Presented at the 2022 ICEAA Professional Development & Training Workshop: www.iceaaonline.com/pit2022

NASA Instrument Cost Model: Introductory Training

2022 ICEAA Professional Development and Training Workshop

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Jet Propulsion Laboratory
California Institute of Technology

May 17-19, 2022

Agenda

- Acknowledgements
- NICM 101
  - Introduction
  - Instrument Data
  - Modeling Methodologies
  - Models
  - JCL
  - Tool Demonstration

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NICM Stakeholders

- Sponsor: NASA HQ OCFO/SID
  - Special thank you to James Johnson
- 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 9 Team

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- Justin Boland
- Kyle Brown
- Robert Cesarone
- Mike DiNicola
- Michael Fong
- Melissa Hooke
- Joe Mrozinski
- Al Nash
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NICM Team

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NICM 101

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November 2, 2020

Jet Propulsion Laboratory
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NICM Introduction

- NICM is the ***NASA*** Instrument Cost Model**:**
  - Instrument Cost and Schedule Estimating Tool Suite based off of previously flown space flight instruments across all of NASA
  - Includes objective-input-based parametric cost and schedule models, cost and schedule analogy tools and JCL capabilities.
  - Models exist at both the total instrument and instrument subsystem levels.
- Users:
  - All NASA Centers, Contractors, Universities etc.
  - Proposal Teams as well as by Proposal Evaluators.
  - Over 600 individuals have attended NICM Training sessions
- For Training Contact: NICM@jpl.nasa.gov
- Download the NICM Excel file from:
  - www.oncedata.com (Civil and Contractor version)
  - www.software.nasa.gov (Contractor Version only)

A Brief NICM History

- 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 the highlights of 16 years of NICM history into 8 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: Mission Class as a cost driver added.
  - NICM 9: Data Imputation Utilized, Multiple Build estimates introduced

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NICM Data

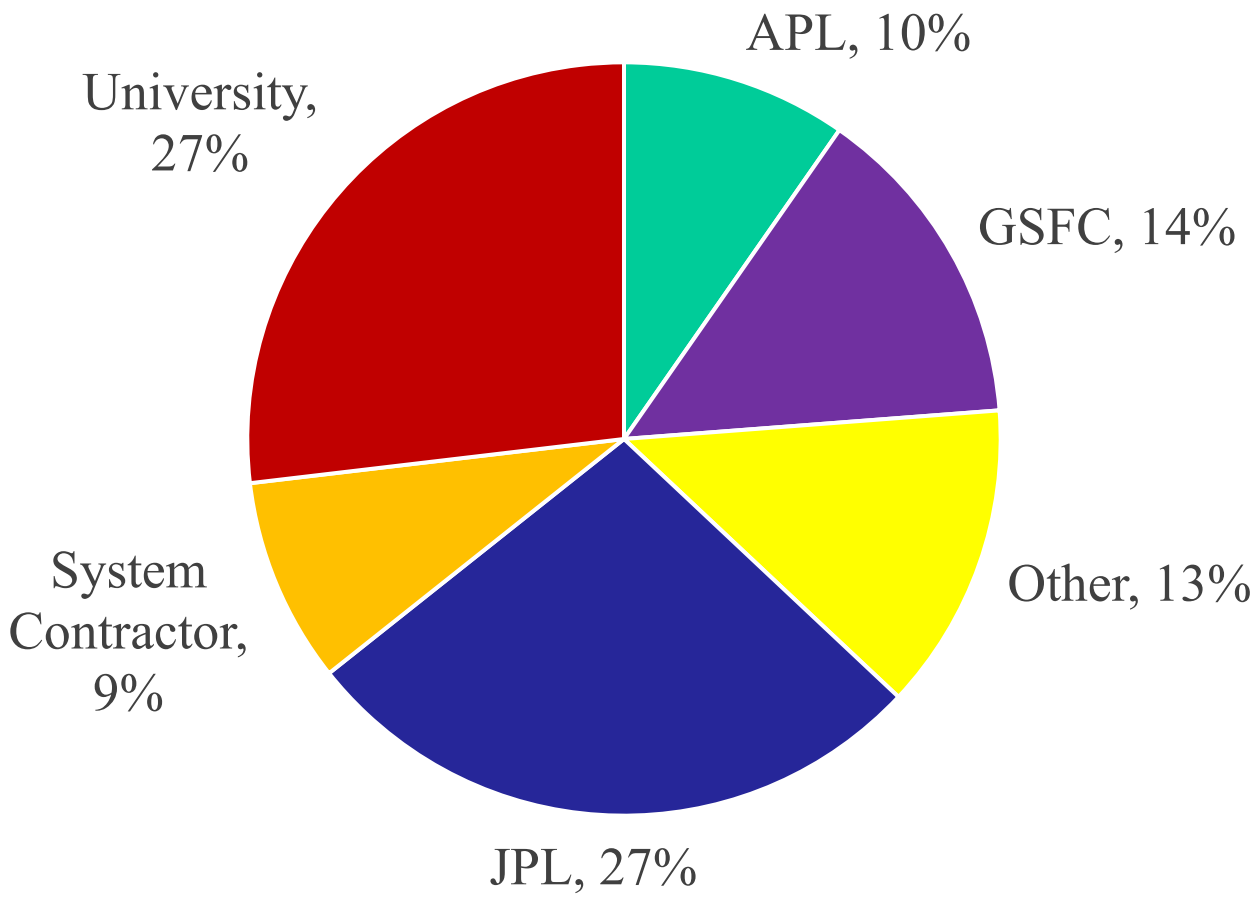
- Interviewing, Analyzing, Normalizing and Reviewing technical and cost Data is the heart and main strength of the NICM. Good models require good data.
- We are stringent when it comes to the quality, applicability and completeness of the data: before data is used for modeling, all records and normalization approaches are reviewed and blessed by both individuals who built the hardware as well as the multi-disciplinary NICM Team.

