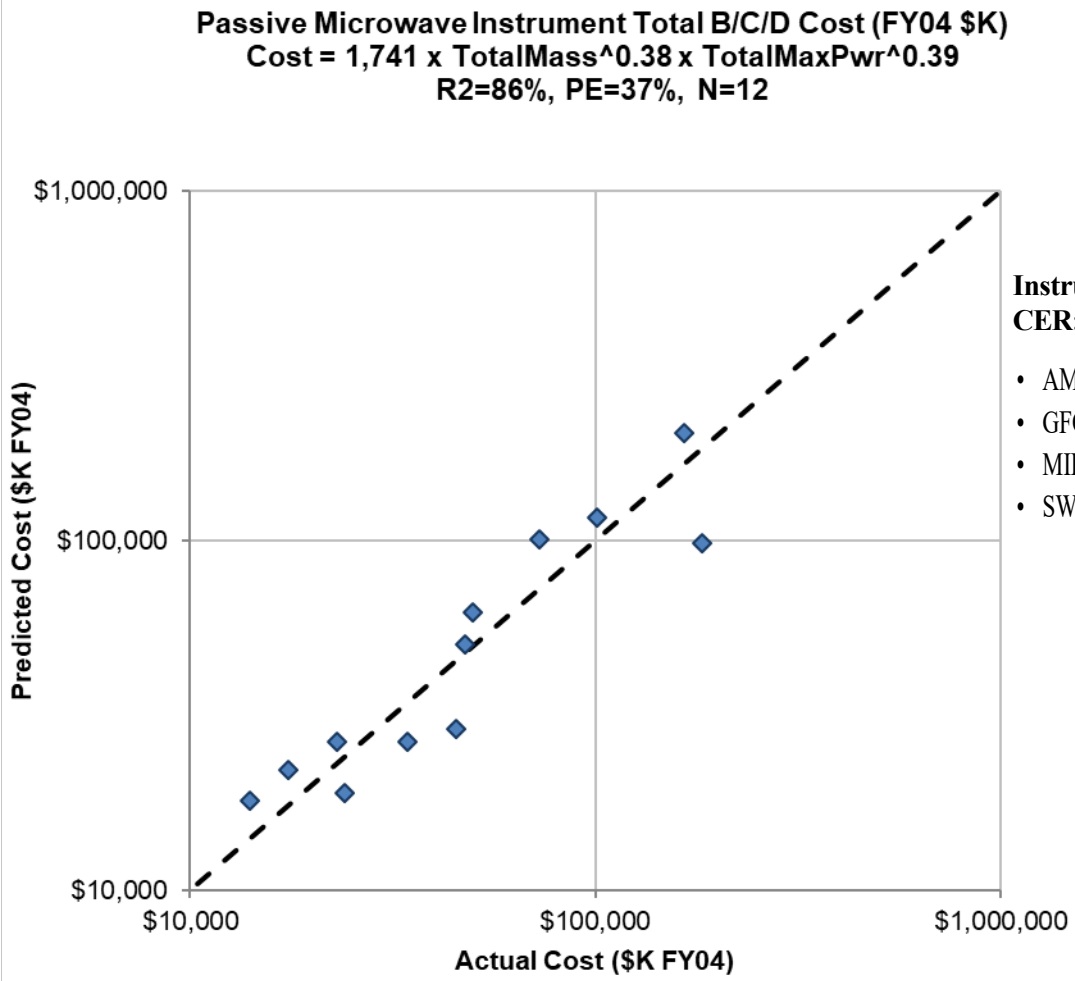
Active Microwave CER



Instruments used in the development of the Active Microwave Instrument CER:

- Cassini Radar
- Grace Instrument
- NSCAT
- TOPEX ALT
- CPR
- LGRS
- SeaWinds
- GFO-Alt
- MARSIS
- SMAP

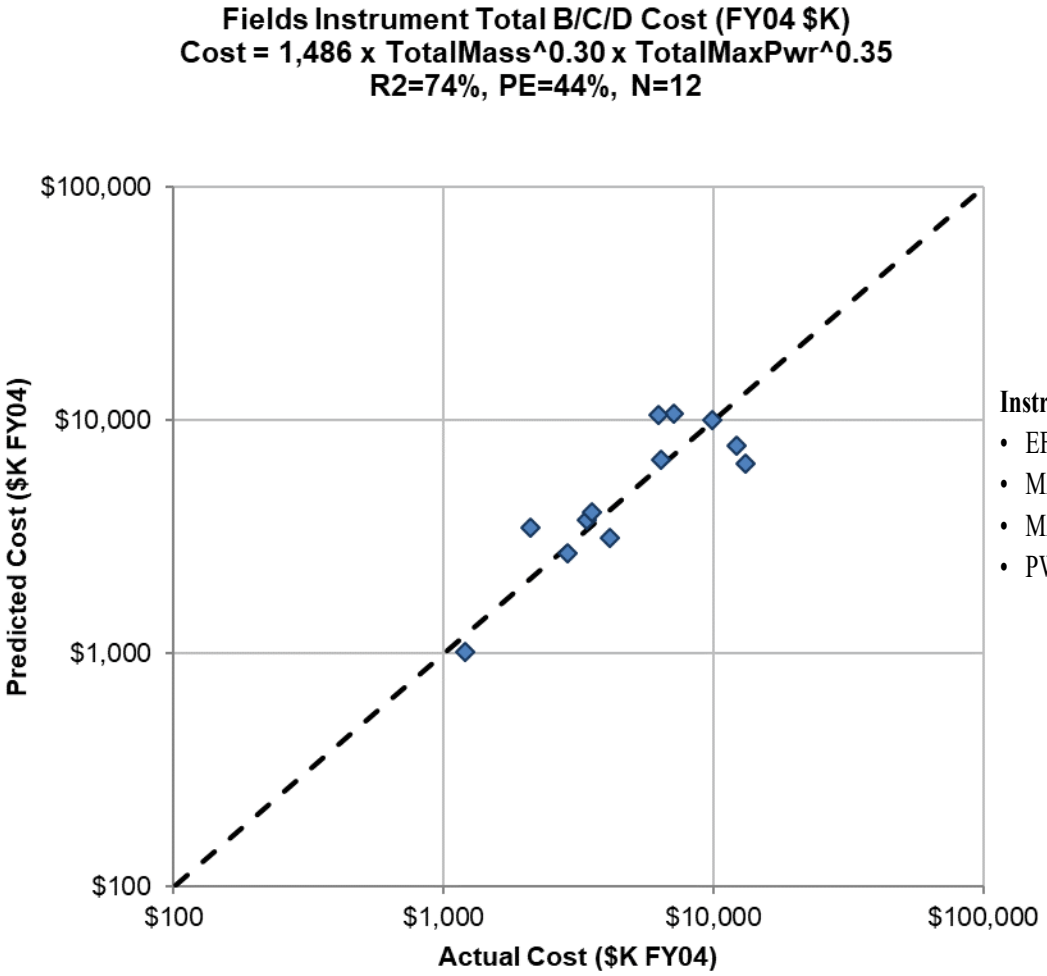
Passive Microwave CER



Instruments used in the development of the Passive Microwave Instrument CER:

- AMR
- GFO Radiometer
- MIRO
- SWAS
- AMSU-A
- GMI
- MLS
- TMR
- EMLS
- JMR
- MWR
- WMAP

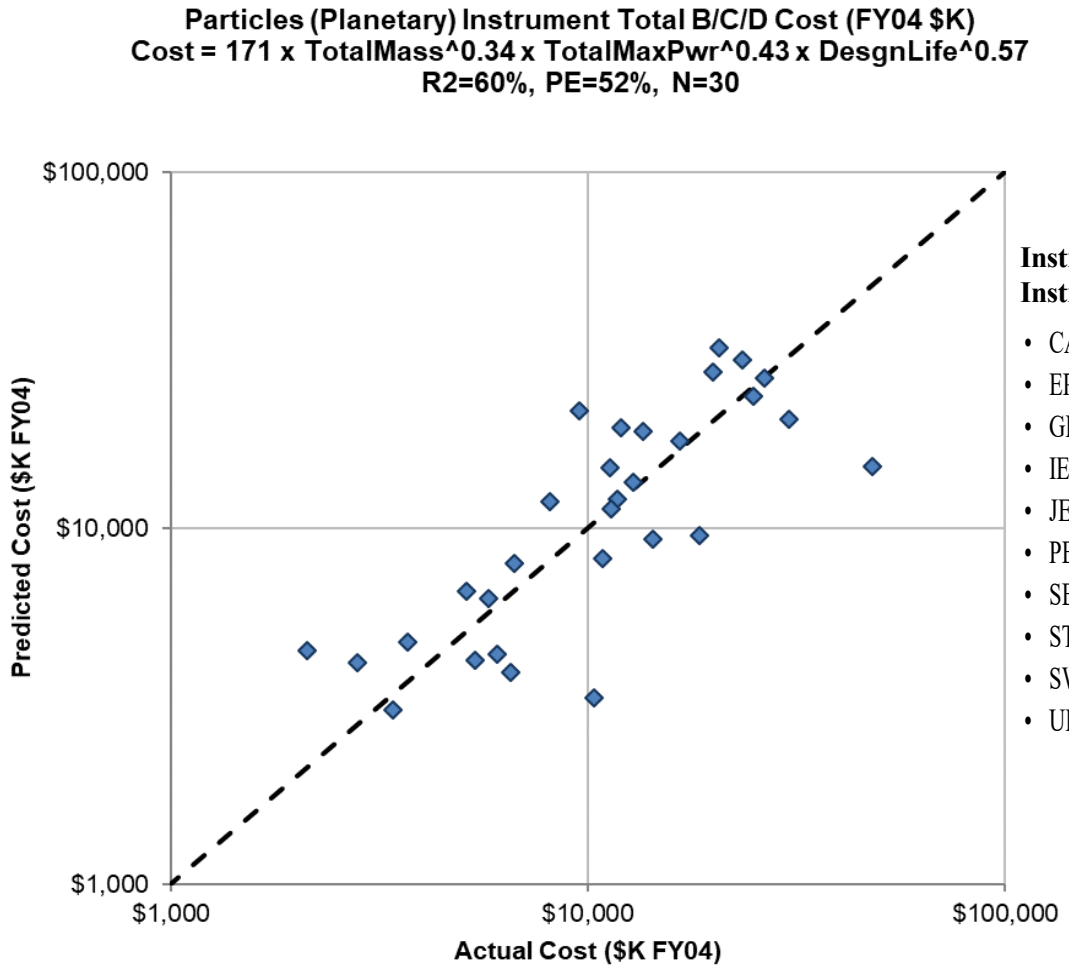
Fields CER



Instruments used in the development of the Fields Instrument CER:

- EFI_Polar
- EFPE
- FGM-ASC
- MAG FAST
- MAG MAVEN
- MAG MESSENGER
- MAG NEAR
- MAG-ST5
- MFI
- PWI
- WAVES_Juno
- WAVES_STEREO

Particles Planetary CER



Instruments used in the development of the Particles (Planetary) Instrument CER:

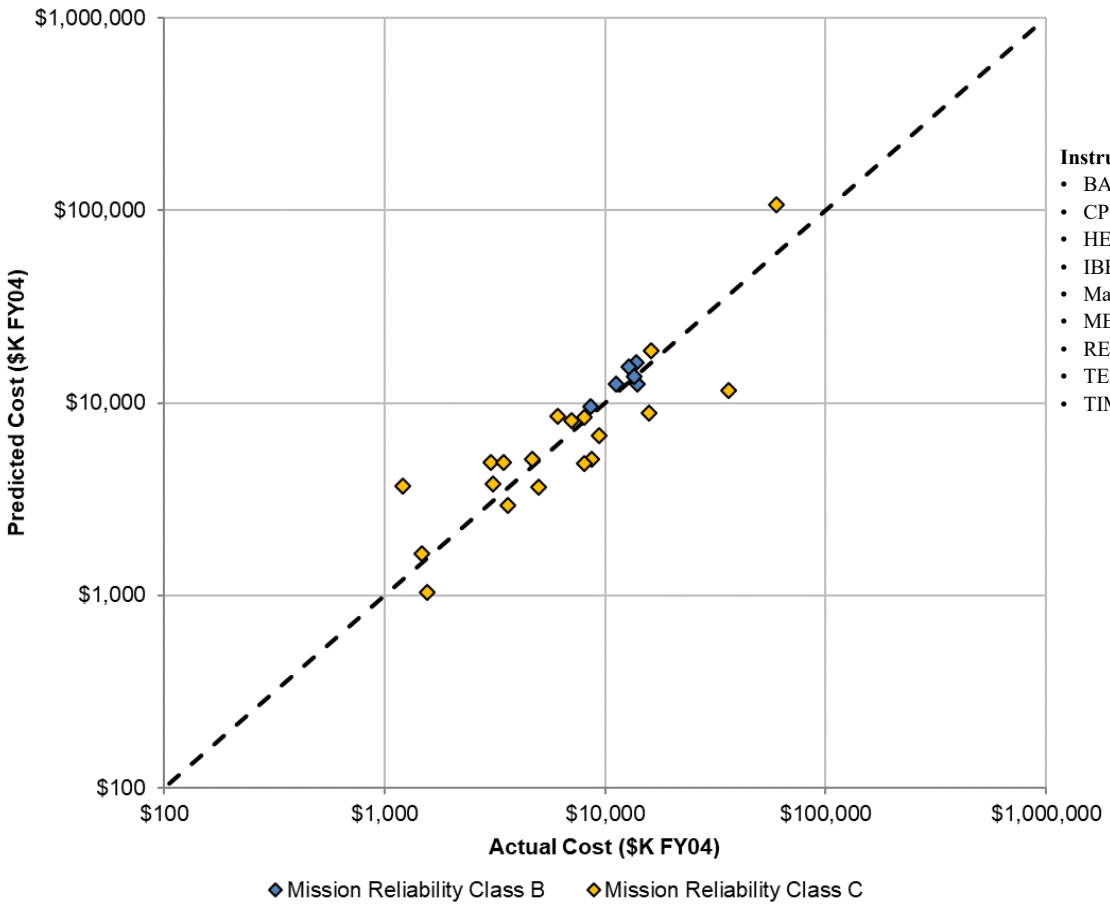
- CAPS
- CRATER
- CRIS_ACE
- EPPS
- GRAND
- GRNS
- GRS_MO
- GRS_Odyssey
- HISCALE
- IES
- INMS
- JADE
- JEDI
- MARIE
- MIMI
- PEPE
- PEPSSI
- RPWS
- SEP
- SEPICA
- SIS
- STATIC
- SWAP
- SWEA
- SWIA
- SWICS_Ulysses
- ULEIS
- URAP
- XRS-GRS
- XRS-MESSENGER

Particles Earth Orbiting CER

Particles (Earth Orbiting) Instrument Total B/C/D Cost (FY04 $K)

$$\text{Cost} = \begin{cases} 1{,}361 \times \text{TotalMass}^{0.47} \times \text{TotalMaxPwr}^{0.39} & \text{if Mission Class B} \\ 706 \times \text{TotalMass}^{0.47} \times \text{TotalMaxPwr}^{0.39} & \text{if Mission Class C} \end{cases}$$

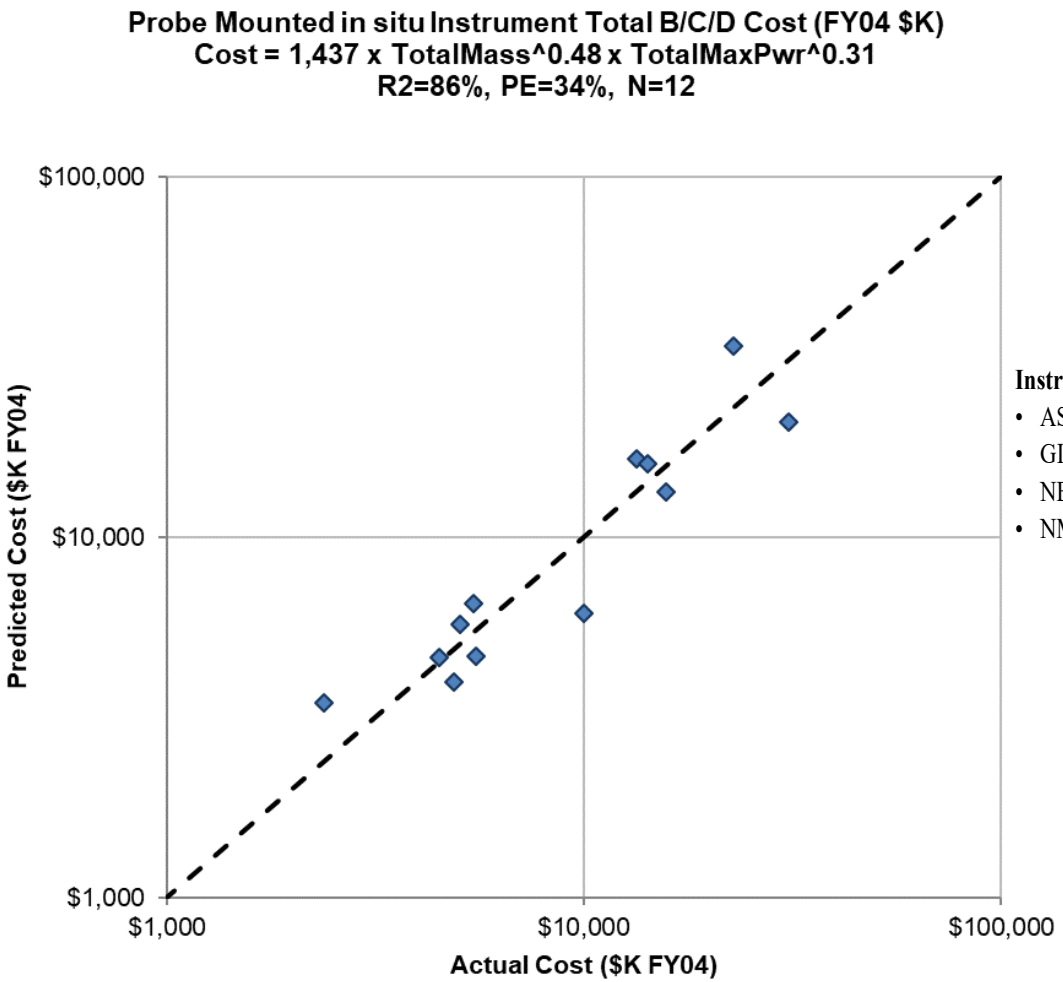
R2=77%, PE=53%, N=25



Instruments used in the development of the Particles (Earth Orbiting) Instrument CER:

- BAT
- CAMMICE
- CINDI
- CPI
- ESA_FAST
- ESA_THEMIS
- HENA
- HOPE
- HYDRA
- IBEX
- LEICA
- LENA
- MagEISHigh
- MagEISLowMedium
- MAST_&_PET
- MENA
- PIXIE
- RBSPICE
- REPT
- SST
- SXC
- TEAMS
- TIDE
- TIDI
- TIMAS

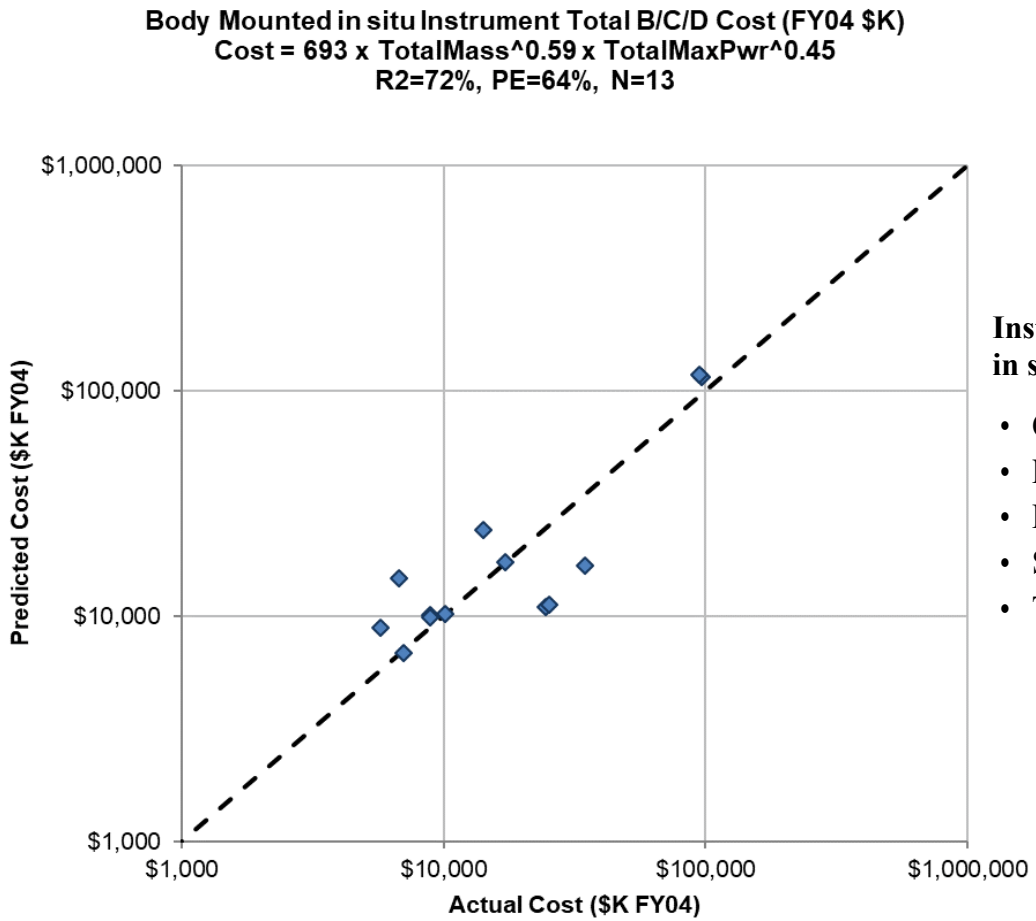
Probe Mounted In-Situ CER



Instruments used in the development of the Probe Mounted in situ Instrument CER:

- ASI_GalileoProbe
- GIM
- NEP
- NMS_LADEE
- ENose
- GSWC
- NFR
- NMS-Galileo_Probe
- GCMS
- LDEX
- NGIMS_MAVEN
- VCAM ISS

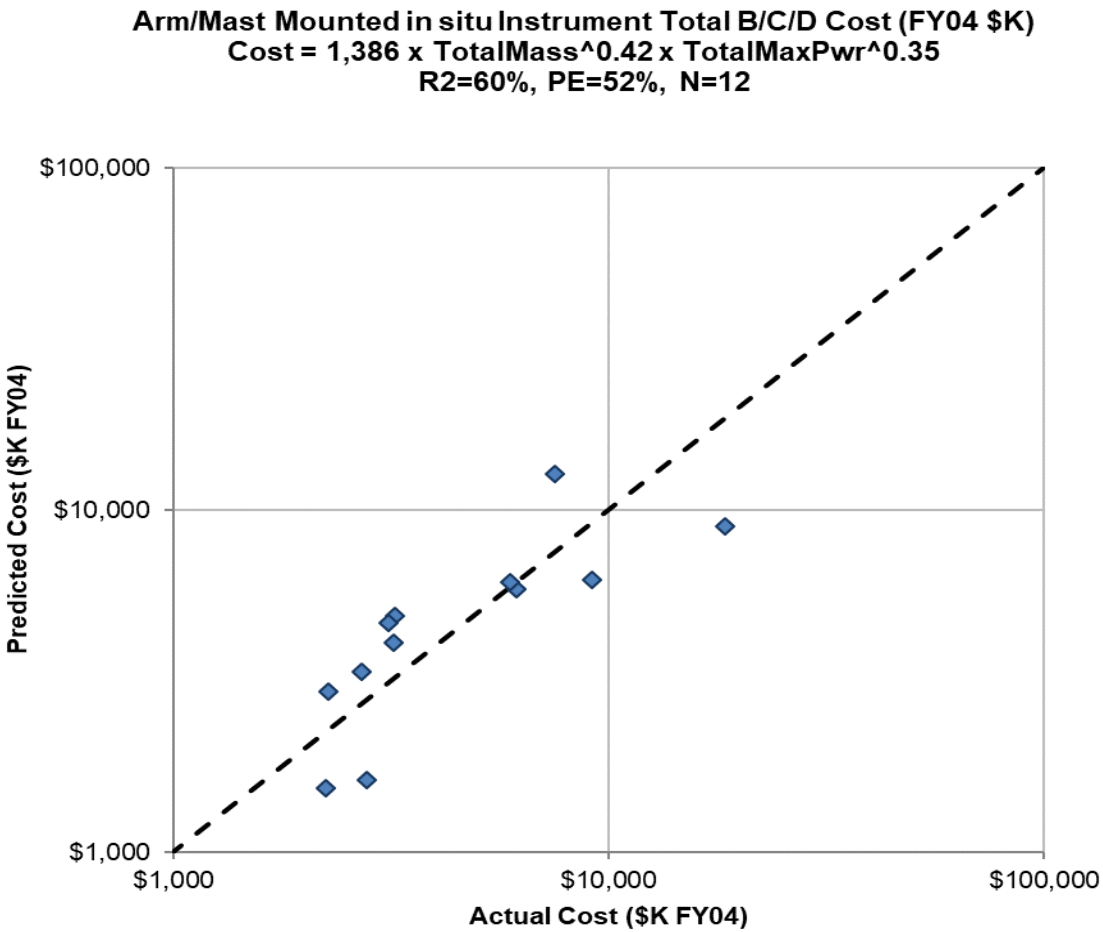
Body Mounted In-Situ CER



Instruments used in the development of the Body Mounted in situ Instrument CER:

- CheMin
- MECA-Surveyor
- RA-MPL
- SA-SPaH
- TLS
- IDD
- MFEX
- RA-Phoenix
- TEGA-MPL
- MECA-Phoenix
- MIP
- SAM
- TEGA-Phoenix

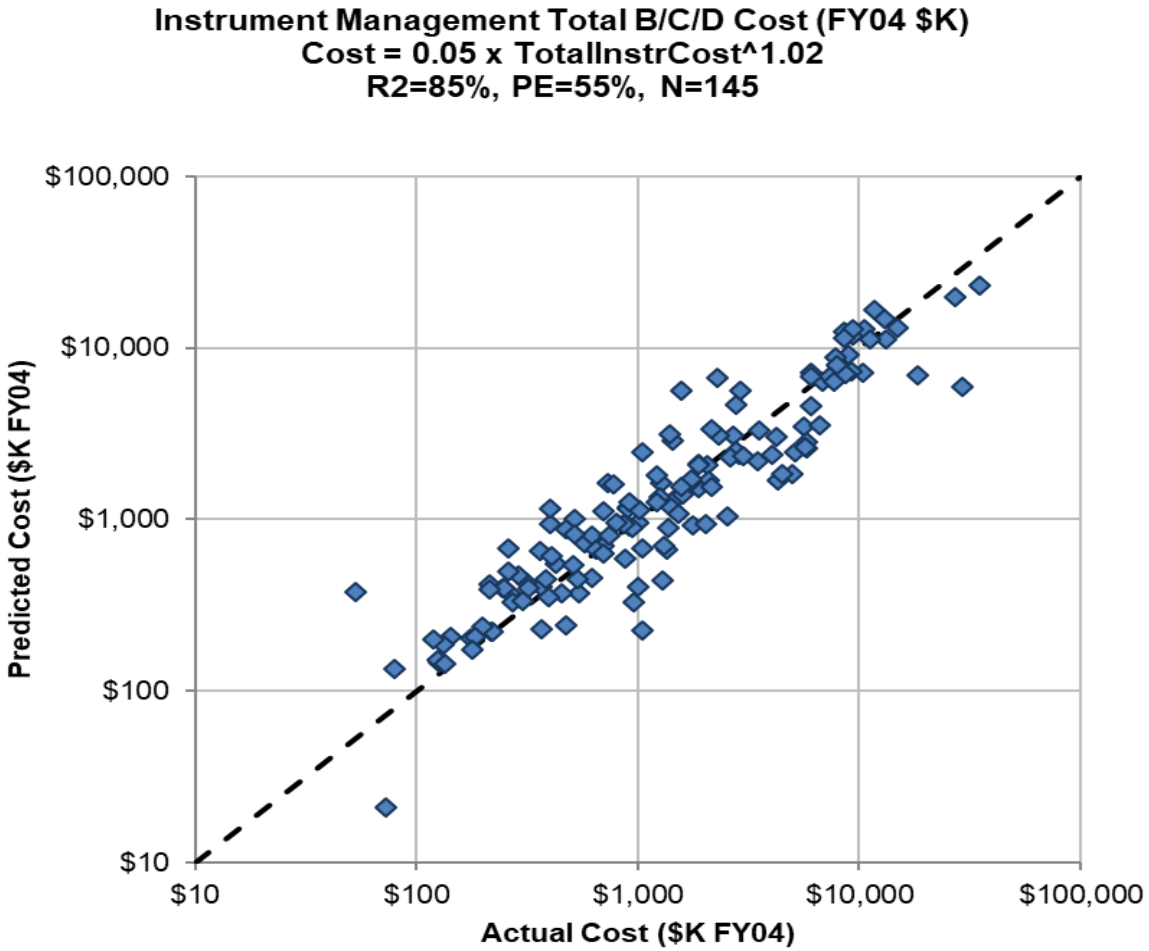
Arm/Mast Mounted In-Situ CER



Instruments used in the development of the Arm/Mast Mounted in situ Instrument CER:

- ASI_MET
- IMP
- MAHLI
- MARDI-MPL
- MARDI-MSL
- MastCam
- MET-MPL
- MiniTES
- RAT
- SSI-MPL
- SSI-Phoenix
- TES Electrometer

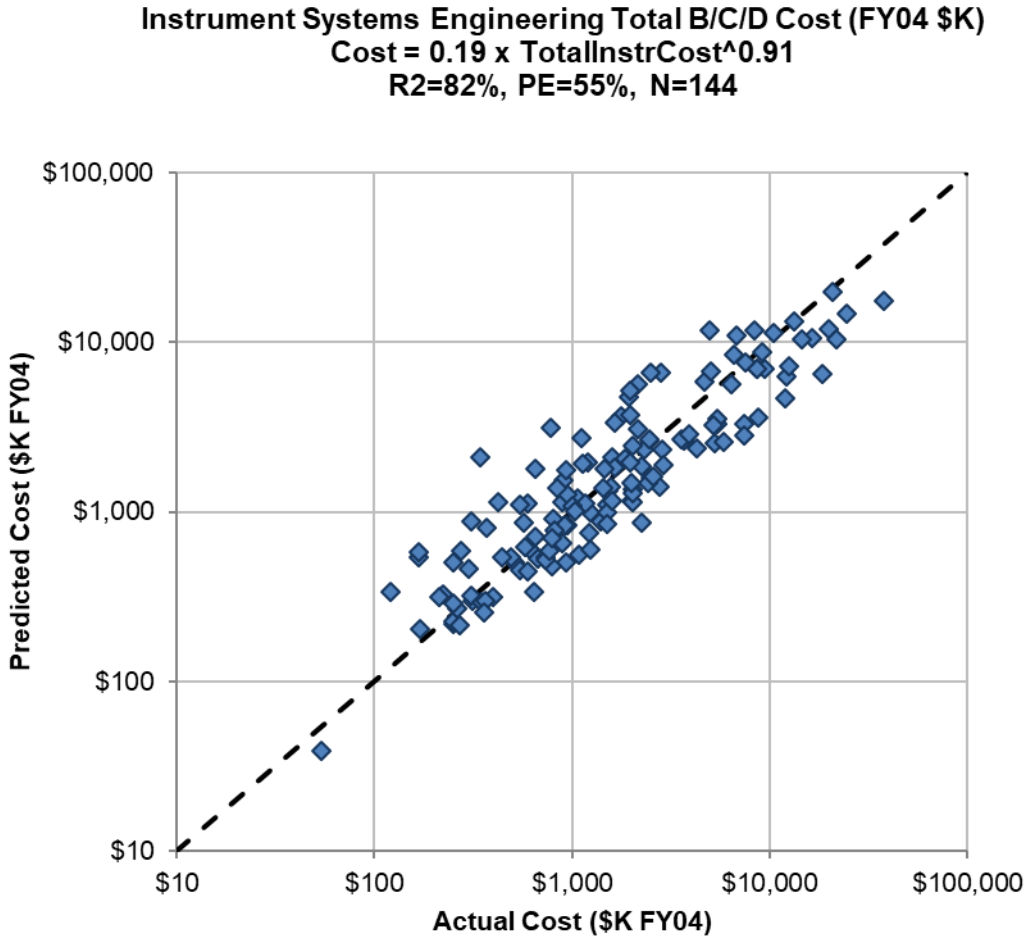
Management CER



Instruments used in the development of the Instrument Management CER:

- ACIS
- ACRIM III
- ACS
- AIA
- AIRS
- AMR
- AMSU-A
- ASI_MET
- CAPS
- Cassini Radar
- CFI
- CheMin
- CIPS
- CIRS
- CPR
- CRISM
- CRISP
- CTX
- DLRE
- EFI_Polar
- EFPE
- EMLS
- ENose
- EPPS
- ESA_FAST
- FGM-ASC
- FUSE
- GALEX
- GCMS
- GFO Radiometer
- GFO-Alt
- GIM
- GLAS
- GMI
- Grace Instrument
- GRAND
- GRNS
- GRS_MO
- GRS_Odyssey
- GSPEC-OCO
- GSWC
- GUVI
- HIRDLS
- HiRISE
- HISCALE
- HRC
- HRI_Deep_Impact
- HYDRA
- IBEX
- IDD
- IMP
- INMS
- IRAC
- IRS
- ISS
- ITS
- JADE
- JEDI
- JMR
- JunoCam
- Kepler
- LGRS
- LOLA
- LORRI
- M3
- MAG FAST
- MAG MESSENGER
- MAG NEAR
- MAHLI
- MARCI
- MARDI-MPL
- MARDI-MSL
- MARIE
- MARSIS
- MASCS
- MastCam
- MCS
- MDIS
- MECA-Phoenix
- MECA-TECP
- MER Camera
- MET-MPL
- MFEX
- MFI
- MICAS
- MIMI
- MiniTES
- MIPS
- MIR
- MIRO
- MISR
- MLA
- MLS
- MOC-MO
- MODIS
- MOLA-MO
- MRI
- MSI
- MWR
- NavCam
- NGIMS_MAVEN
- NICMOS
- NIS
- NSCAT
- OLI
- ONC
- PEPE
- PEPSSI
- PMIRR
- RAD
- RA-MPL
- RA-Phoenix
- RAT
- RBSPICE
- RPWS
- SAM
- SA-SPaH
- SeaWinds
- SMAP
- SOFIE

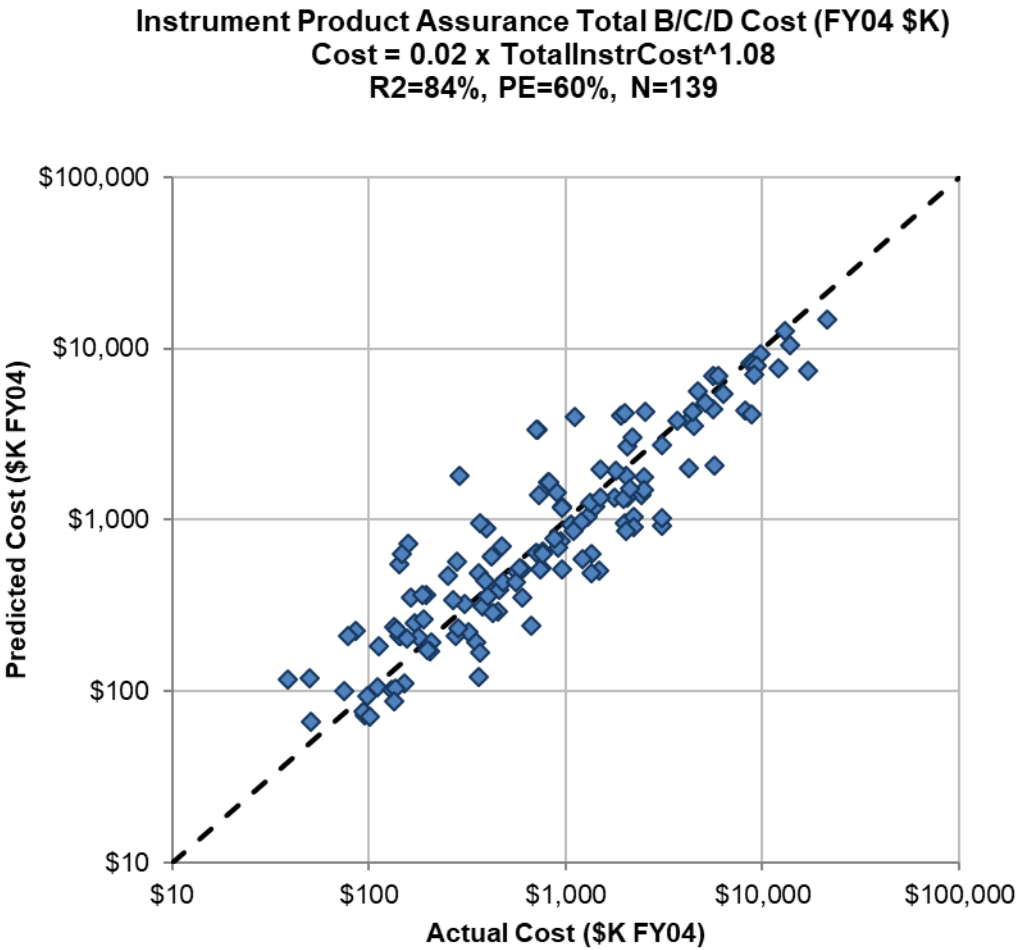
Systems Engineering CER



Instruments used in the development of the Instrument Systems Engineering CER:

- ACIS
- AIA
- AMSU-A
- Cassini Radar
- CIPS
- CRISM
- DLRE
- EMLS
- ESA_FAST
- GALEX
- GFO-Alt
- Grace Instrument
- GRS_MO
- GSWC
- HiRISE
- HRI_Deep_Impact
- IDD
- IRAC
- ITS
- JMR
- LGRS
- M3
- MAG NEAR
- MARDI-MPL
- MARSIS
- MCS
- MECA-TECP
- MFEX
- MIMI
- MIR
- MLA
- MODIS
- MSI
- NGIMS_MAVEN
- NSCAT
- PEPE
- RAD
- RBSPICE
- SA-SPaH
- SOFIE
- ACRIM III
- AIRS
- ASI_MET
- CFI
- CIRS
- CRISP
- EFI_Polar
- ENose
- FGM-ASC
- GCMS
- GIM
- GRAND
- GRS_Odyssey
- GUVI
- HISCALE
- HYDRA
- IMP
- IRS
- JADE
- JunoCam
- LOLA
- MAG FAST
- MAHLI
- MARDI-MSL
- MASCS
- MDIS
- MER Camera
- MFI
- MiniTES
- MIRO
- MLS
- MOLA-MO
- MWR
- NICMOS
- OLI
- PEPSSI
- RA-Phoenix
- RPWS
- SeaWinds
- SSI-MPL
- ACS
- AMR
- CAPS
- CheMin
- CPR
- CTX
- EFPE
- EPPS
- FUSE
- GFO Radiometer
- GMI
- GRNS
- GSPEC-OCO
- HIRDLS
- HRC
- IBEX
- INMS
- ISS
- JEDI
- Kepler
- LORRI
- MAG MESSENGER
- MARCI
- MARIE
- MastCam
- MECA-Phoenix
- MET-MPL
- MICAS
- MIPS
- MISR
- MOC-MO
- MRI
- NavCam
- NIS
- ONC
- PMIRR
- RAT
- SAM
- SMAP
- SSI-Phoenix