- **NICM 9 includes 299 Data Records**

NICM Data

- All 299 NICM data records share the following characteristics:
  - All have been built/flown.
  - All have launched 1985 or after.
  - All are space flight hardware (no ground-based or airborne).
  - All cost and schedules data covers phases B/C/D only.
    - 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 data points have been normalized to a single unit build where necessary.

Data by Instrument Lead Organizations



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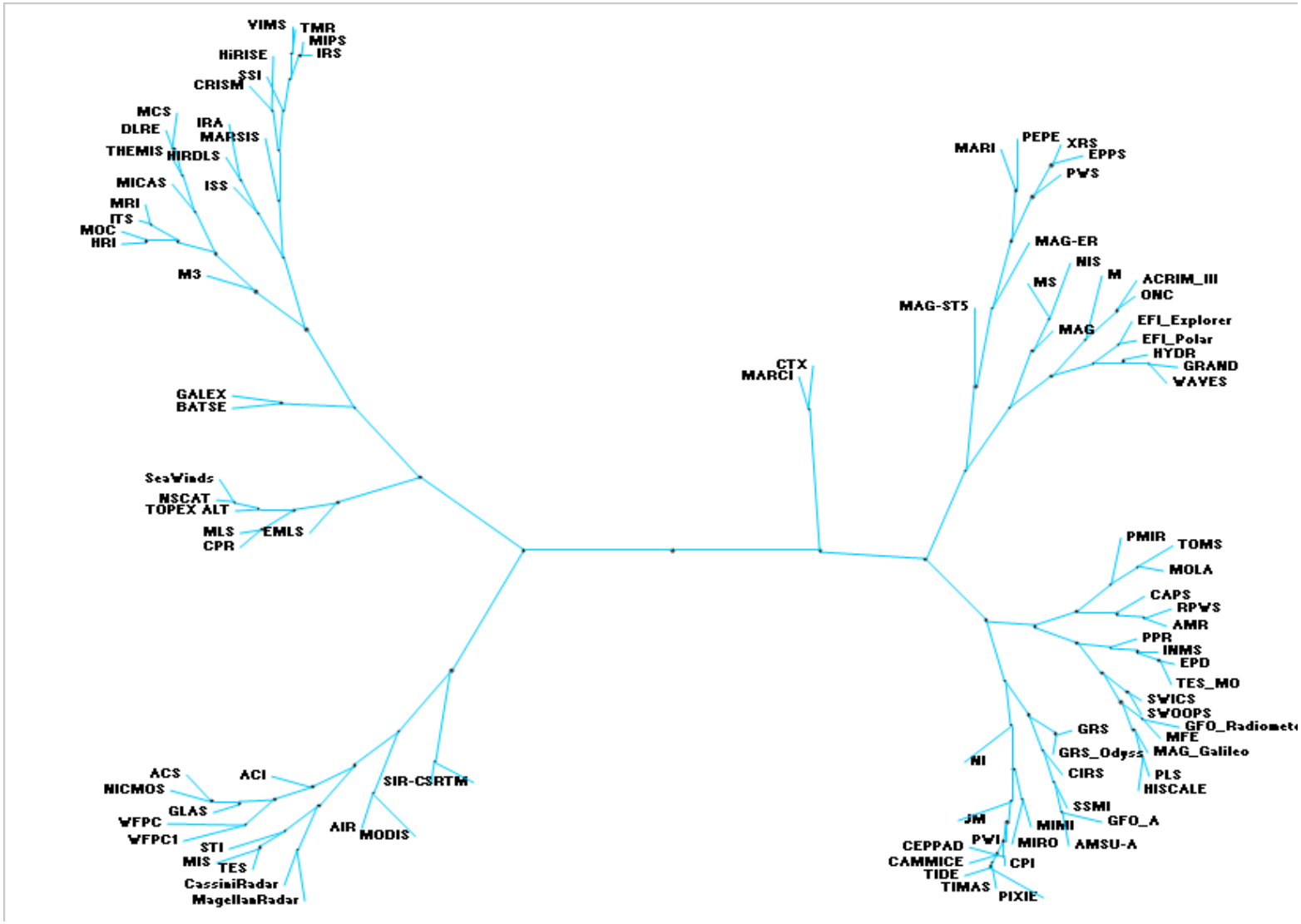
Modeling Methodology

- 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 NICM 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.
- Imputation: Allows for use of incomplete records.

Cluster Analysis: Remote Sensing Instruments



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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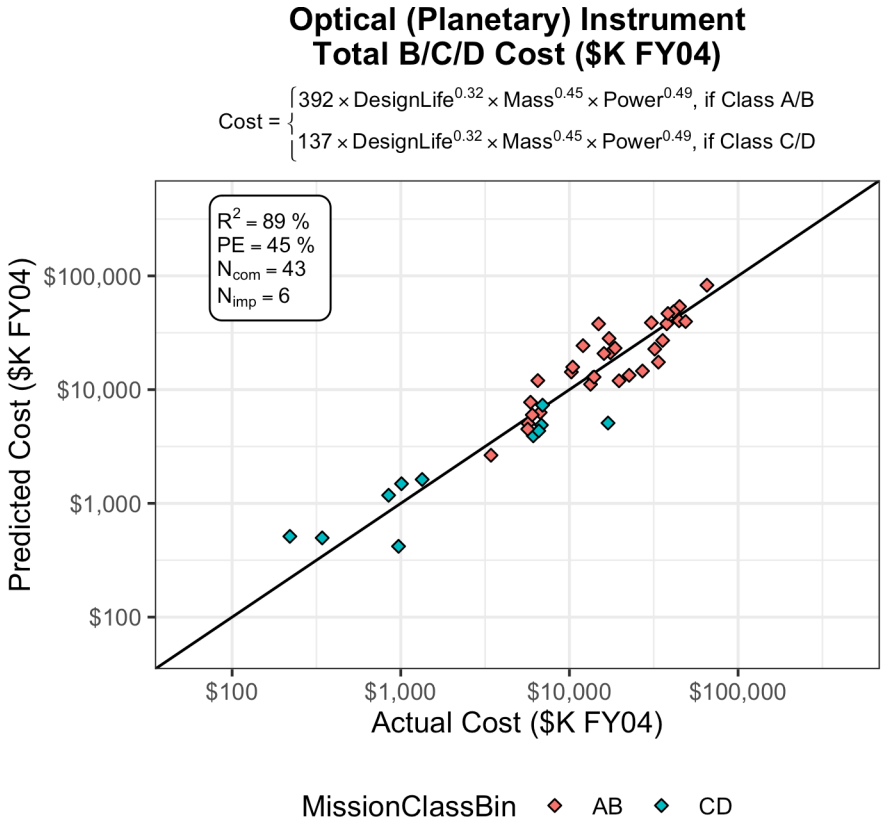
Model Overview

- 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 only produce a total instrument schedule (they do not provide subsystem schedules).