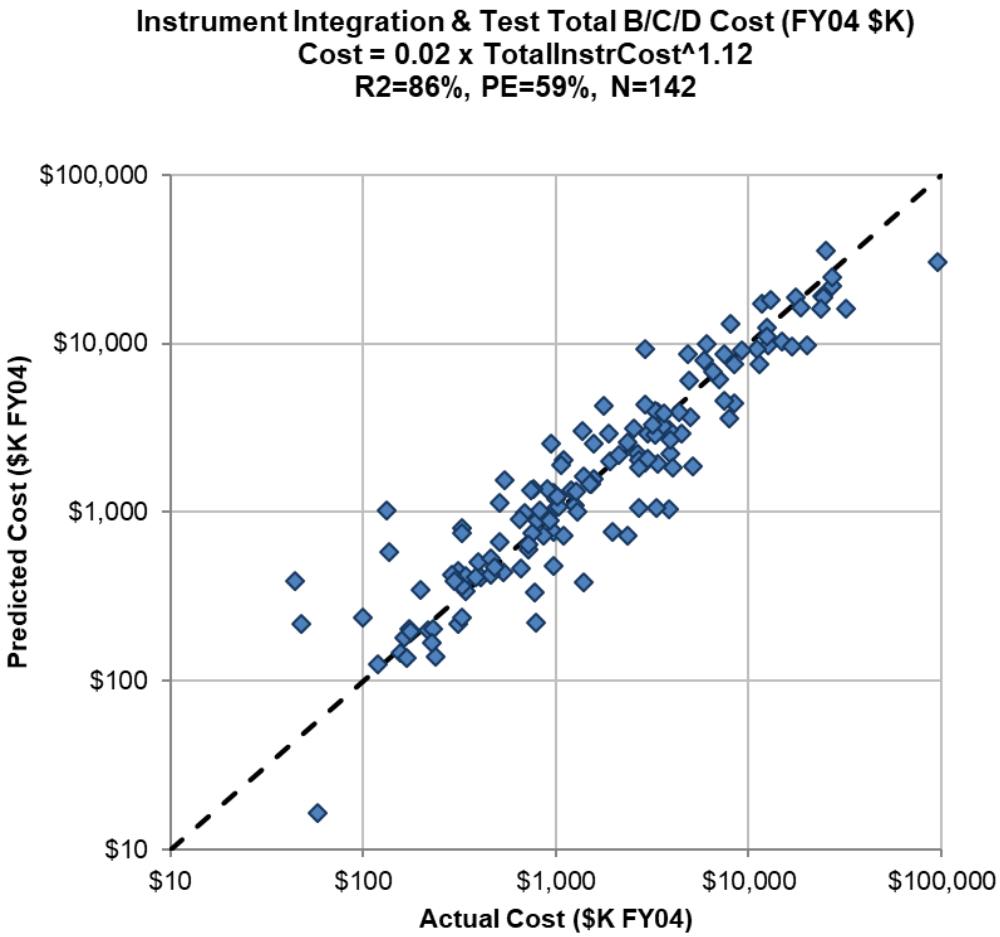
Product Assurance CER



Instruments used in the development of the Instrument Product Assurance CER:

- ACIS
- AIA
- AMSU-A
- Cassini Radar
- CIPS
- CRISM
- EFI_Polar
- ENose
- FGM-ASC
- GCMS
- GIM
- Grace Instrument
- GRS_MO
- GSWC
- HiRISE
- HRI_Deep_Impact
- IDD
- IRAC
- ITS
- JMR
- LGRS
- M3
- MAG NEAR
- MARDI-MSL
- MASCS
- MDIS
- MET-MPL
- MIMI
- MIR
- MLS
- MOLA-MO
- MWR
- NICMOS
- OLI
- PEPSSI
- RA-Phoenix
- RPWS
- SeaWinds
- SSI-MPL
- SWAP
- ACRIM III
- AIRS
- ASI_MET
- CFI
- CIRS
- CRISP
- EFPE
- EPPS
- FUSE
- GFO Radiometer
- GLAS
- GRAND
- GRS_Odyssey
- GUVI
- HISCALE
- HYDRA
- IMP
- IRS
- JADE
- JunoCam
- LOLA
- MAG FAST
- MAHLI
- MARIE
- MastCam
- MECA-Phoenix
- MFEX
- MiniTES
- MISR
- MOC-MO
- MRI
- NavCam
- NIS
- ONC
- PMIRR
- RAT
- SAM
- SMAP
- SSI-Phoenix
- TEAMS
- ACS
- AMR
- CAPS
- CheMin
- CPR
- DLRE
- EMLS
- ESA_FAST
- GALEX
- GFO-Alt
- GMI
- GRNS
- GSPEC-OCO
- HIRDLS
- HRC
- IBEX
- INMS
- ISS
- JEDI
- Kepler
- LORRI
- MAG MESSENGER
- MARDI-MPL
- MARSIS
- MCS
- MER Camera
- MFI
- MIPS
- MLA
- MODIS
- MSI
- NGIMS_MAVEN
- NSCAT
- PEPE
- RAD
- RBSPICE
- SA-SPaH
- SOFIE
- STIS
- TEGA-MPL

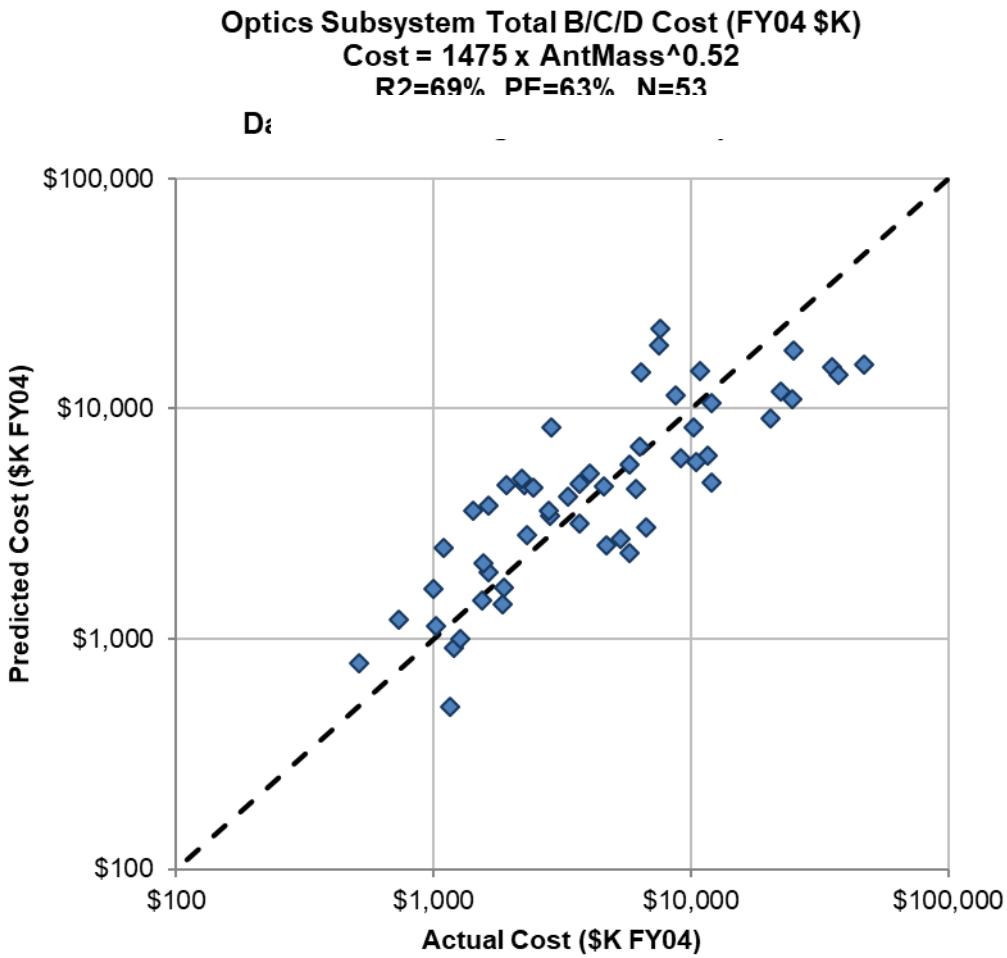
Integration & Test CER



Instruments used in the development of the Instrument Integration & Test CER:

- ACIS
- AIA
- AMSU-A
- Cassini Radar
- CIPS
- CRISM
- DLRE
- EMLS
- ESA_FAST
- GALEX
- GFO-Alt
- GMI
- GRNS
- GSPEC-OCO
- HIRDLS
- HRC
- IBEX
- INMS
- ISS
- JEDI
- Kepler
- LORRI
- MAG MESSENGER
- MARDI-MPL
- MARSIS
- MCS
- MECA-TECP
- MFEX
- MIMI
- MIR
- MLA
- MODIS
- MWR
- NICMOS
- ONC
- PMIRR
- RA-Phoenix
- RPWS
- SeaWinds
- SSI-MPL
- ACRIM III
- AIRS
- ASI_MET
- CFI
- CIRS
- CRISP
- EFI_Polar
- ENose
- FGM-ASC
- GCMS
- GIM
- Grace Instrument
- GRS_MO
- GSWC
- HiRISE
- HRI_Deep_Impact
- IDD
- IRAC
- ITS
- JMR
- LGRS
- M3
- MAHLI
- MARDI-MSL
- MASCS
- MDIS
- MER Camera
- MFI
- MiniTES
- MIRO
- MLS
- MOLA-MO
- NavCam
- NSCAT
- PEPE
- RAD
- RAT
- SAM
- SMAP
- SSI-Phoenix
- ACS
- AMR
- CAPS
- CheMin
- CPR
- CTX
- EFPE
- EPPS
- FUSE
- GFO Radiometer
- GLAS
- GRAND
- GRS_Odyssey
- GUVI
- HISCALE
- HYDRA
- IMP
- IRS
- JADE
- JunoCam
- LOLA
- MAG FAST
- MARCI
- MARIE
- MastCam
- MECA-Phoenix
- MET-MPL
- MICAS
- MIPS
- MISR
- MOC-MO
- MRI
- NGIMS_MAVEN
- OLI
- PEPSSI
- RA-MPL
- RBSPICE
- SA-SPaH
- SOFIE
- STIS

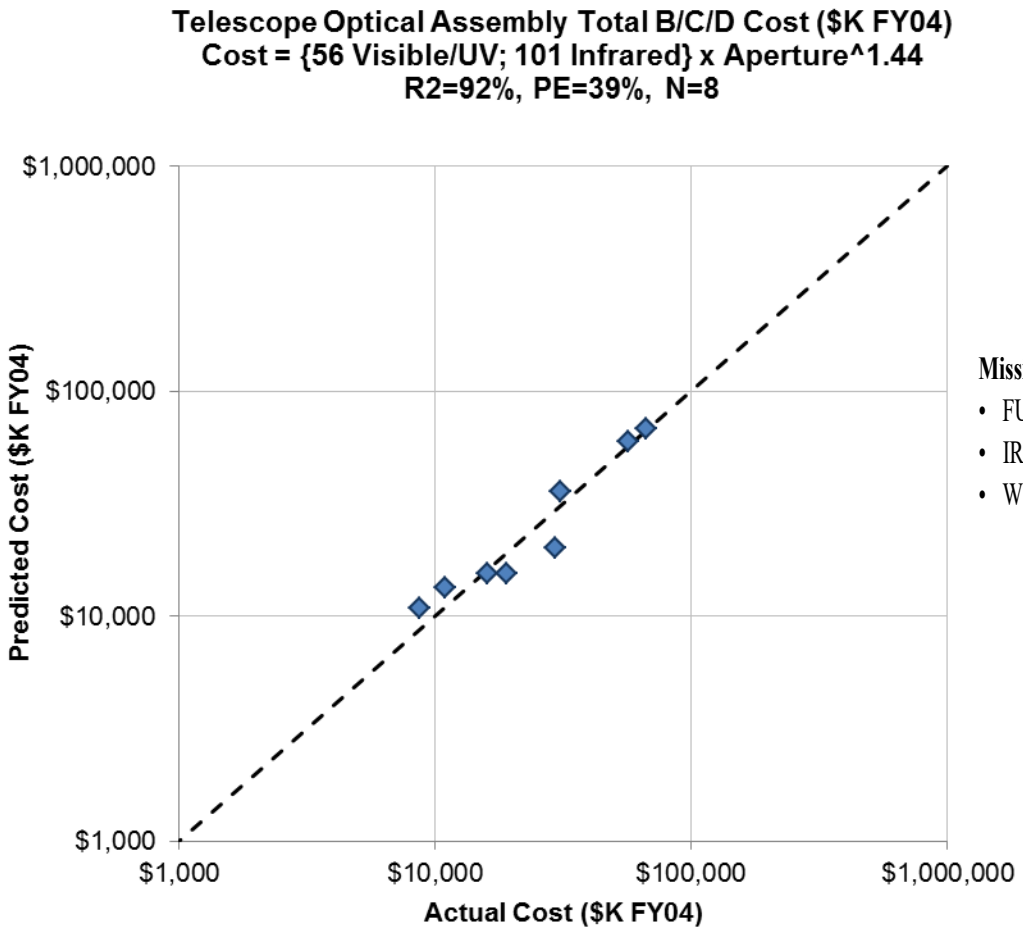
Optics Subsystem CER



Instruments used in the development of the Optics Subsystem CER:

- ACRIM III
- AIRS
- CRISM
- DLRE
- HRI_Deep_Impact
- IRS
- JunoCam
- M3
- MCS
- MIPS
- MOC-MO
- MRI
- NIS
- ONC
- SOFIE
- TES_MO
- UVIS
- WFPC1
- ACS
- CIPS
- CRISP
- GLAS
- HYDRA
- ISS
- LOLA
- MARCI
- MDIS
- MISR
- MODIS
- NavCam
- NuStar
- PMIRR
- STIS
- THEMIS
- UVS - Juno
- WFPC2
- AIA
- CIRS
- CTX
- GSPEC-OCO
- IRAC
- ITS
- LORRI
- MASCS
- MICAS
- MLA
- MOLA-MO
- NICMOS
- OLI
- RHESSI
- TES_Aura
- TOMS
- VIMS

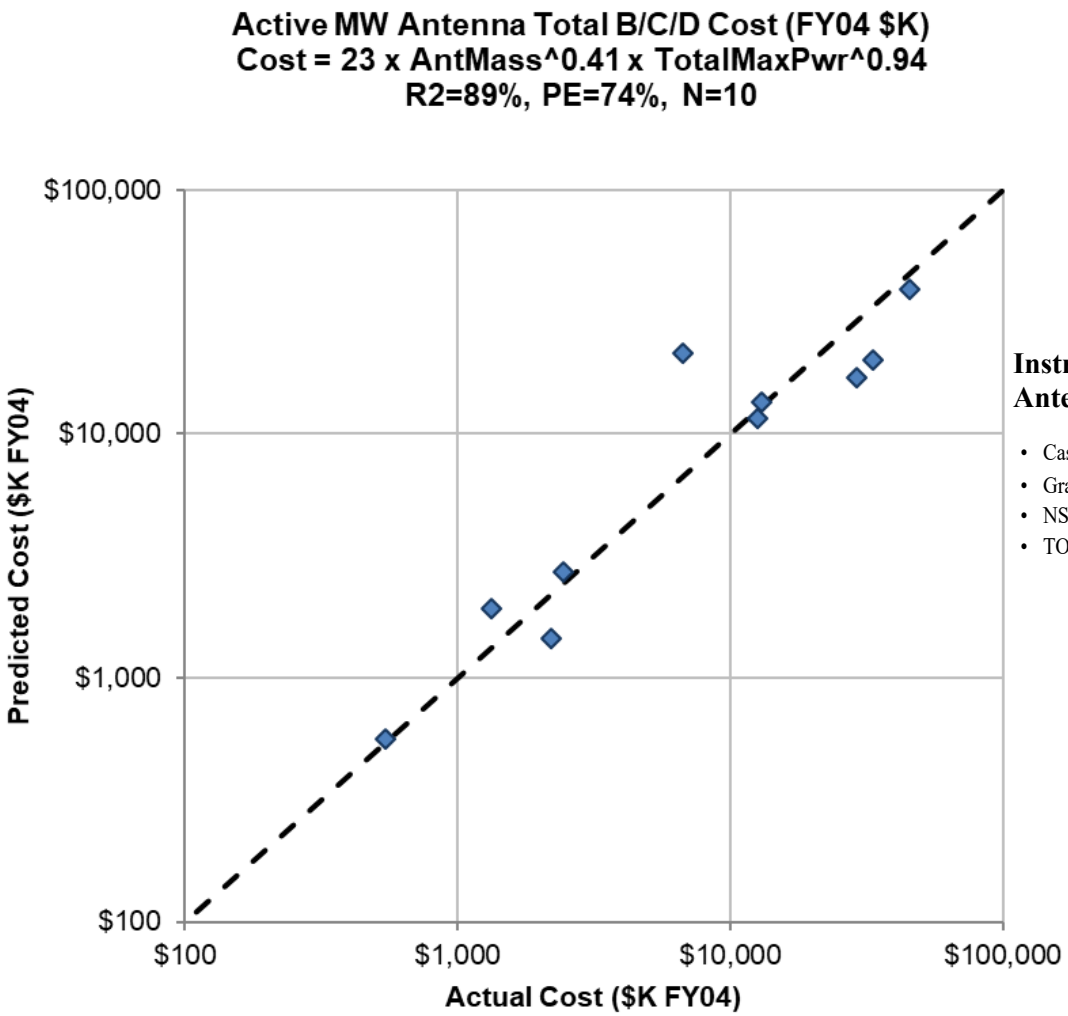
Telescope Optical Assembly Subsystem CER



Missions used in the development of the Telescope Optical Assembly CER:

- FUSE
- IRAS
- WIRE
- GALEX
- Kepler
- WISE
- HiRISE
- Spitzer

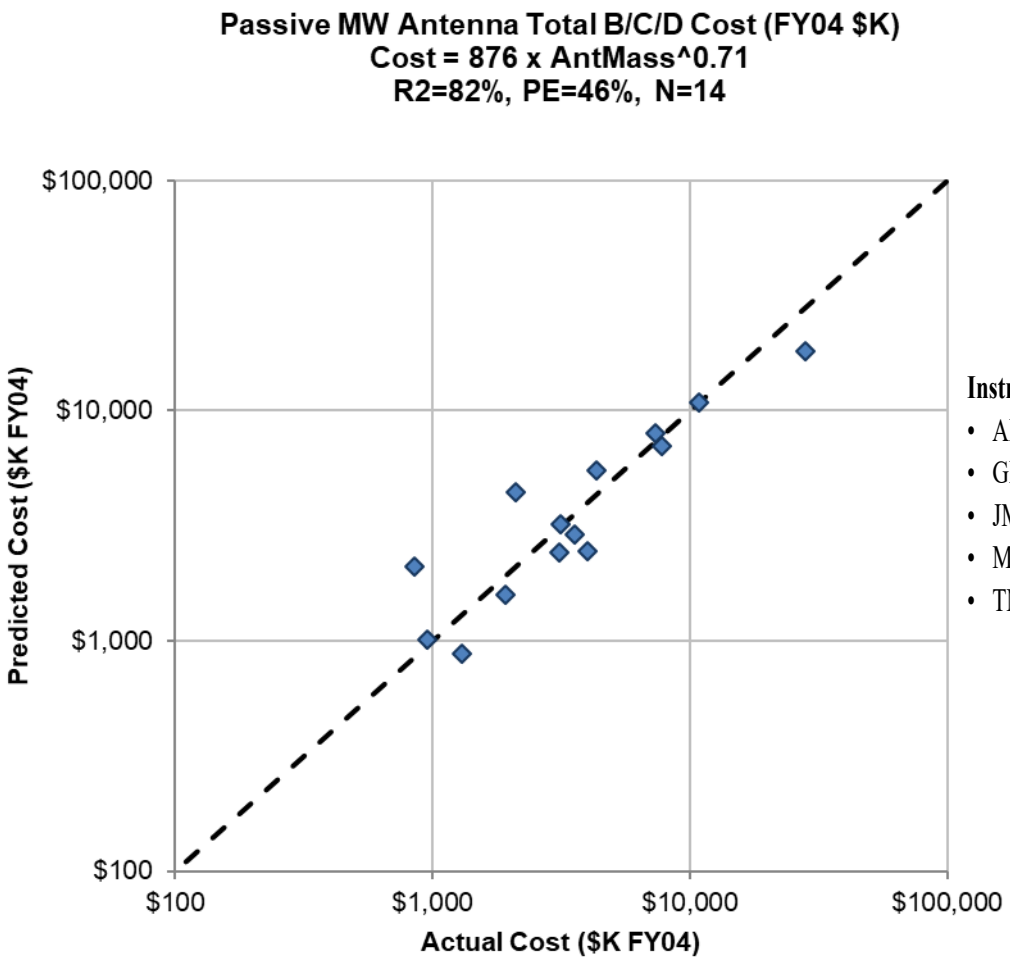
Active Microwave Antenna Subsystem CER



Instruments used in the development of the Active MW Antenna Subsystem CER:

- Cassini Radar
- Grace Instrument
- NSCAT
- TOPEX ALT
- CPR
- LGRS
- SeaWinds
- GFO-Alt
- MARSIS
- SMAP