System Level CERs

Optical Planetary CER



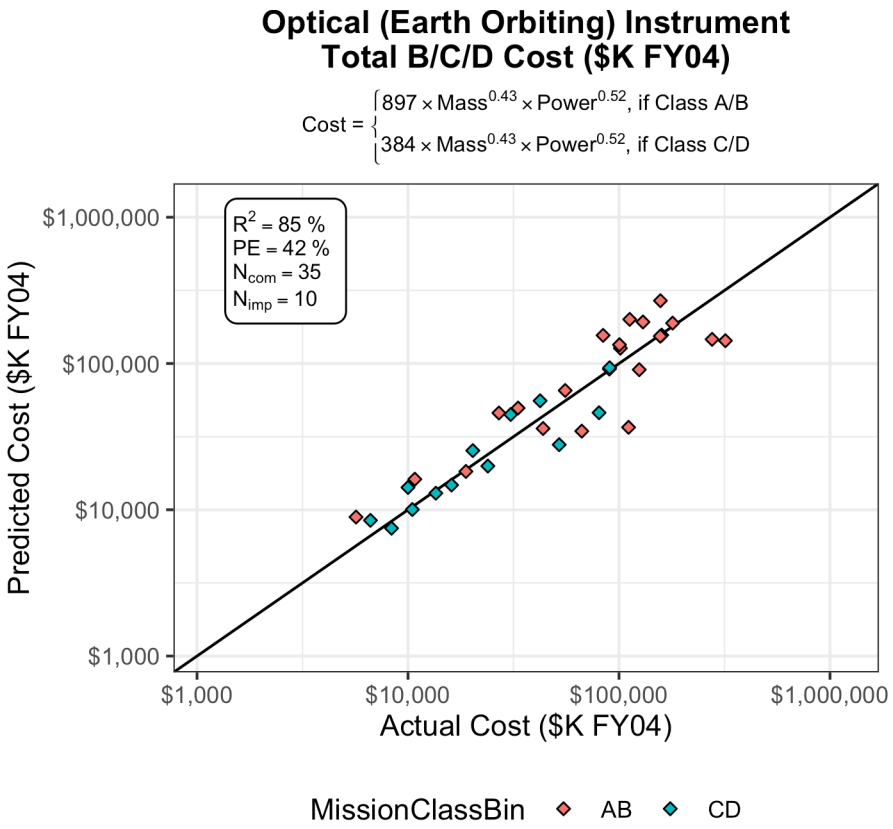
Instruments used in this CER:			Imputed instruments used:
ALICE_Rosetta	CFI	CIRS	ALICE
CRISM	CRISP	CTX	IUVS
DLRE	IRAC	IRS	MDI
ISS	ITS	JunoCam	Ralph
LOLA	LORRI	LROC	SECCHI
M3	MARCI	MASCS	UVCS
MCS	MDIS	MICAS	
MIPS	MIR	MLA	
MOC-MO	MOLA-MO	MRI	
MSI	NavCam	NIR	
NIS	NLR	NSP	
ONC	PMIRR	TES_MO	
THEMIS	TLP	UVIS	
UVS - Juno	VIMS	VIS_LCROSS	
VSP			

Alternative form of equation:

$$Cost = 392\ DesignLife^{0.32}\ Mass^{0.45}\ Power^{0.49}\ exp(MissionClassBin)^{-1.05}$$

where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Optical Earth Orbiting CER



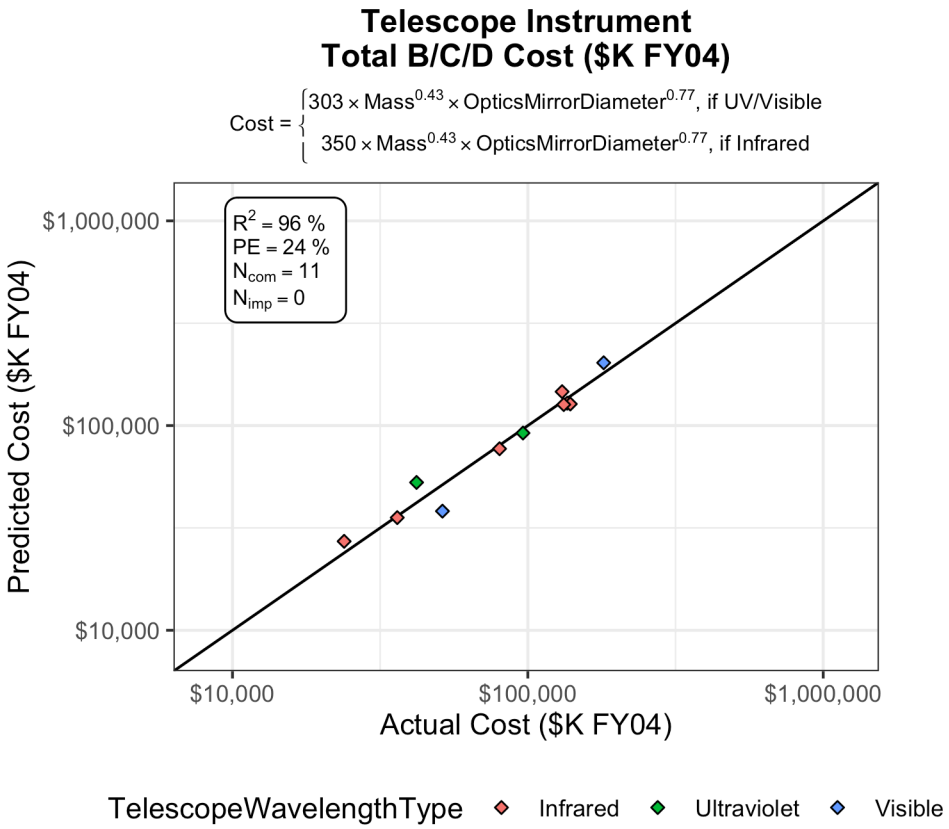
Instruments used in this CER:			Imputed instruments used:
ACIS	ACRIM II	ACRIM III	ALI
ACS	AIA	AIRS	CERES_Aqua
APS-Glory	CERES	CHIPS	CrIS_SuomiNPP
CIPS	EVE	FUV	EUV_IMAGE
GLAS	GSPEC-OCO	GUVI	LEISA
HIRDLS	HMI	HRC	MODIS_Aqua
IRIS	LAC	MISR	OMPS
MODIS	NICMOS	NuStar	SEE
OLI	RHESSI	SABER	SIM
SOFIE	STIS	TES_Aura	XPS
TIDI	TOMS	TRACE	
WFPC1	WFPC2		

Alternative form of equation:

$$Cost = 897\ Mass^{0.43}\ Power^{0.52} \exp(MissionClassBin)^{-0.85}$$

where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Telescope Instrument CER (for Apertures >= 30 cm)



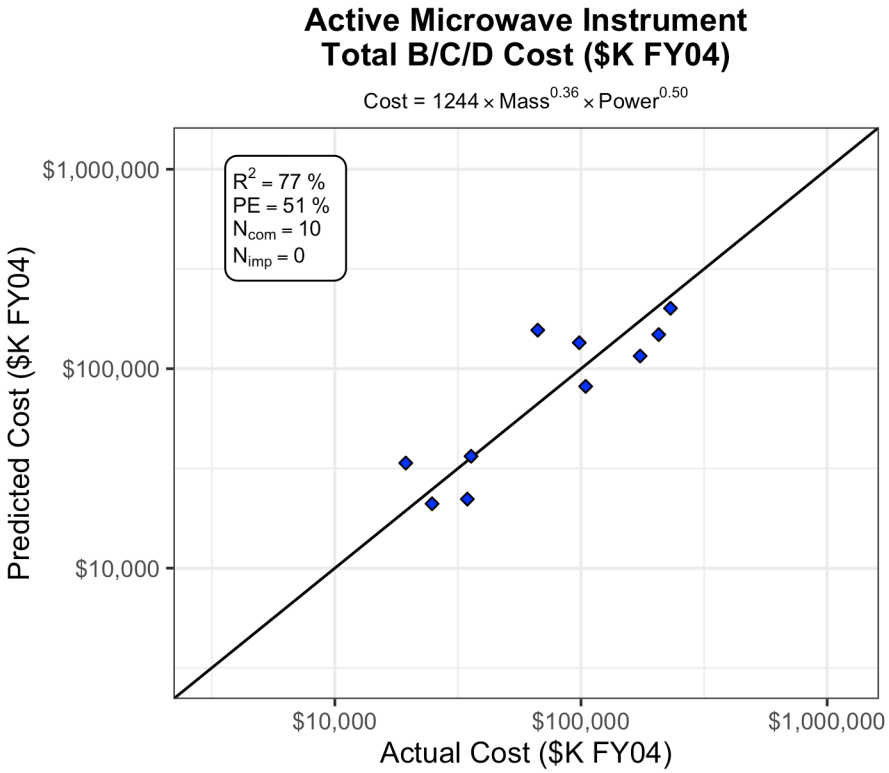
Instruments used in this CER:			Imputed instruments used:
FUSE	GALEX	HiRISE	
HRI_Deep_Impact	IRAS	Kepler	
Spitzer-IRAC	Spitzer-IRS	Spitzer-MIPS	
WIRE	WISE		

Alternative form of equation:

$$Cost = 303\ Mass^{0.43}\ OpticsMirrorDiameter^{0.77}\ exp(TelescopeWavelengthType)^{0.14}$$