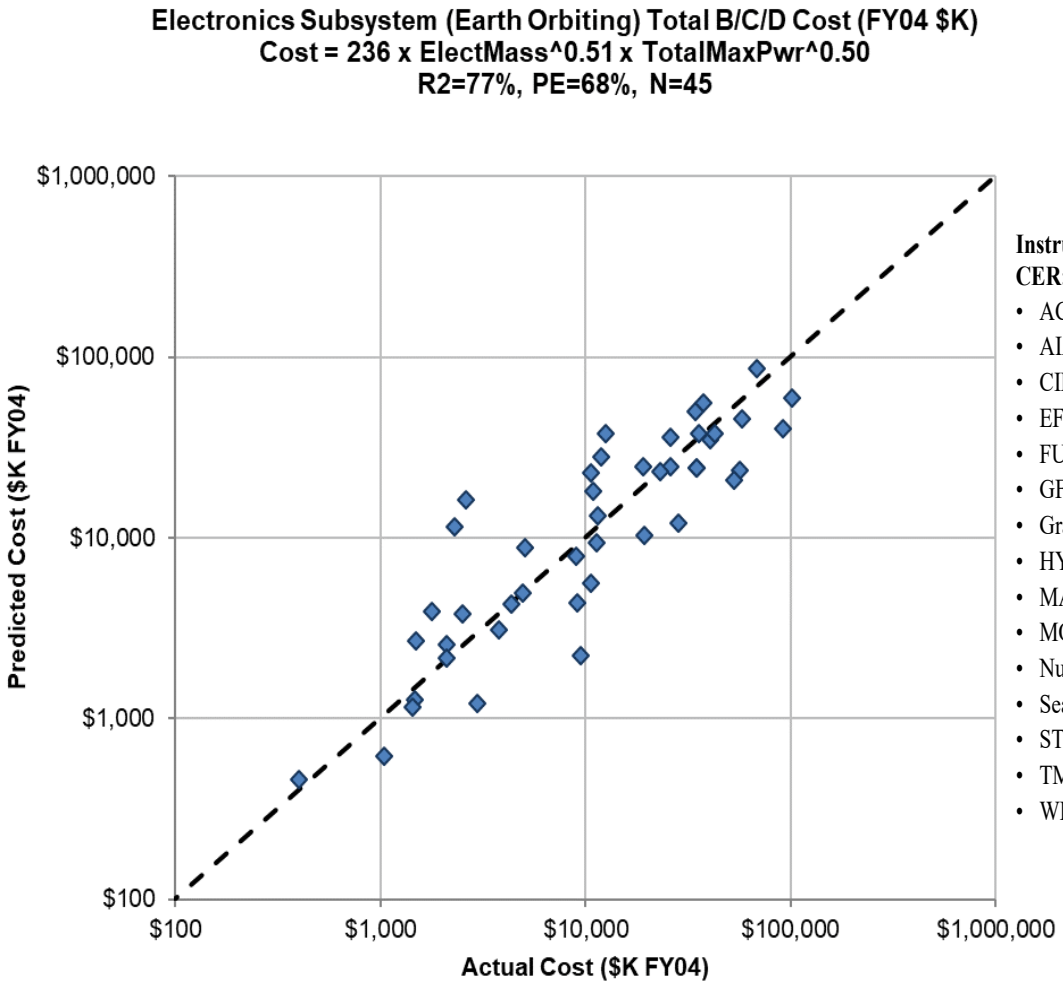
Passive Microwave Antenna Subsystem CER



Instruments used in the development of the Passive MW Antenna CER:

- AMR
- GFO Radiometer
- JMR
- MWR
- TMR
- EMLS
- GMI
- MIRO
- RPWS
- WAVES_Juno
- FGM-ASC
- JADE
- MLS
- SWICS_Ulysses

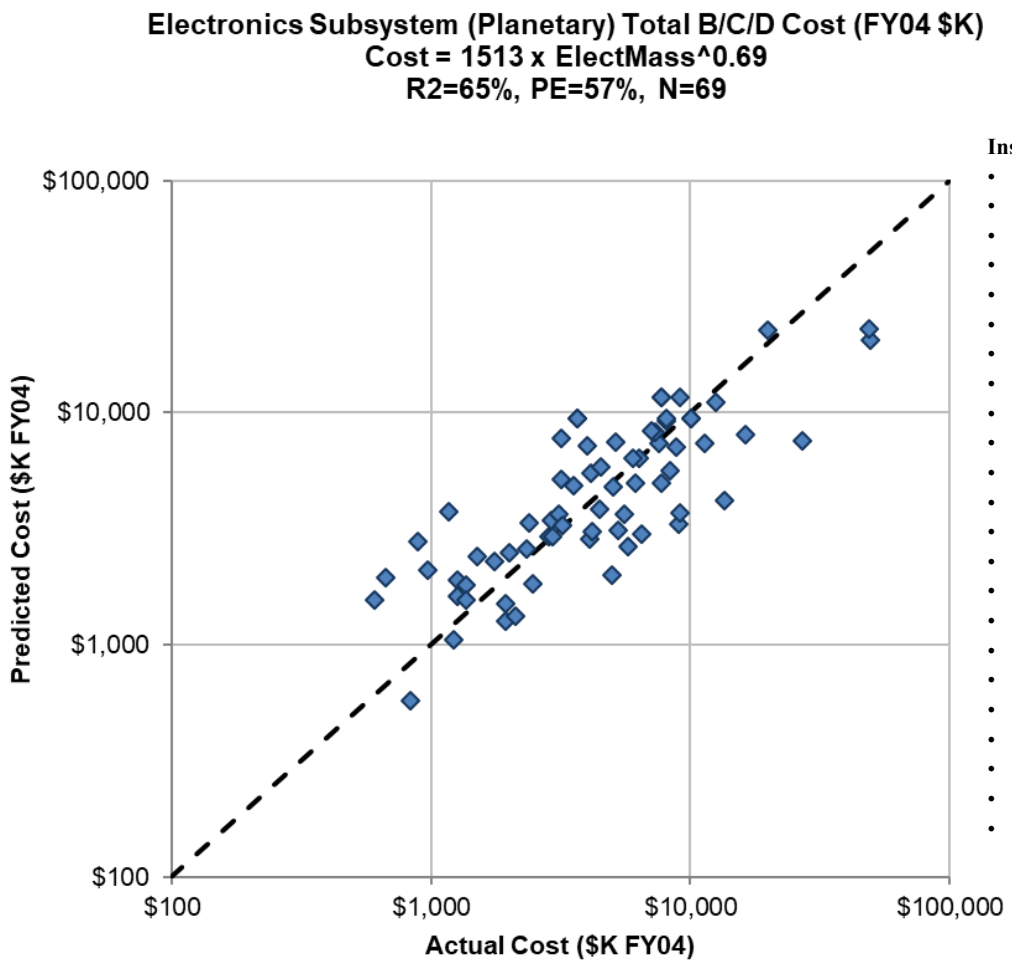
Electronics Earth Orbiting Subsystem CER



Instruments used in the development of the Electronics Subsystem (Earth Orbiting) CER:

- ACIS
- ACRIM III
- ACS
- AIA
- AIRS
- AMR
- CIPS
- CPR
- EFI_Polar
- EFPE
- EMLS
- ESA_FAST
- FUSE
- GALEX
- GFO Radiometer
- GFO-Alt
- GLAS
- GMI
- Grace Instrument
- GSPEC-OCO
- GUVI
- HYDRA
- IBEX
- JMR
- MAG FAST
- MISR
- MLS
- MODIS
- NICMOS
- NSCAT
- NuStar
- OLI
- RHESSI
- SeaWinds
- SMAP
- SOFIE
- STIS
- TEAMS
- TES_Aura
- TMR
- TOMS
- TOPEX ALT
- WFPC1
- WFPC2
- WISE

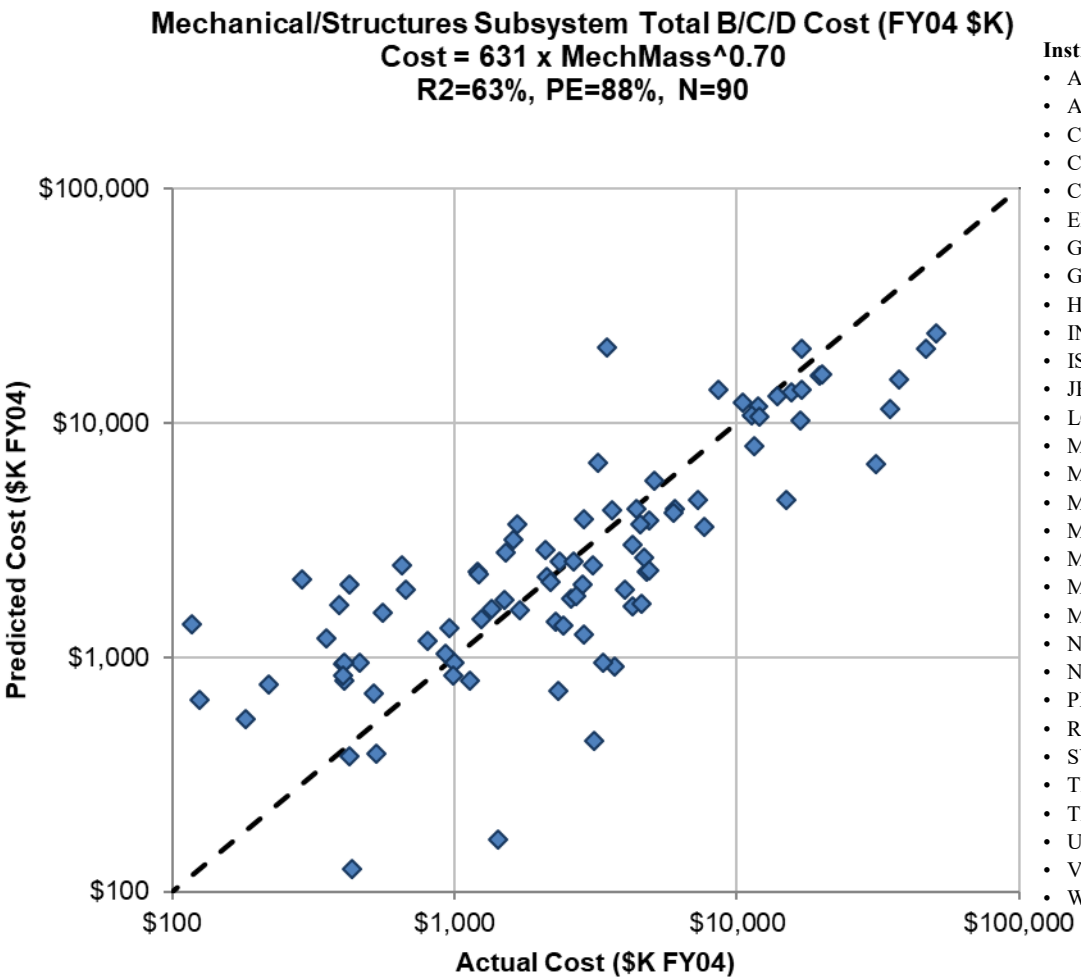
Electronics Planetary Subsystem CER



Instruments used in the development of the Electronics Subsystem (Planetary) CER:

- CAPS
- CIRS
- CTX
- FGM-ASC
- GRS_MO
- HISCALE
- IRAC
- ITS
- JunoCam
- LOLA
- MAG MESSENGER
- MARIE
- MCS
- MICAS
- MLA
- MRI
- NavCam
- PEPE
- Spitzer-MIPS
- SWAP
- THEMIS
- VIMS
- WMAP
- Cassini Radar
- CRISM
- DLRE
- GRAND
- GRS_Odyssey
- HRI_Deep_Impact
- IRS
- JADE
- Kepler
- LORRI
- MAG NEAR
- MARSIS
- MDIS
- MIPS
- MOC-MO
- MSI
- NIS
- PMIRR
- Spitzer-IRAC
- SWICS_Ulysses
- UVIS
- WAVES_Juno
- XRS-GRS
- CFI
- CRISP
- EPPS
- GRNS
- HiRISE
- INMS
- ISS
- JEDI
- LGRS
- M3
- MARCI
- MASCS
- MFI
- MIRO
- MOLA-MO
- MWR
- ONC
- RPWS
- Spitzer-IRS
- TES_MO
- UVS - Juno
- WAVES_STEREO
- XRS-MESSENGER

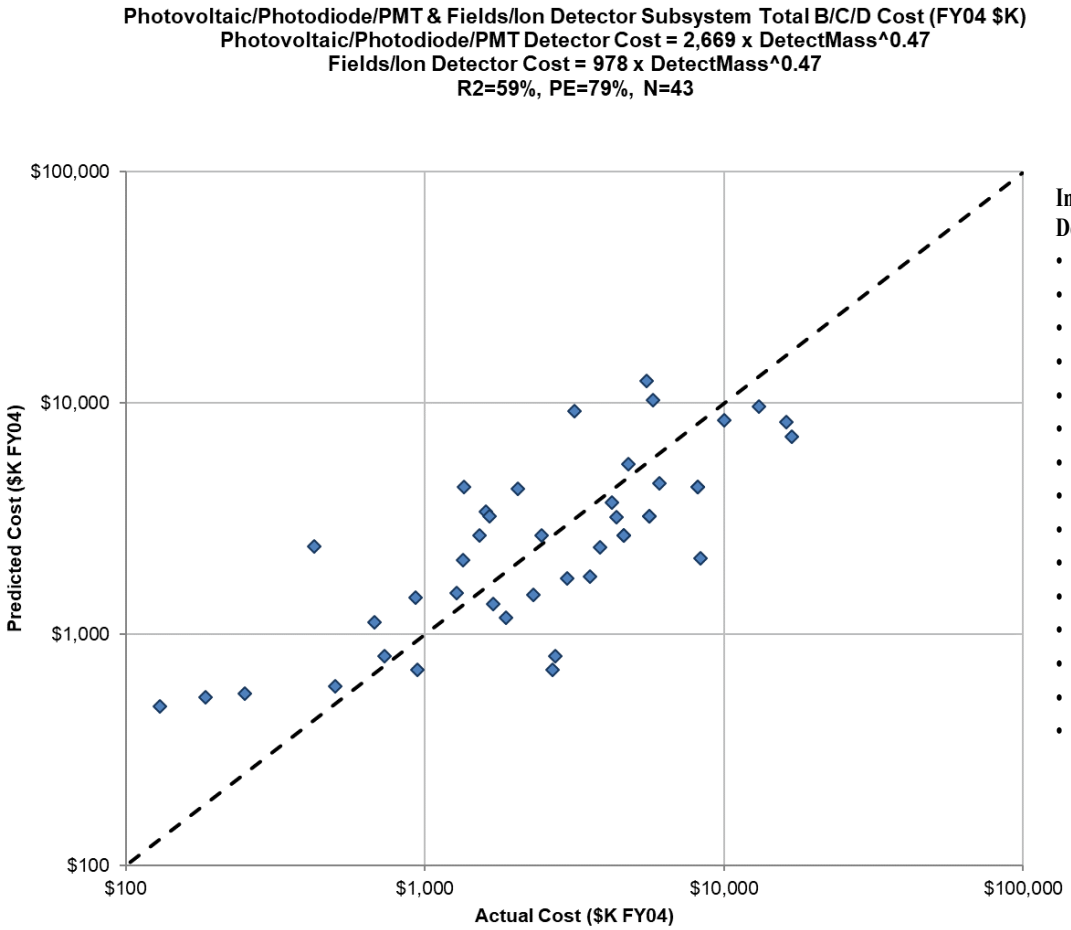
Mechanical/Structures Subsystem CER



Instruments used in the development of the Mechanical/Structures Subsystem CER:

- ACIS
- ACRIM III
- ACS
- AIA
- AIRS
- AMR
- CAPS
- CFI
- CIRS
- CPR
- CRISM
- CRISP
- CTX
- DLRE
- EMLS
- EPPS
- GLAS
- GMI
- Grace Instrument
- GRAND
- GRNS
- GRS_MO
- GRS_Odyssey
- GSPEC-OCO
- HISCALE
- HRI_Deep_Impact
- HYDRA
- INMS
- IRAC
- IRS
- ISS
- ITS
- JADE
- JEDI
- JMR
- JunoCam
- LGRS
- LOLA
- LORRI
- M3
- MAG MESSENGER
- MARCI
- MARIE
- MARSIS
- MASCS
- MCS
- MDIS
- MICAS
- MIPS
- MIR
- MIRO
- MISR
- MLA
- MLS
- MOC-MO
- MODIS
- MOLA-MO
- MRI
- MWR
- NavCam
- NICMOS
- NIR
- NIS
- NSP
- NuStar
- OLI
- PEPE
- PMIRR
- RHESSI
- RPWS
- SMAP
- STIS
- SWAP
- SWICS_Ulysses
- TES_Aura
- TES_MO
- THEMIS
- TLP
- TMR
- TOMS
- UVIS
- UVS - Juno
- VIMS
- VIS_LCROSS
- VSP
- WAVES_Juno
- WFPC1
- WFPC2
- XRS-GRS
- XRS-MESSENGER

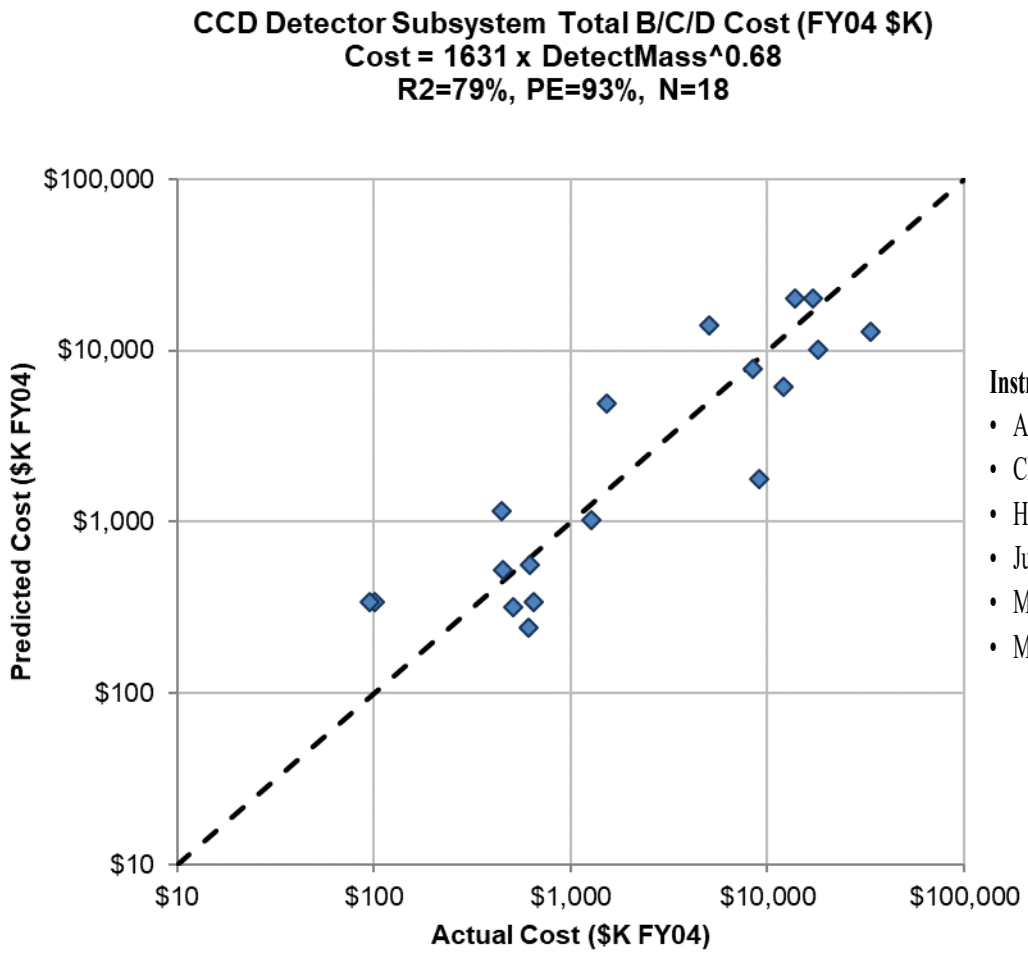
Photovoltaic/Photodiode/Photo Multiplier Tube (PMT) Detectors & Fields/Ion Detector Subsystems CER



Instruments used in the development of the Photovoltaic/Photodiode/PMT & Fields/Ion Detector Subsystem CER:

- CIRS
- EFPE
- GLAS
- GRS_MO
- HISCALE
- IRAC
- M3
- MASCS
- MLA
- PEPE
- SOFIE
- Spitzer-IRS
- TEAMS
- TOMS
- WISE
- CRISM
- ESA_FAST
- GRAND
- GRS_Odyssey
- HYDRA
- IRS
- MAG FAST
- MFI
- MOLA-MO
- PMIRR
- Spitzer-MIPS
- SWAP
- TES_Aura
- UVIS
- EFI_Polar
- GALEX
- GRNS
- GSPEC-OCO
- INMS
- LOLA
- MAG NEAR
- MIPS
- NuStar
- RPWS
- Spitzer-IRAC
- SWICS_Ulysses
- TES_MO
- WAVES_STEREO