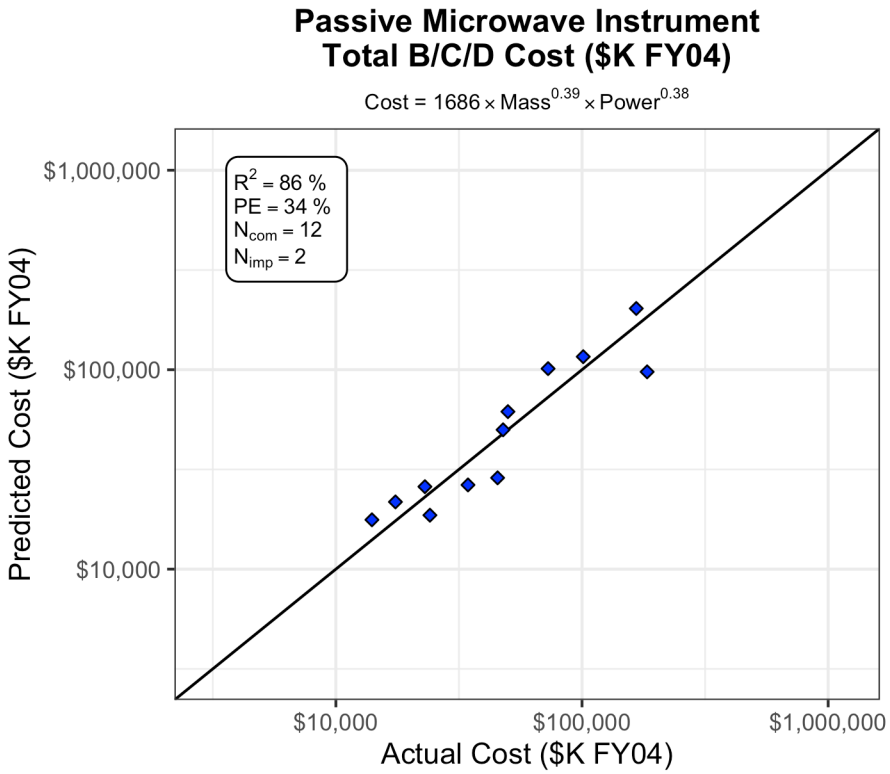
where TelescopeWavelengthType = 0 if Visible/Ultraviolet, & TelescopeWavelengthType = 1 if Infrared

Active Microwave CER



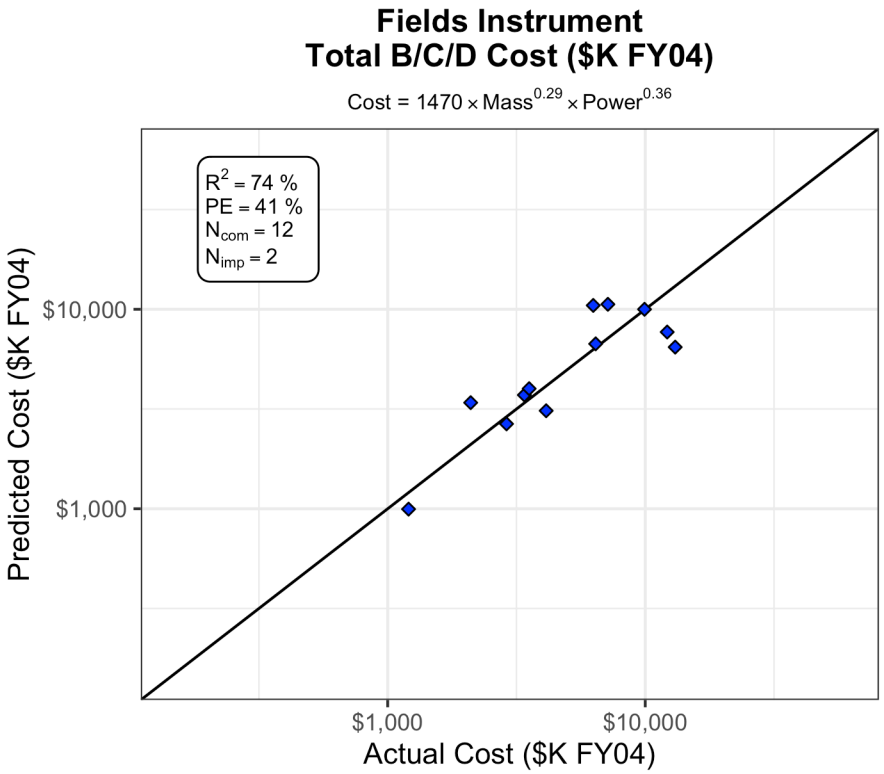
Instruments used in this CER:			Imputed instruments used:
Cassini Radar	CPR	GFO-Alt	
Grace Instrument	LGRS	MARSIS	
NSCAT	SeaWinds	SMAP	
TOPEX ALT			

Passive Microwave CER



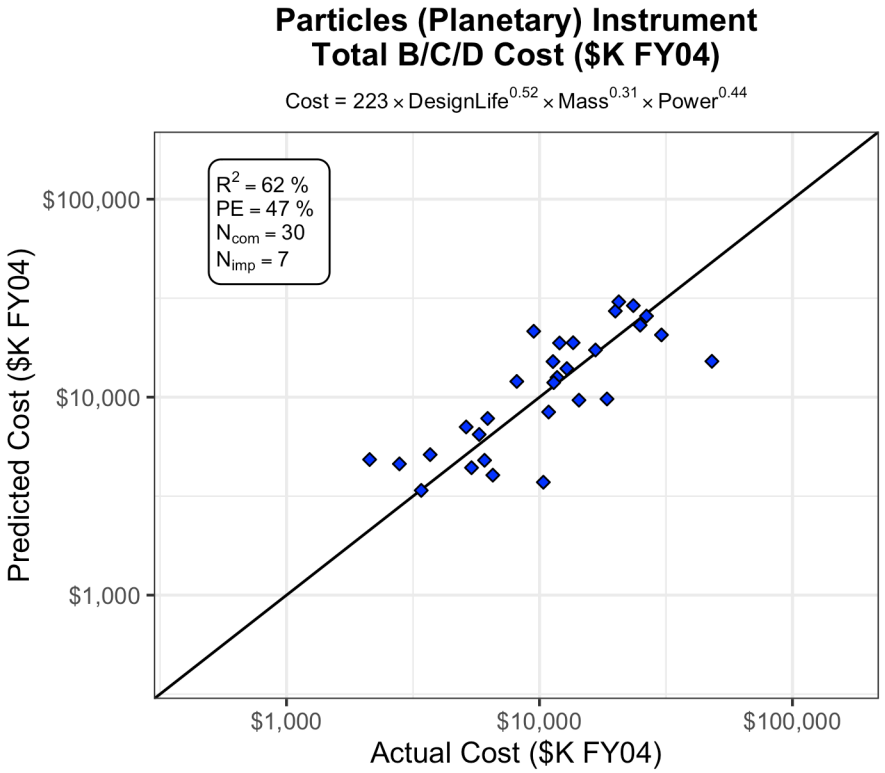
Instruments used in this CER:			Imputed instruments used:
AMR	AMSU-A	EMLS	ATMS
GFO Radiometer	GMI	JMR	TMI
MIRO	MLS	MWR	
SWAS	TMR	WMAP	

Fields CER



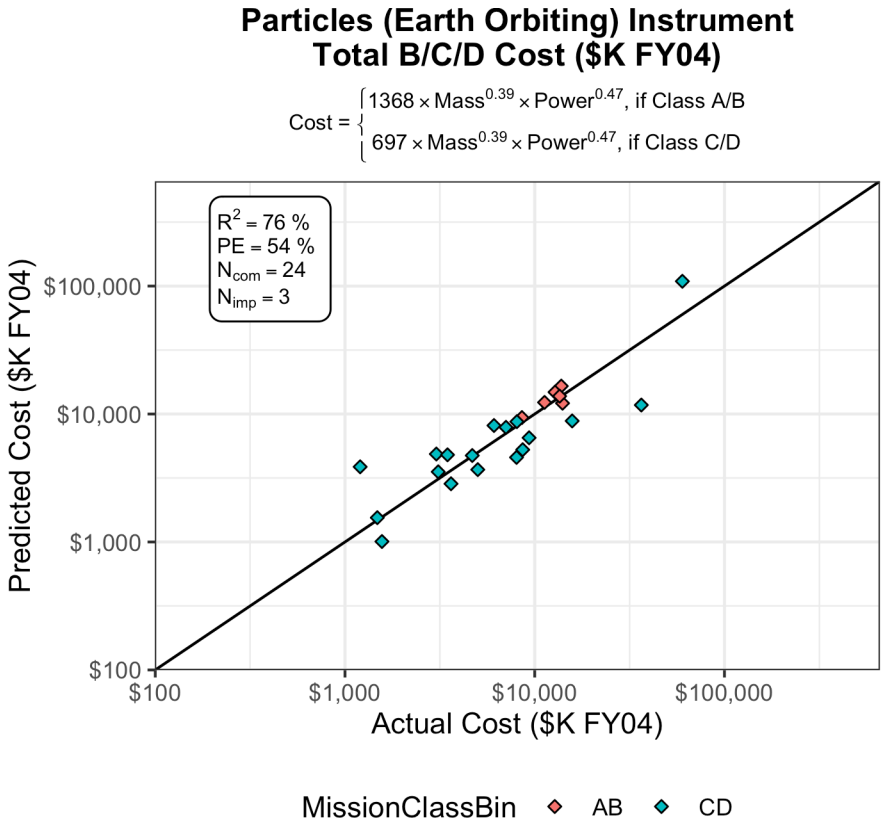
Instruments used in this CER:			Imputed instruments used:
EFI_Polar	EFPE	FGM-ASC	EFW
MAG FAST	MAG MAVEN	MAG MESSENGER	Mag-ER
MAG NEAR	MAG-ST5	MFI	
PWI	WAVES_Juno	WAVES_STEREO	