CCD Detectors Subsystem CER

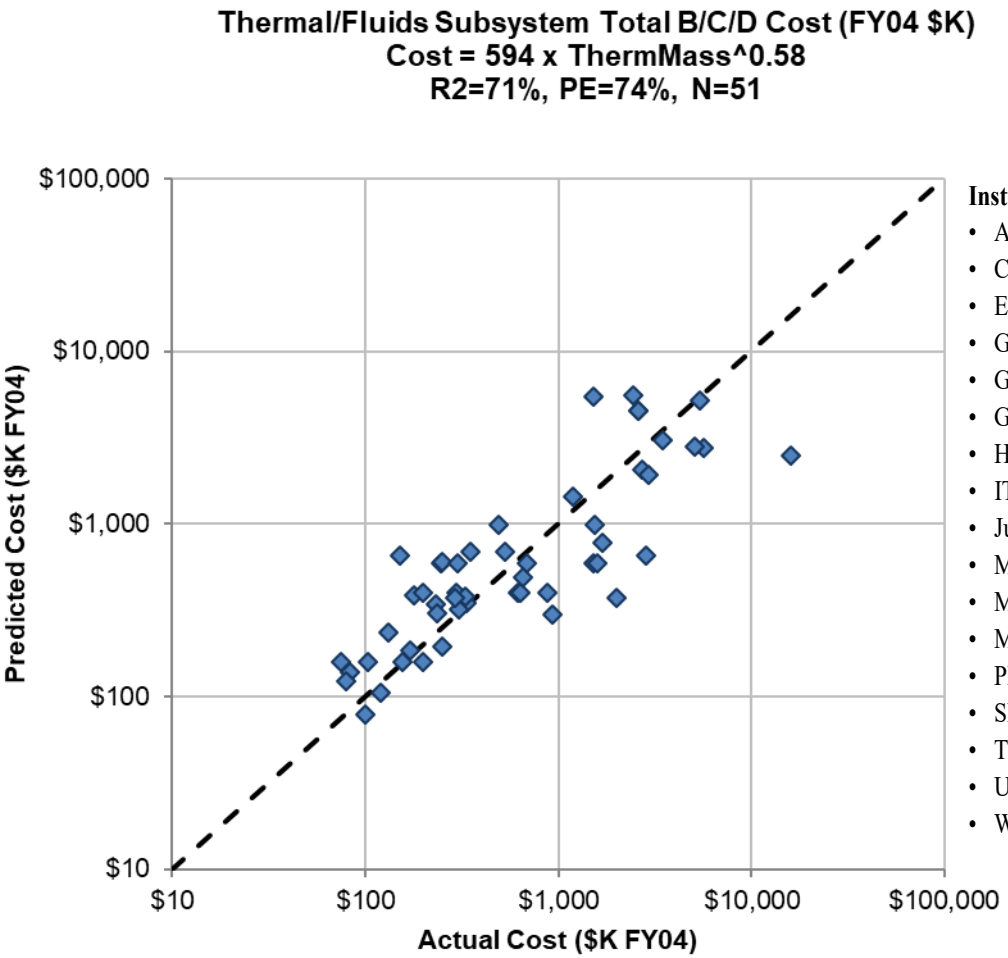


Instruments used in the development of the CCD Detector Subsystem CER:

- ACIS
- CFI
- HiRISE
- JunoCam
- MARCI
- MRI
- ACS
- CIPS
- ISS
- Kepler
- MICAS
- WFPC1
- AIA
- CTX
- ITS
- LORRI
- MOC-MO
- WFPC2

Thermal/Fluid Subsystem CER

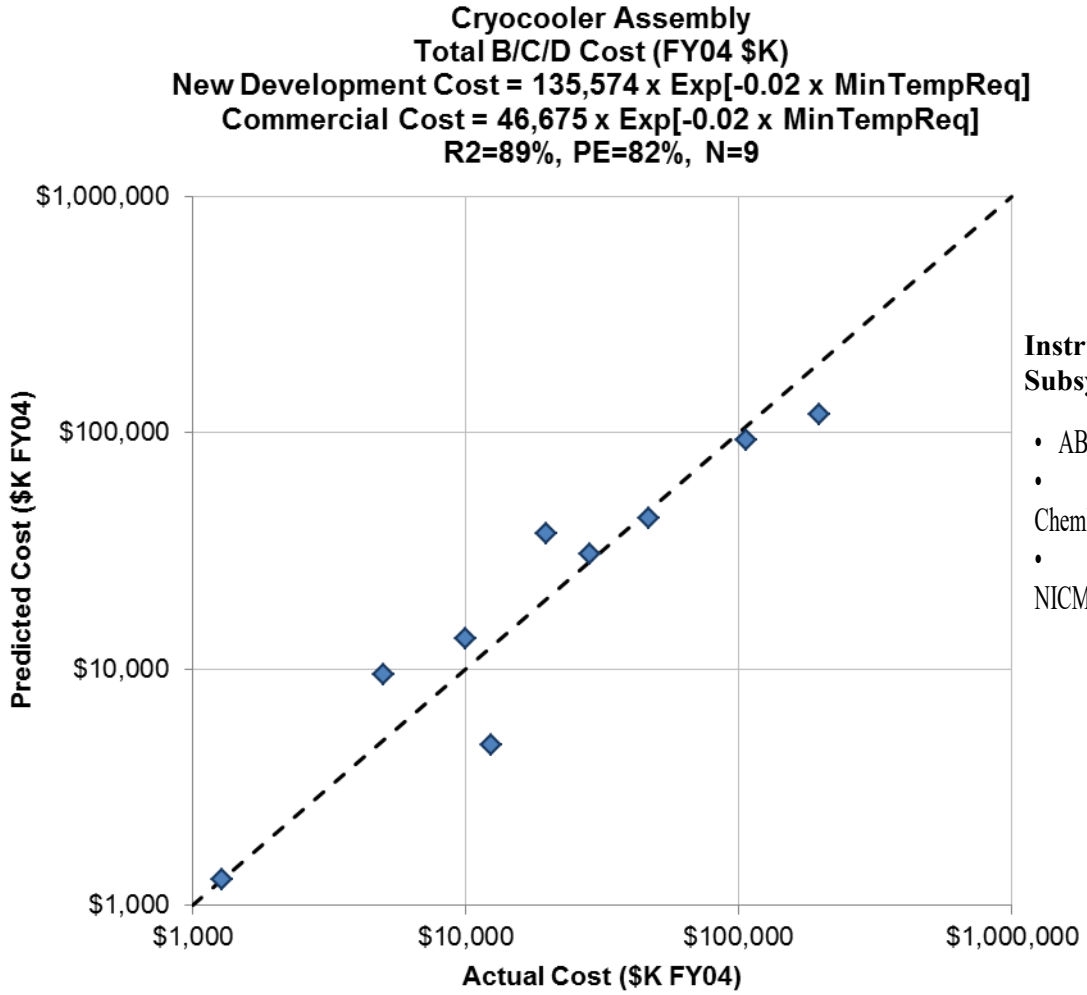
(non-Cryocooler/cryostat/dewar)



Instruments used in the development of the Thermal/Fluids Subsystem CER:

- ACIS
- ACS
- AMR
- CIRS
- CTX
- DLRE
- EMLS
- EPPS
- FGM-ASC
- GLAS
- GMI
- Grace Instrument
- GRAND
- GRNS
- GRS_MO
- GRS_Odyssey
- GSPEC-OCO
- HISCALE
- HRI_Deep_Impact
- INMS
- ISS
- ITS
- JADE
- JEDI
- JunoCam
- LOLA
- M3
- MARCI
- MDIS
- MICAS
- MLA
- MODIS
- MOLA-MO
- MRI
- NavCam
- OLI
- PEPE
- PMIRR
- RPWS
- SMAP
- SWICS_Ulysses
- TES_MO
- THEMIS
- TOMS
- UVIS
- UVS - Juno
- VIMS
- WAVES_Juno
- WFPC1
- WFPC2
- XRS-MESSENGER

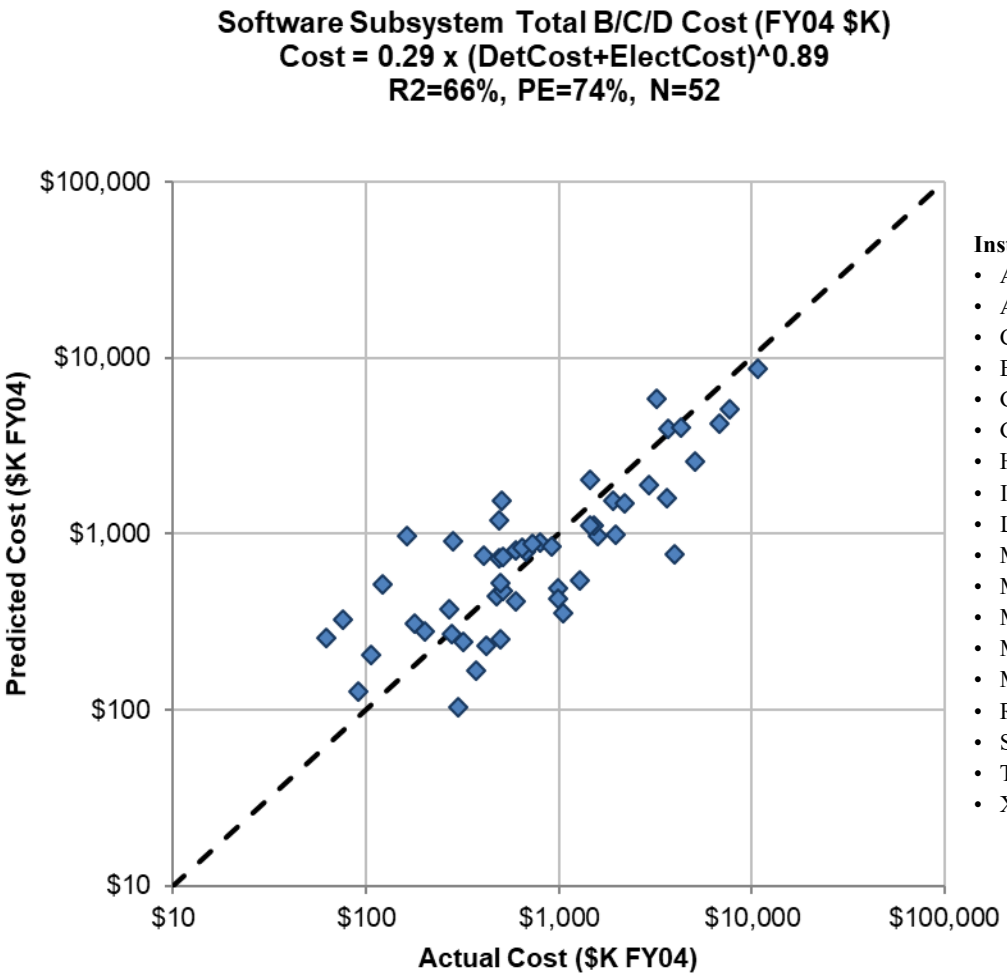
Cryocooler Assembly Subsystem CER



Instruments used in the development of the Thermal/Fluids Subsystem CER:

- ABI_Cryocooler
- AIRS_Cryocooler
- AMS-02_Cryocooler
- ChemMin_Cryocooler
- MIRI_Cryocooler_Full_Sys
- MIRI_Cryocooler_PT_Assembly
- NICMOS_Cryocooler
- OCO-2_Cryocooler
- TES_Cryocooler

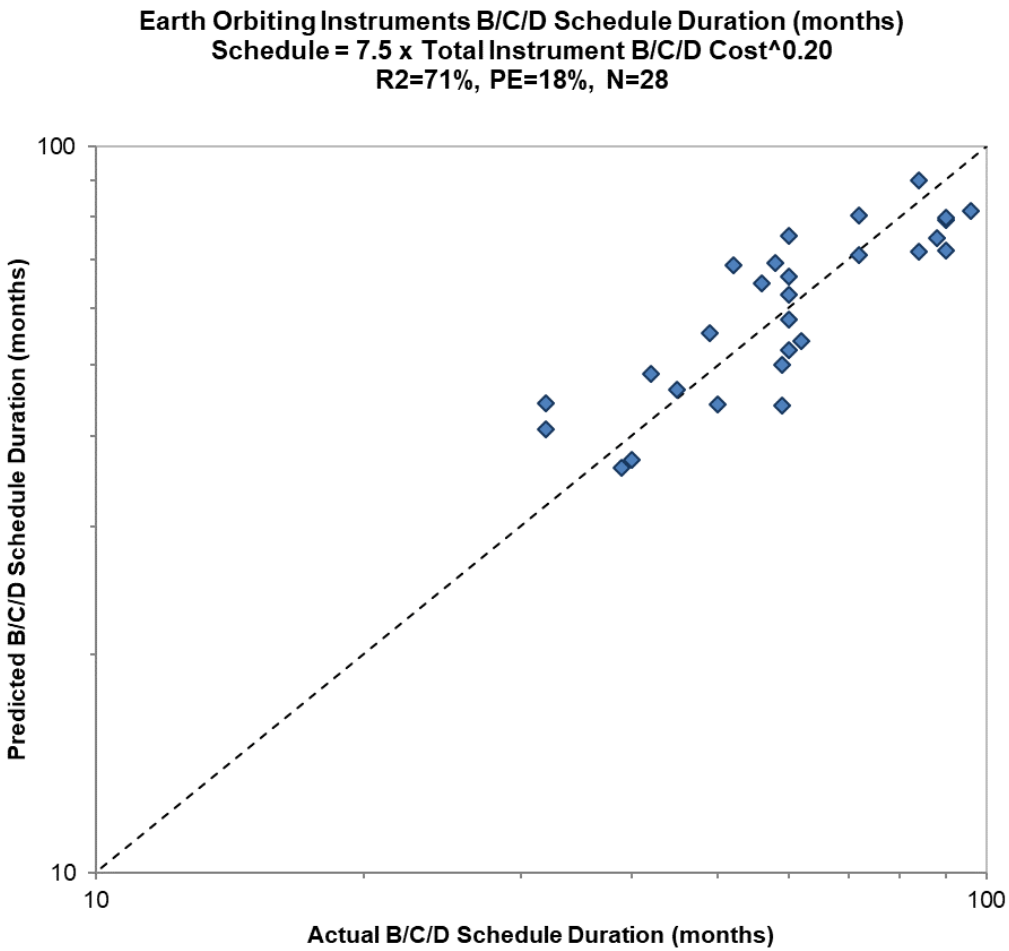
Software Subsystem CER



Instruments used in the development of the Software Subsystem CER:

- ACIS
- AIRS
- CRISP
- ESA_FAST
- GRNS
- GUVI
- HYDRA
- ISS
- LOLA
- MAG MESSENGER
- MARIE
- MDIS
- MIPS
- MRI
- RBSPICE
- STIS
- TOMS
- XRS-MESSENGER
- ACS
- CAPS
- CTX
- GMI
- GRS_MO
- HIRDLS
- INMS
- ITS
- LORRI
- MAG NEAR
- MASCS
- MICAS
- MOC-MO
- NIS
- RPWS
- SWAP
- VIMS
- AIA
- CRISM
- EFI_Polar
- GRAND
- GRS_Odyssey
- HRI_Deep_Impact
- IRS
- JunoCam
- M3
- MARCI
- MCS
- MIMI
- MOLA-MO
- PEPE
- SOFIE
- TES_Aura
- XRS-GRS

Earth Orbiting SER



Instruments used in the development of the Earth Orbiting Instrument SER:

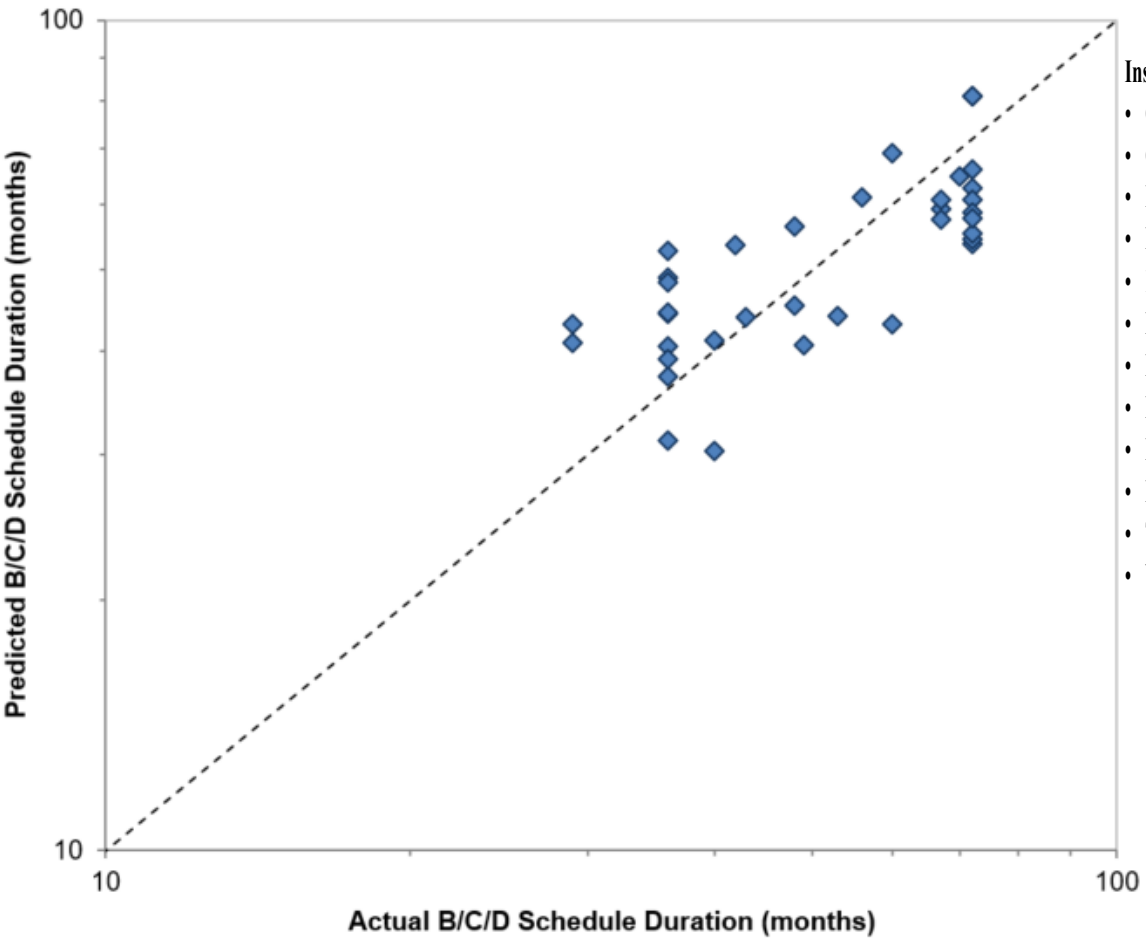
- ACIS
- AIRS
- BAT
- CINDI
- GFO-Alt
- GUVI
- HYDRA
- MISR
- SABER
- TIDI
- ACRIM III
- AMSU-A
- CAMMICE
- EMLS
- GMI
- HIRDLS
- LEICA
- MLS
- SeaWinds
- ACS
- APS-Glory
- CEPPAD
- GALEX
- GSPEC-OCO
- HRC
- MAST_&_PET
- NICMOS
- TES_Aura

Planetary Remote Sensing SER

Planetary Instruments B/C/D Schedule Duration (months)

$$\text{Schedule} = \begin{cases} 1.6 \times TIC^{0.34} & \text{if Optical/MW} \\ 2.1 \times TIC^{0.34} & \text{if Fields/Particles} \end{cases}$$

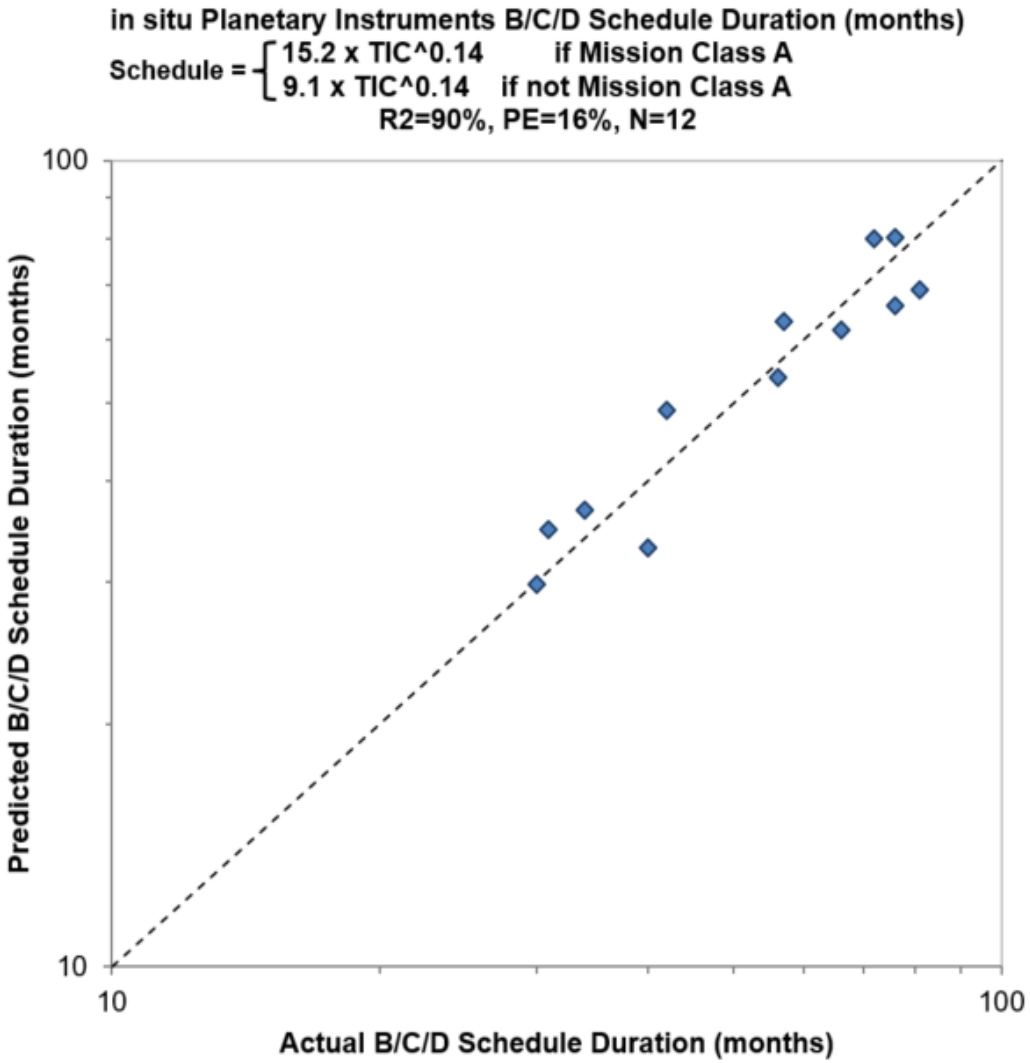
R2=55%, PE=23%, N=36



Instruments used in the development of the Planetary, Remote Sensing Instrument SER:

- CAPS
- CRISP
- EPPS
- HISCALE
- ISS
- MASCS
- MICAS
- MLA
- MRI
- RPWS
- THEMIS
- UVS - Juno
- Cassini Radar
- CTX
- GRNS
- IRAC
- ITS
- MCS
- MIMI
- MOC-MO
- MWR
- SWAP
- URAP
- VIMS
- CRISM
- DLRE
- GRS_MO
- IRS
- M3
- MDIS
- MIPS
- MOLA-MO
- PMIRR
- TES_MO
- UVIS
- XRS-MESSENGER

Planetary In-Situ SER



Instruments used in the development of the Planetary, *in situ* Instrument SER:

- CheMin
- MARDI-MSL
- RAD
- SA-SPaH
- IDD
- MastCam
- RA-Phoenix
- SSI-Phoenix
- MAHLI
- MER Camera
- SAM
- TLS

Rules-of-Thumb for Cost & Schedule Phase Breakdown

Instrument Type	Mission Class	Cost Phase B	Cost Phase C	Cost Phase D	Schedule Phase B	Schedule Phase C	Schedule Phase D
Optical	Earth Orbiting	5%	82%	13%	14%	64%	22%
Optical	Planetary Flagship	6%	76%	18%	15%	60%	25%
Optical	Planetary Nominal	4%	76%	20%	13%	55%	32%
Active	Earth Orbiting	8%	72%	20%	16%	58%	26%
Active	Planetary Flagship	3%	73%	24%	11%	59%	30%
Active	Planetary Nominal	10%	72%	18%	19%	53%	28%
Passive	Earth Orbiting	7%	74%	19%	18%	49%	33%
Passive	Planetary Flagship	5%	75%	20%	15%	60%	25%
Passive	Planetary Nominal	7%	74%	19%	12%	62%	26%
Particles	Earth Orbiting	4%	82%	14%	16%	60%	24%
Particles	Planetary Flagship	3%	83%	14%	13%	66%	21%
Particles	Planetary Nominal	5%	75%	20%	17%	55%	28%
Fields	Earth Orbiting	4%	82%	14%	16%	60%	24%
Fields	Planetary Flagship	3%	83%	14%	13%	66%	21%
Fields	Planetary Nominal	5%	75%	20%	17%	55%	28%
Arm/Mast	Earth Orbiting	N/A	N/A	N/A	N/A	N/A	N/A
Arm/Mast	Planetary Flagship	8%	75%	17%	19%	52%	29%
Arm/Mast	Planetary Nominal	8%	69%	23%	18%	51%	31%
Body	Earth Orbiting	N/A	N/A	N/A	N/A	N/A	N/A
Body	Planetary Flagship	6%	72%	22%	13%	63%	24%
Body	Planetary Nominal	7%	71%	22%	14%	62%	24%
Probe	Earth Orbiting	N/A	N/A	N/A	N/A	N/A	N/A
Probe	Planetary Flagship	5%	82%	13%	18%	54%	28%
Probe	Planetary Nominal	7%	80%	13%	19%	57%	24%

Instrument Data: Implications for Modeling

- NICM is built off of data of completed instruments.
  - Masses, costs and other parameters in NICM are actuals.
  - Therefore, for cost estimates for your instrument, think in terms of actuals.
  - For example, if the tool ask for your mass as an input:
    - Provide what you think your instrument's actual mass will be, aka, your current best estimate + *contingency*.
    - The cost estimate NICM provides you will be the estimated cost you will have occurred by the time your instrument is complete, aka, it will *include* your *reserve*.

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  - Instrument Data
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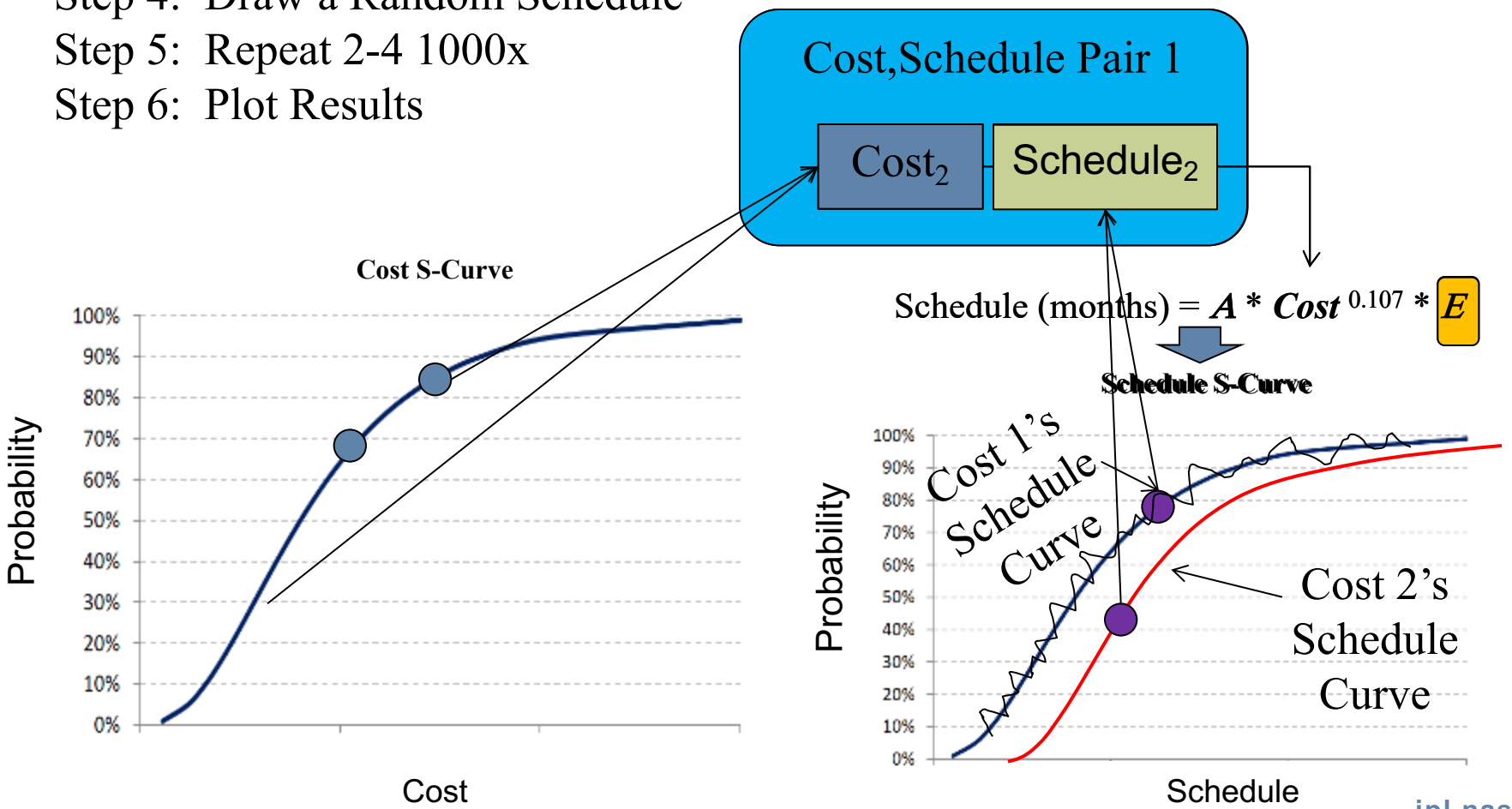
  - Models
  - **JCL**
  - Tool Demonstration
- Deeper Dive: NICM VIII Improvements
  - Class-based CERs vs. NICM-E
  - Telescope Cost as a Subsystem & “Telescope Instruments”
  - Improved Cryocooler Estimations

JCL Simulation

Goal: Determine the Joint Probability of building instrument below Cost Cap and Schedule Cap

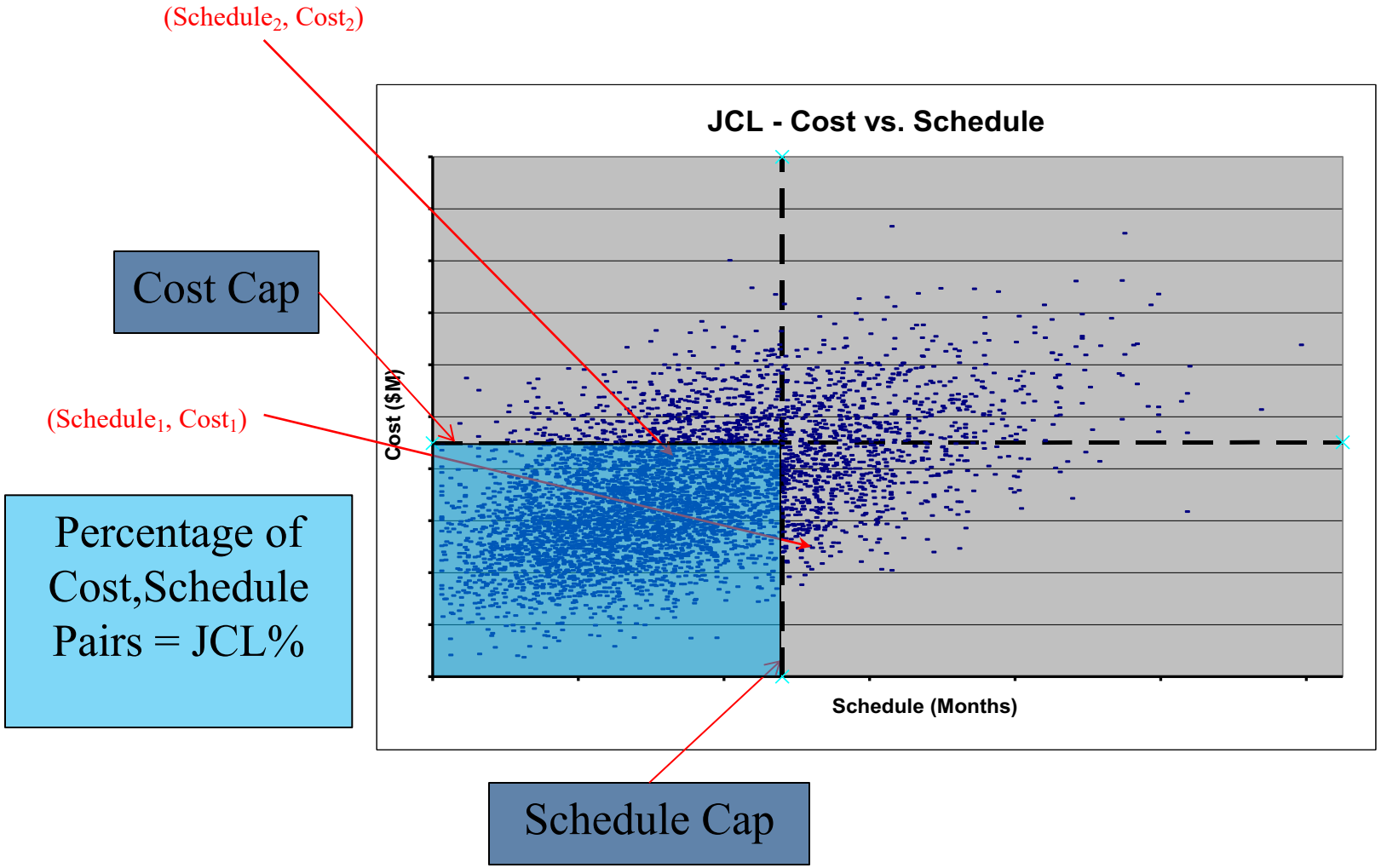
JCL Simulation

Step 1: Run the Cost Estimating Relationship, which yields a Cost S-Curve
Step 2: Draw a Random Cost
Step 3: Plug the Random Cost into the Schedule Estimating Relationship
Step 4: Draw a Random Schedule
Step 5: Repeat 2-4 1000x
Step 6: Plot Results



JCL Simulation

Joint Cost & Schedule Plot



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NICM VIII Tool Suite Demonstration

- NICM VIII Tool Suite Contains 3 main tools
  - Probabilistic Cost Estimation
    - **System Tool**
    - **Subsystem Tool**
  - Cost Analogy Tool
    - **Search Engine**

- Software Requirements for all tools
  - NICM VIII is an Excel Tool
  - Utilize VBA Macros
  - Coded for Windows PC on Windows 10
    - Recommend Mac Users run Parallels on Mac
  - Coded in Excel 2016, some preliminary testing in Excel 2013.
    - NICM no longer supporting Excel 2010 or earlier. Some features will NOT work in Excel 2010.
  - Hint: For faster performance, close all other Excel workbooks

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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

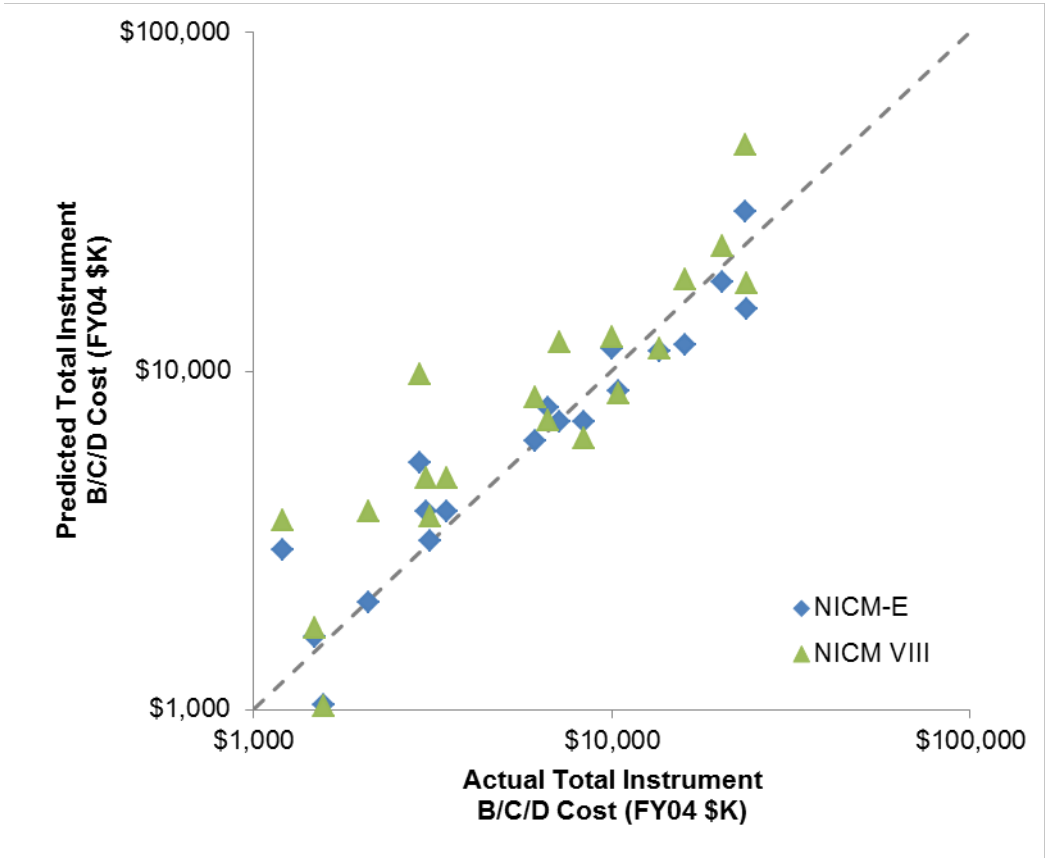
	Optical Earth Orbiting	Optical Planetary	Particles Earth Orbiting	Particles Planetary	Fields	Active Microwave	Passive Microwave
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓	✓	✓
C	X	X	✓	✓	X	X	X
C: NICM-E	✓	X	✓	X	✓	X	X
D	X	X	X	X	X	N/A	N/A

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

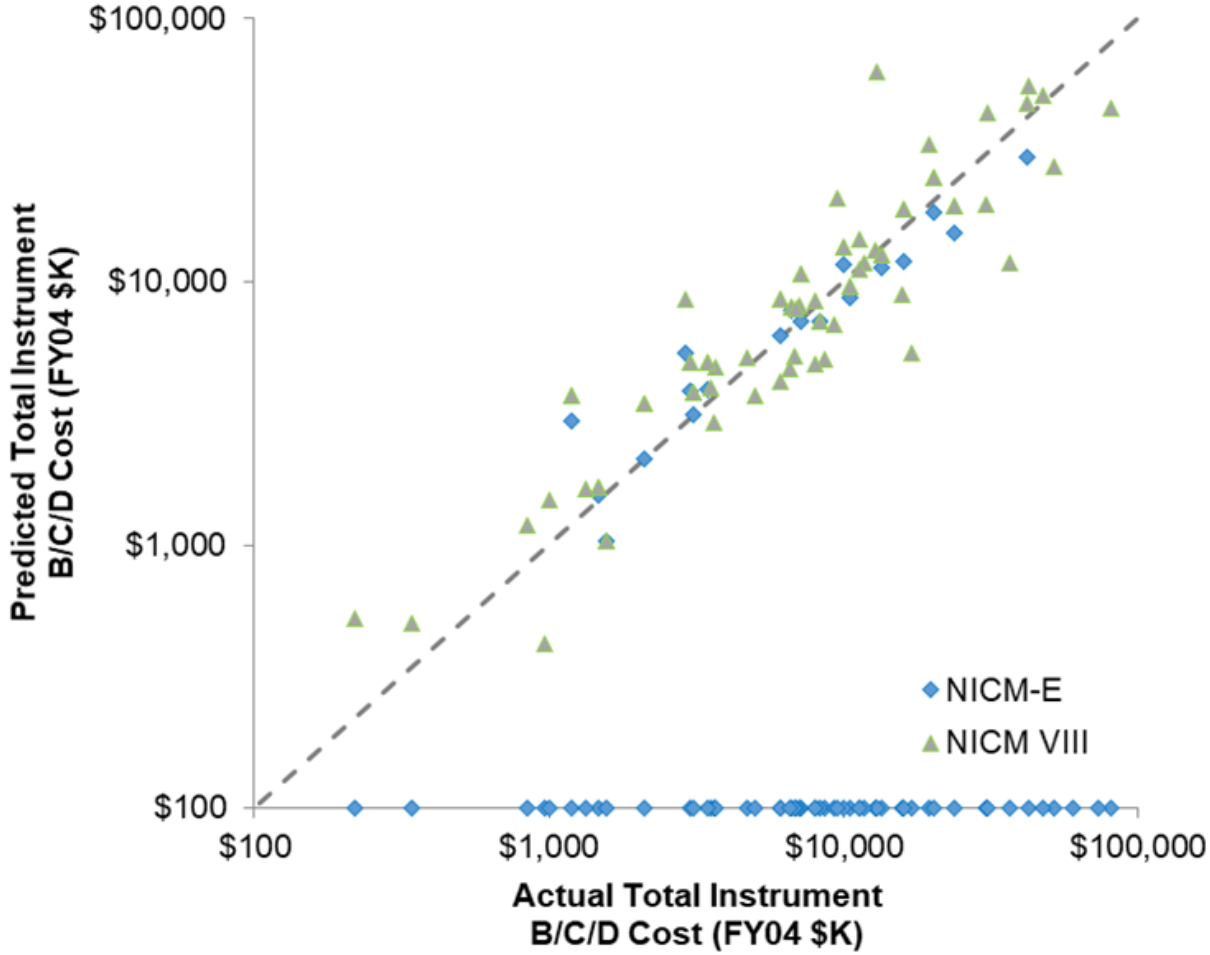
CONCLUSION: NICM VIII services more Instrument Types and Classes

NICM VIII CERs applied to the NICM-E Instruments



- Plotted are the original NICM-E instruments
- Note that the new NICM VIII CERs estimate quite closely to the NICM-E CERs, within the noise of both models for most instruments.

NICM-E Equation Applied to the NICM VIII Data



- Plotted are the NICM VIII Instruments used to develop the new Class-Based CERs
- Note that NICM-E would not be applicable for most of these instruments!

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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Telescope Lingo

- Telescope Optical Assembly (TOA), or “Telescope” for short in the context of NICM.
  - This is just the front end, it does not include the backend detectors.
  - In other words, a “Telescope” is NOT an instrument, as it can produce no science without a backend.
- Backend
  - The detector, electronics etc. that sit behind the telescope.
- “Telescope Instrument”: In the context of NICM, this is an instrument which includes both the TOA and a backend detector.
  - A “Telescope Instrument” is an instrument.

Telescope Lingo

- We just said that a “Telescope Instrument” is an instrument
  - Therefore it is a “System” in the context of NICM.
  - Therefore we’d expect to be able to estimate a cost for a Telescope Instrument in the *System Tool*.
- But what about a Telescope by itself? Should it be treated as a System or as a Subsystem?
  - Argument for a System: It contains what NICM would treat as subsystems: optics, structures/mechanisms, sometimes some simple electronics, etc.
  - Argument for a Subsystem: In NICM, an Instrument is a System. A telescope by itself is not an instrument, therefore it is not a System, therefore it must be a Subsystem.

Telescope Lingo

- We just said that a “Telescope Instrument” is an instrument
  - Therefore it is a “System” in the context of NICM.
  - Therefore we’d expect to be able to estimate a cost for a Telescope Instrument in the *System Tool*.
- But what about a Telescope by itself? Should it be treated as a System or as a Subsystem?

NICM VII	• Argument for a System: It contains what NICM would treat as subsystems: optics, structures/mechanisms, sometimes some simple electronics, etc.
NICM VIII	• Argument for a Subsystem: In NICM, an Instrument is a System. A telescope by itself is not an instrument, therefore it is not a System, therefore it must be a Subsystem.

Telescope Lingo in NICM VII

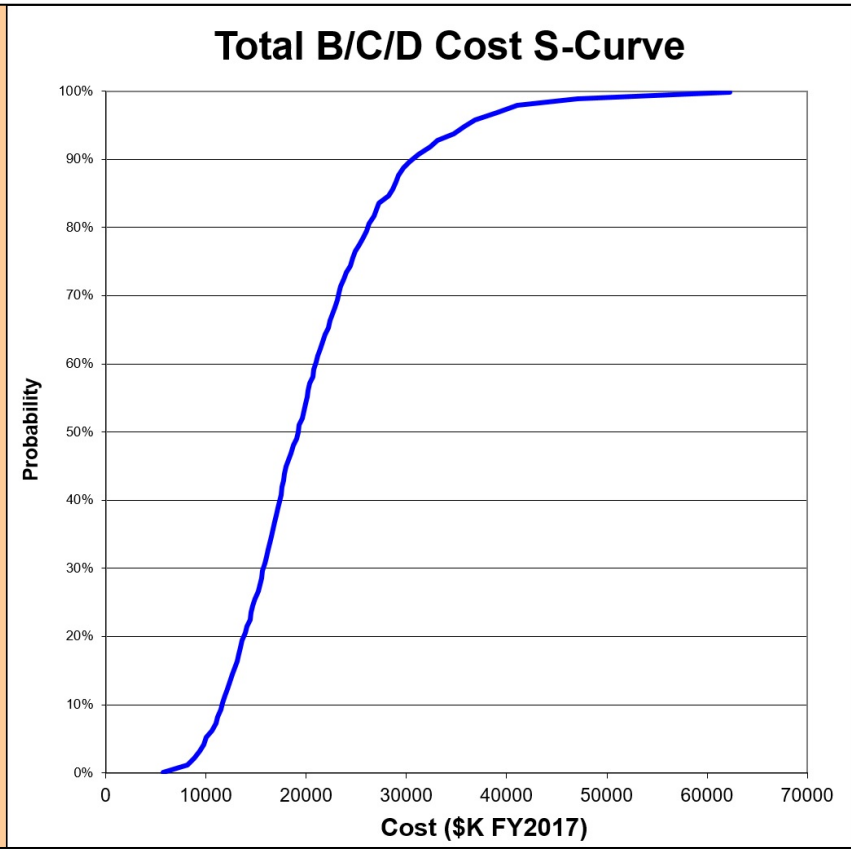
In NICM VII, we treated the Telescope by itself as a SYSTEM

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 VIII

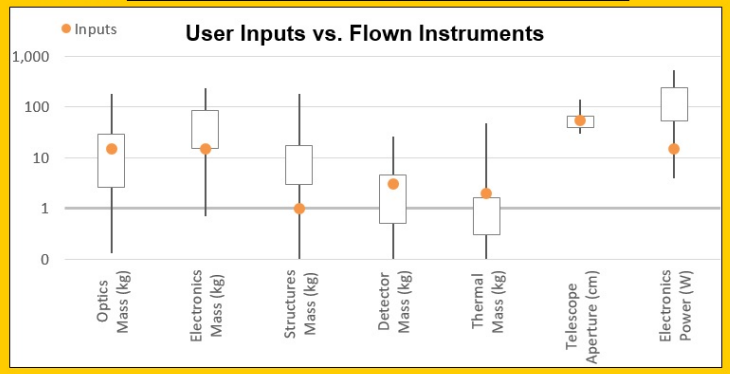
In NICM VIII, we treat the Telescope by itself as a SUBSYSTEM

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

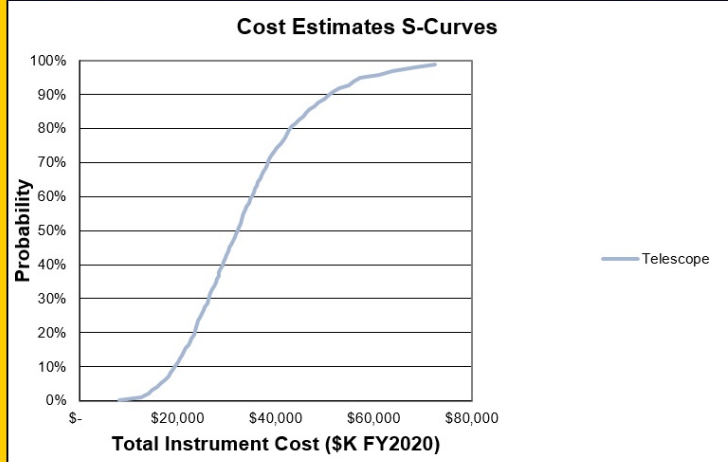
Copy Inputs to Search Engine | Copy Inputs to System Tool

Go to Search Engine | Go to System Tool

NICM VIII July 2018

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 Lingo in NICM VIII

Be careful to exclude your Telescope's mass & power inputs.

Inputs

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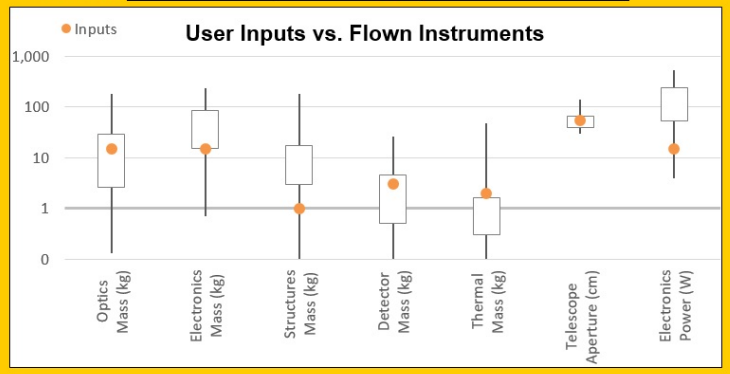
Instrument Name	
Costs in $K FY	2020
Instrument Type	Optical
Environment	Earth Orbiting

Include Telescope?	TRUE
Telescope Type	Infrared
Cryocooler?	FALSE
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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NICM VIII July 2018

Model Cost Estimates

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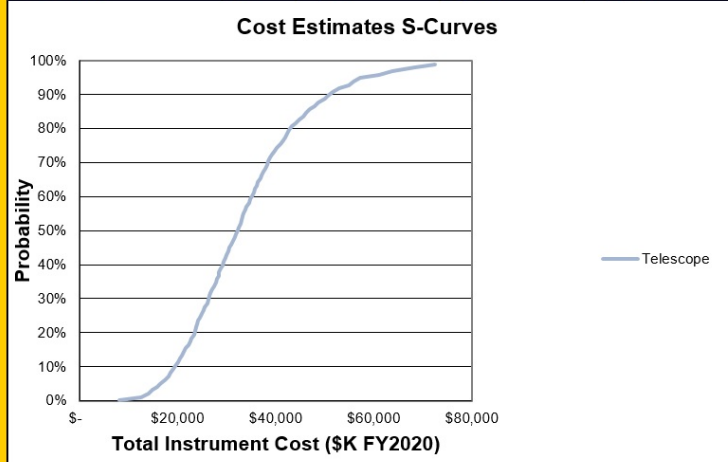
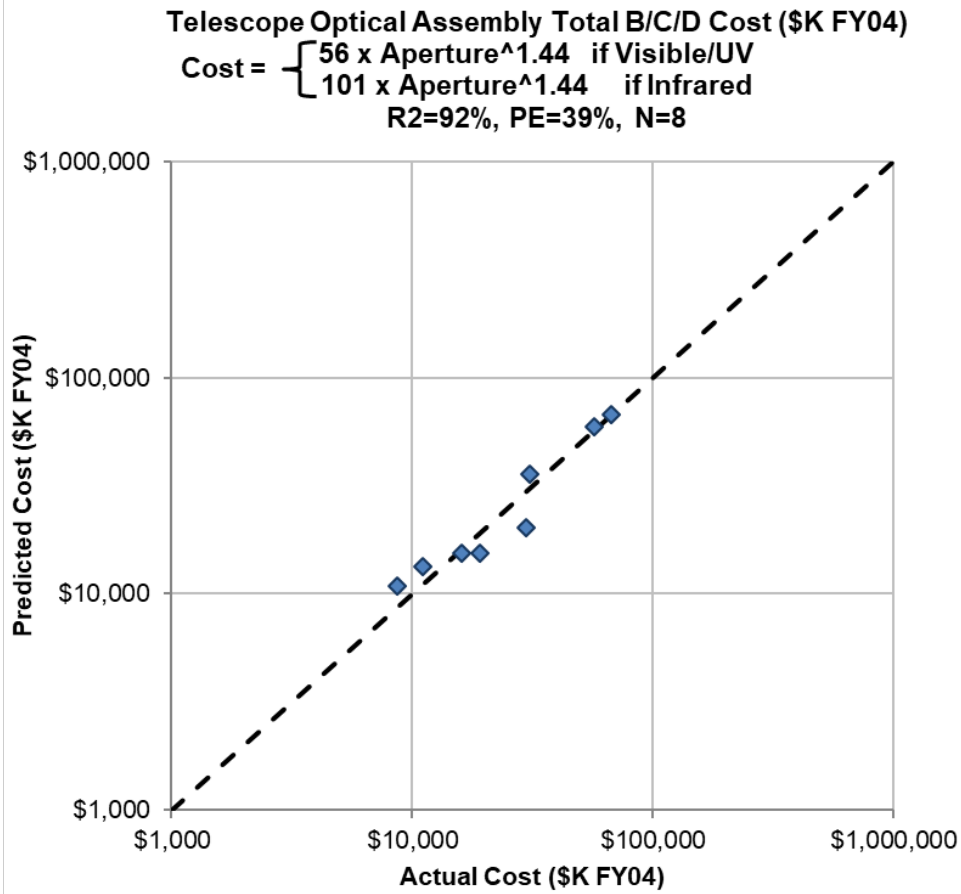


Telescope Lingo in NICM VIII

Be careful to exclude your Telescope's mass & power inputs.



Telescope Lingo in NICM VIII

Why did we move the Telescope CER from the System in NICM VII to the Subsystem Tool in NICM VIII?

Inputs

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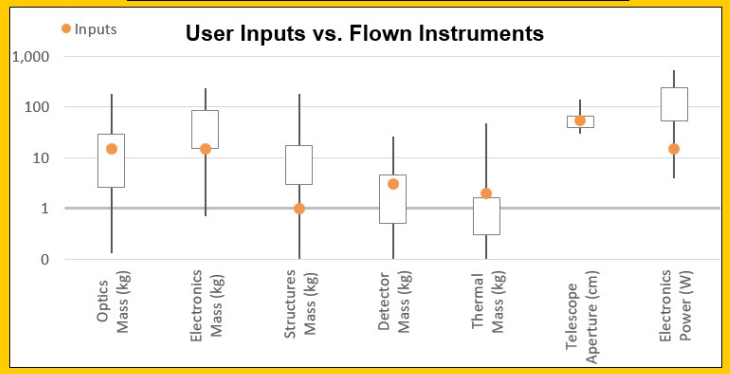
Instrument Name	
Costs in $K FY	2020
Instrument Type	Optical
Environment	Earth Orbiting

Include Telescope?	TRUE
Telescope Type	Infrared
Cryocooler?	FALSE
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

Go to Search Engine | Go to System Tool

NICM VIII July 2018

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
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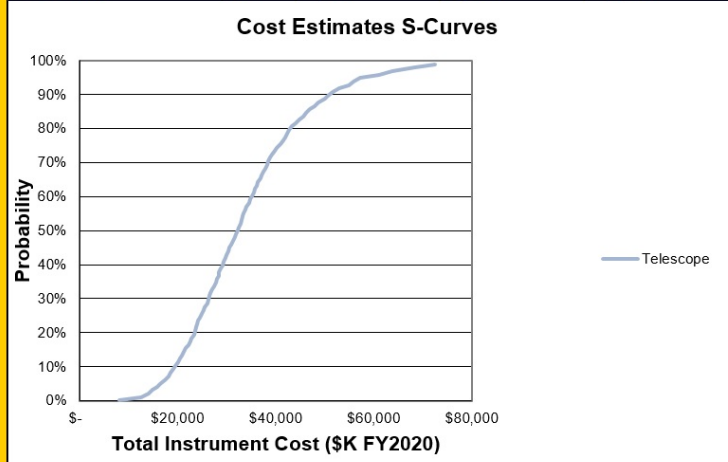
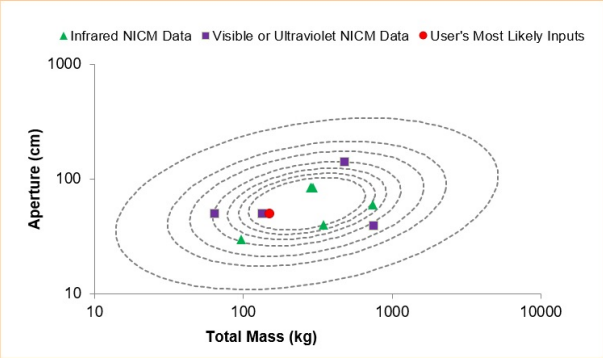


Telescope Lingo in NICM VIII

So we could do this: In the System Tool, we now provide the estimate for a “Telescope Instrument” rather than just a Telescope.

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

Copy Inputs to Search Engine | Copy Inputs to Subsystem | Go to Search Engine | Go to Subsystem Tool

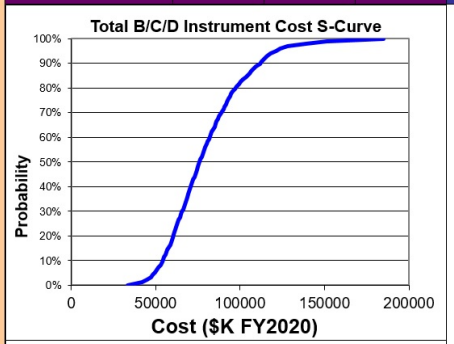
NICM VIII July 2018

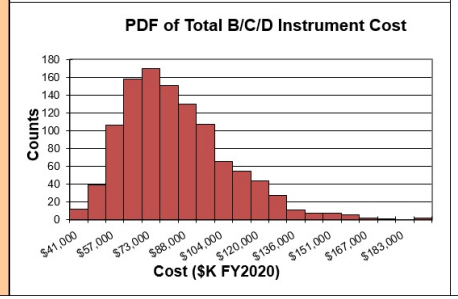
Model Cost Estimates

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

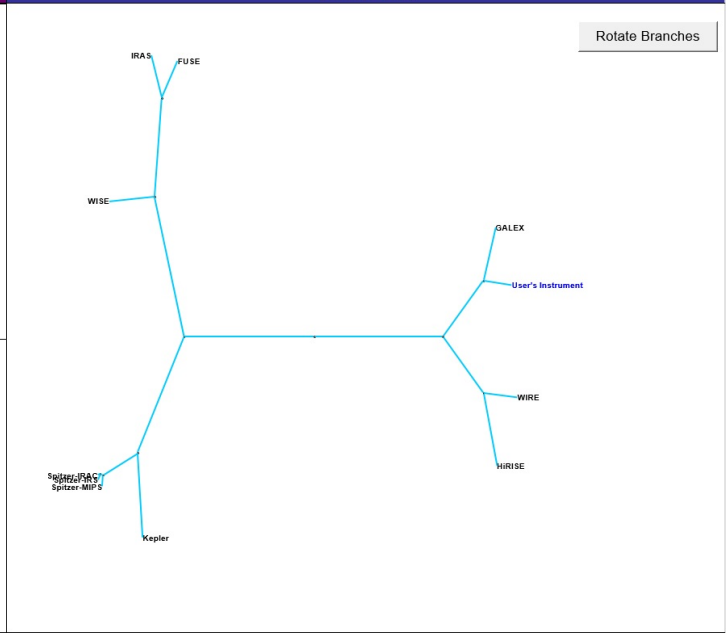
Analogy Cost Estimates

	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

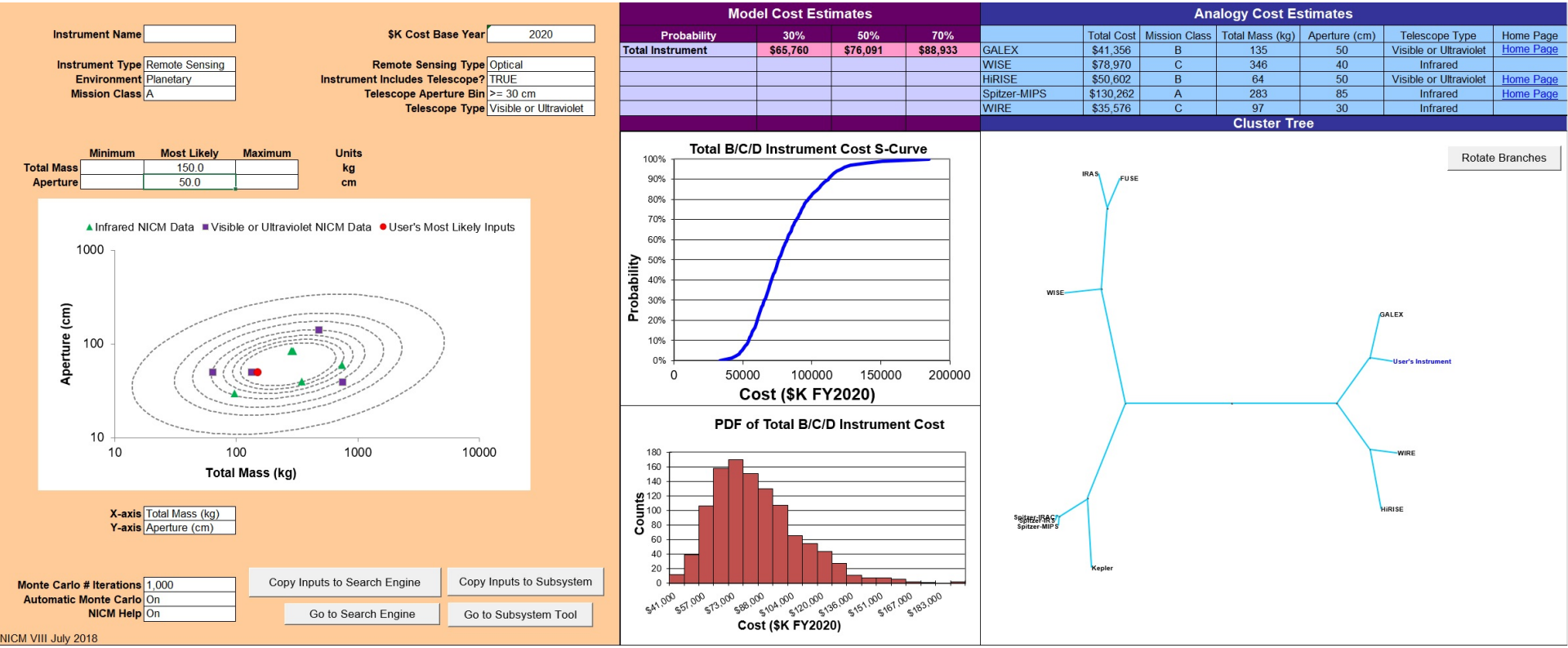


Telescope Lingo in NICM VIII

We are we asking for “Aperture Bin” as well as “Aperture?

< 30 cm, the tool will use the usual Optical CERs.

>= 30 cm, the tool will use the new Telescope Instrument CER.

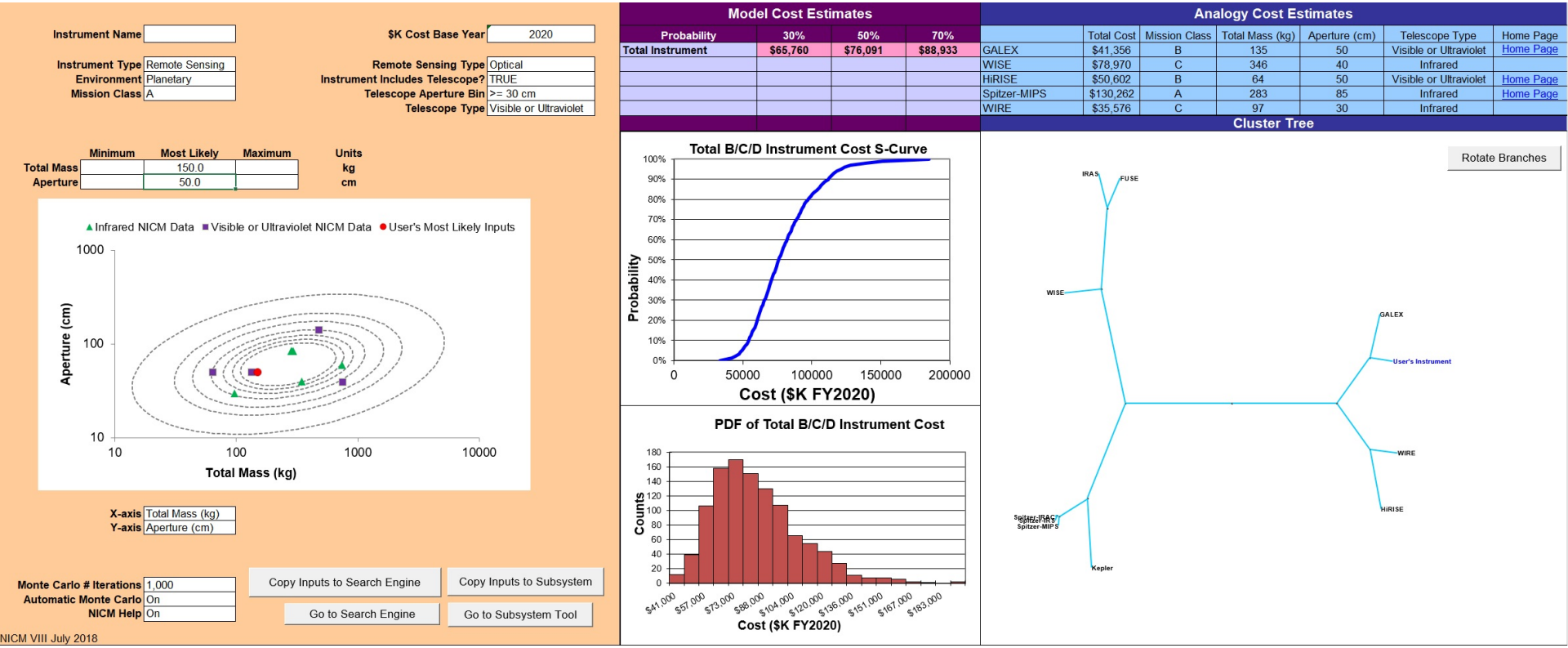


Telescope Lingo in NICM VIII

We are we asking for “Aperture Bin” as well as “Aperture?

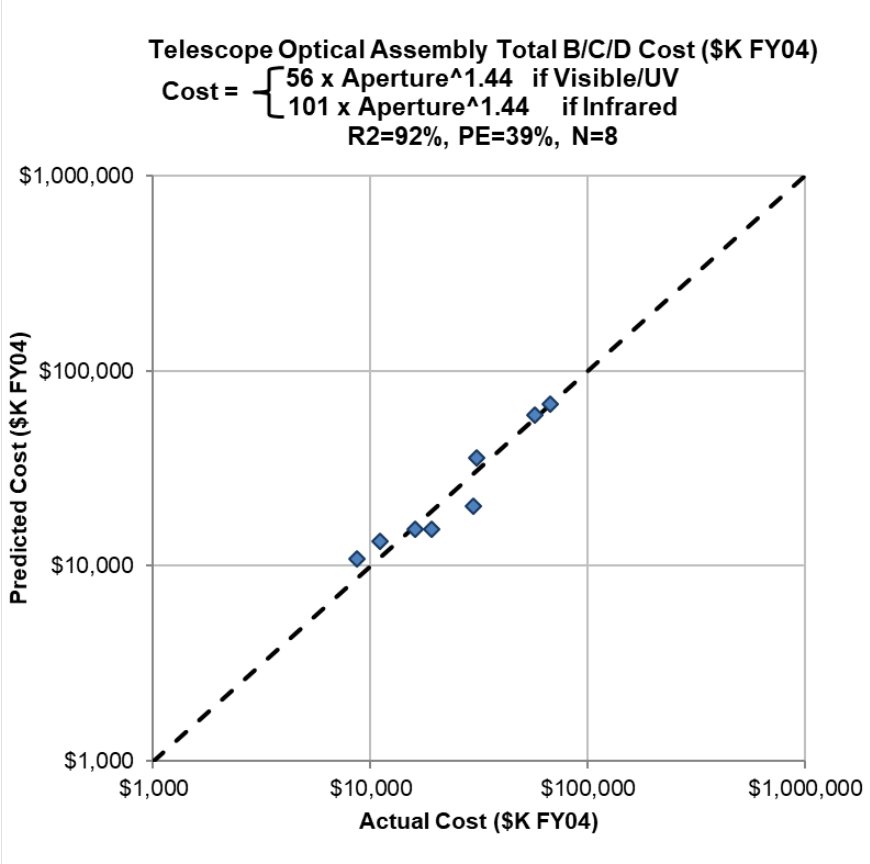
< 30 cm, telescopes and backends tend to be built at once.

>= 30 cm, telescopes and backends tend to be built separately.



The “New” Telescope Subsystem CER

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



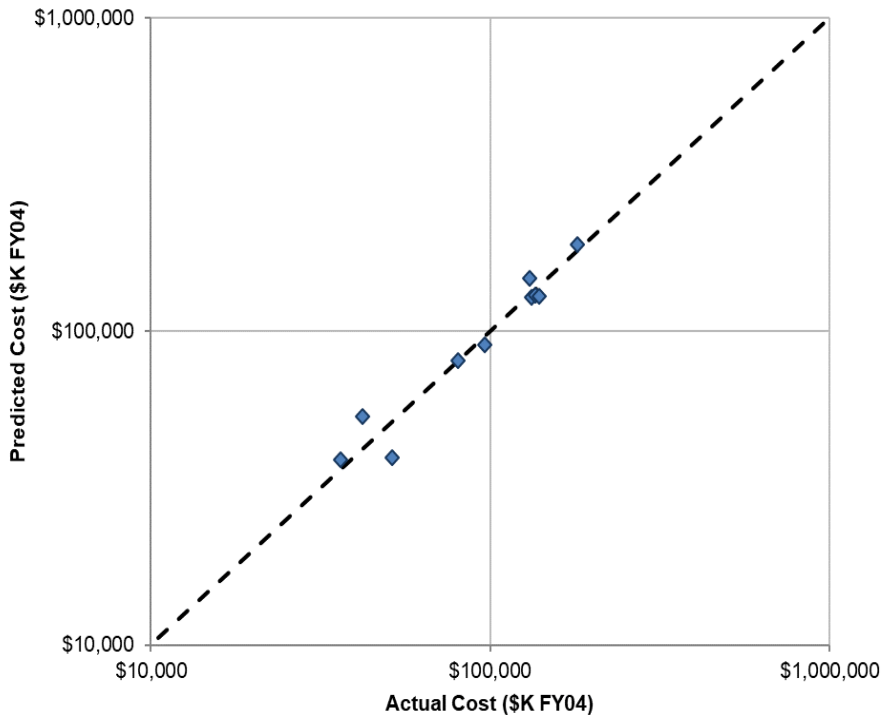
The New "Telescope Instrument" CER

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

Telescope Instrument Total B/C/D Cost (FY04 $K)

Cost = { 421 x PrimMirrorDiam^0.72 x TotalMass^0.41 if UV/Visible
508 x PrimMirrorDiam^0.72 x TotalMass^0.41 if Infrared

R2=94%, PE=29%, N=10



Agenda

- Acknowledgements
- NICM 101
  - Introduction
  - Instrument Data
  - Modeling Methodologies
  - Models
  - JCL
  - Tool Demonstration
- Deeper Dive: NICM VIII Improvements
  - Class-based CERs vs. NICM-E
  - Telescope Cost as a Subsystem & “Telescope Instruments”
  - **Improved Cryocooler 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.**

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.

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

Cryocoolers: NICM VII Equation

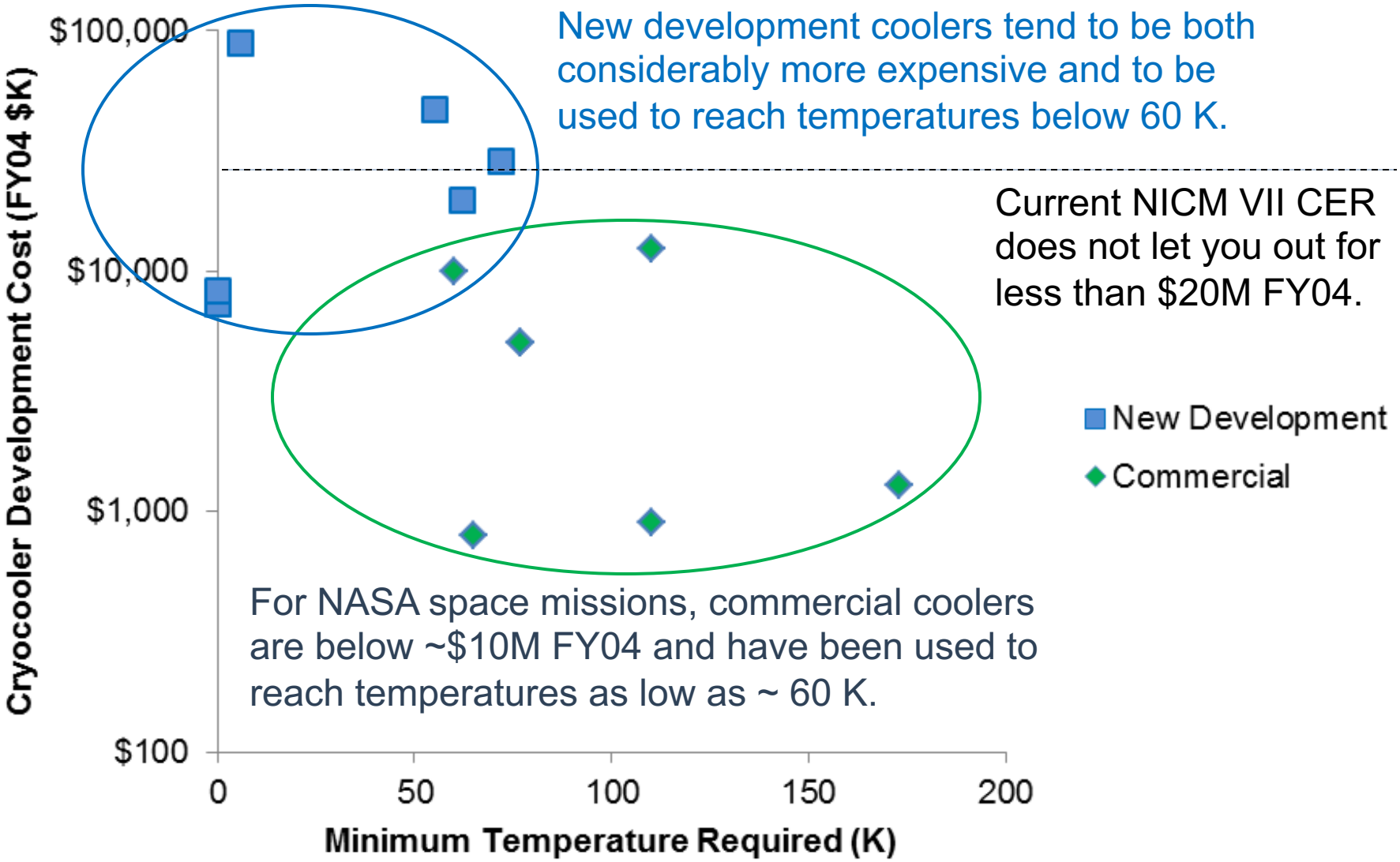
- NICM VII applies the following equation to estimate the cost of a New Cryocooler Development:

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

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

- **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

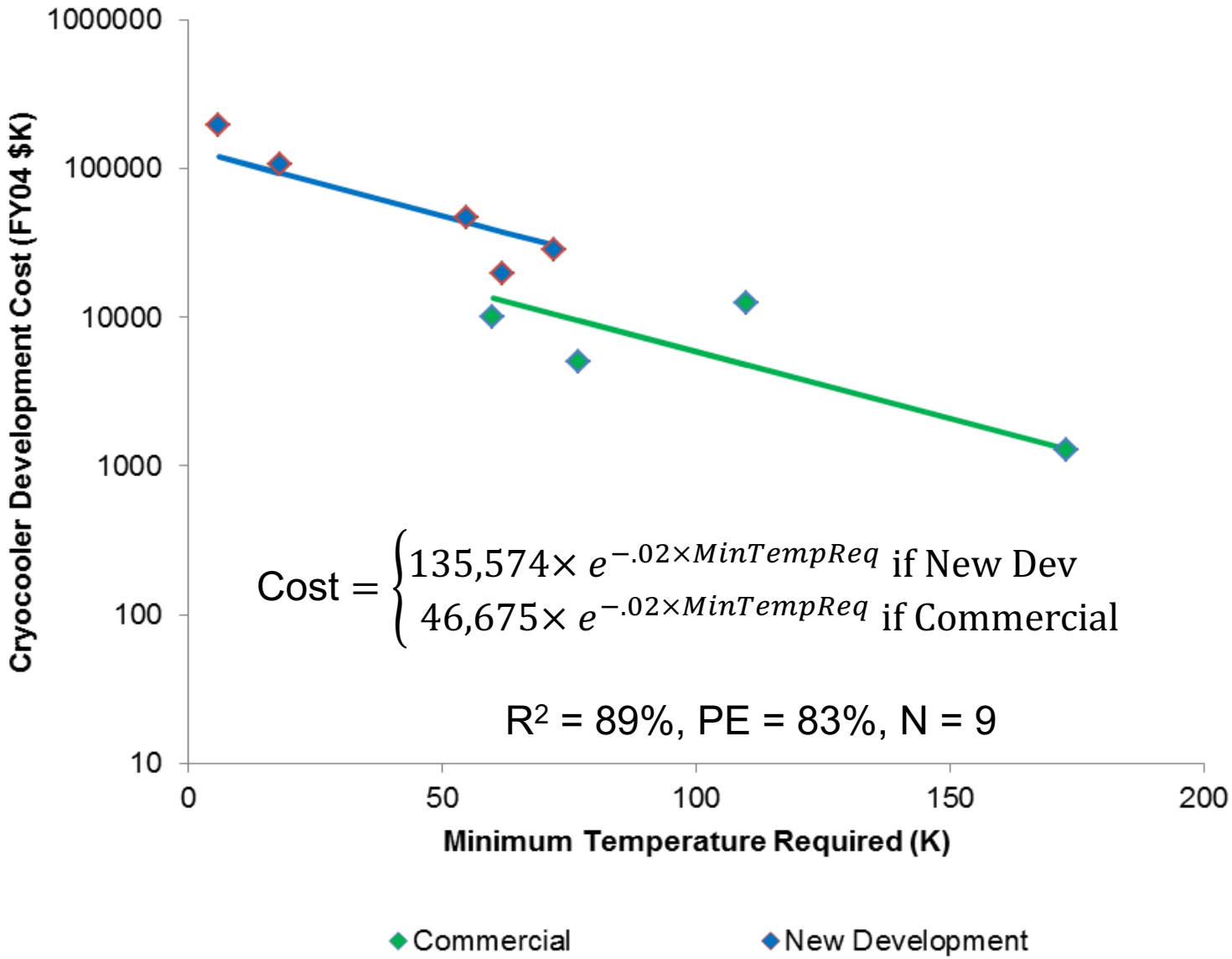
- NICM VII applies the following equation to estimate the cost of a New Cryocooler Development:

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

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

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

Cryocooler CER



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

R^2 = 89%, PE = 83%, N = 9

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

- NICM VIII Rev 2 – if needed, look for a release in 2-3 months.

- 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!

2018 NASA Cost and Schedule Symposium

- August 14-16 at GSFC
- https://www.nasa.gov/offices/ocfo/cost_symposium/
- *Registration Closes on 23 July at 6pm Pacific*
- NICM VIII Presentation
- NICM Breakout Session

NICM Publications & Presentations

1. International Cost Estimation and Analysis Association (ICEAA)
   - 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.
2. IEEE Aerospace
   - NASA Instrument Cost Model for Explorer-like Mission Instruments, 2014 Aerospace Conference, Big Sky, MT, March 2014, H. Habib-Agahi, J. Mrozinski, G. Fox.
   - NASA Instrument Cost and Schedule Model, 2011 Aerospace Conference, Big Sky, MT, March 2011, H. Habib-Agahi, G. Fox, J. Mrozinski.
3. AIAA Space
   - NASA Space Flight Instruments: Cost Time Trends, 2016 Space Conference, Long Beach, CA, September 2016, J. Mrozinski, M. DiNicola, H. Habib-Agahi.
   - Latest NASA Instrument Cost Model (NICM): Version VI, 2014 Space Conference, San Diego, CA, August 2014, J. Mrozinski, H. Habib-Agahi, G. Fox, G. Balls.
4. NASA Cost and Schedule Symposiums
   - NICM: Cryocooler, August 2017, J. Mrozinski, M. DiNicola
   - The Silent *S* in NICM: NICM Schedule Capabilities, August 2017, J. Mrozinski, M. DiNicola
   - NASA Instrument Cost Model: Impact of Mission Class on Cost, Glenn Research Center, August 2016, J. Mrozinski, M. DiNicola, H. Habib-Agahi.
   - NICM Version VII, Ames Research Center, August 2015, H. Habib-Agahi, J. Mrozinski, M. DiNicola.
   - Telescope Cost Estimating, Langley Research Center, August 2014, H. Habib-Agahi, J. Mrozinski.
   - NASA Instrument Cost Model for Explorer-like Mission Instruments, Jet Propulsion Laboratory, August 2013, H. Habib-Agahi, J. Mrozinski, G. Fox, G. Ball.
   - NASA Instrument Cost Model, Applied Physics Laboratory, August 2012, H. Habib-Agahi, J. Mrozinski
   - NICM, Johnson Space Center, August 2011, J. Mrozinski

Questions?

1. International Cost Estimation and Analysis Association (ICEAA)
   - 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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   - NICM Version VII, Ames Research Center, August 2015, H. Habib-Agahi, J. Mrozinski, M. DiNicola.
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