Particles Planetary CER



Instruments used in this CER:			Imputed instruments used:
CAPS	CRATER	CRIS_ACE	APS_LP
EPPS	GRAND	GRNS	GRS_LP
GRS_MO	GRS_Odyssey	HISCALE	NS
IES	INMS	JADE	PLASTIC
JEDI	MARIE	MIMI	SWICS_ACE
PEPE	PEPSSI	RPWS	SWIMS
SEP	SEPICA	SIS	SWOOPS
STATIC	SWAP	SWEA	
SWIA	SWICS_Ulysses	ULEIS	
URAP	XRS-GRS	XRS-MESSENGER	

Particles Earth Orbiting CER



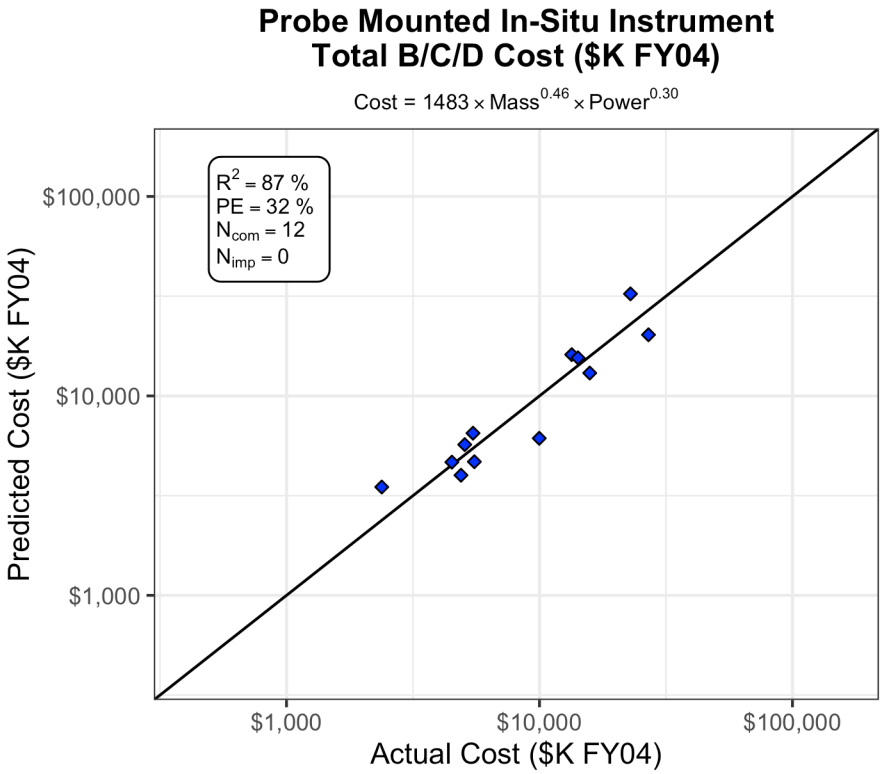
Instruments used in this CER:			Imputed instruments used:
BAT	CAMMICE	CINDI	CEPPAD
CPI	ESA_FAST	ESA_THEMIS	EPIC
HENA	HOPE	HYDRA	RPS
IBEX	LEICA	LENA	
MagEISHigh	MagEISLowMedium	MAST_&_PET	
MENA	PIXIE	RBSPICE	
REPT	SST	SXC	
TEAMS	TIDE	TIMAS	

Alternative form of equation:

$$Cost = 1368\ Mass^{0.39}\ Power^{0.47}\ exp(MissionClassBin)^{-0.67}$$

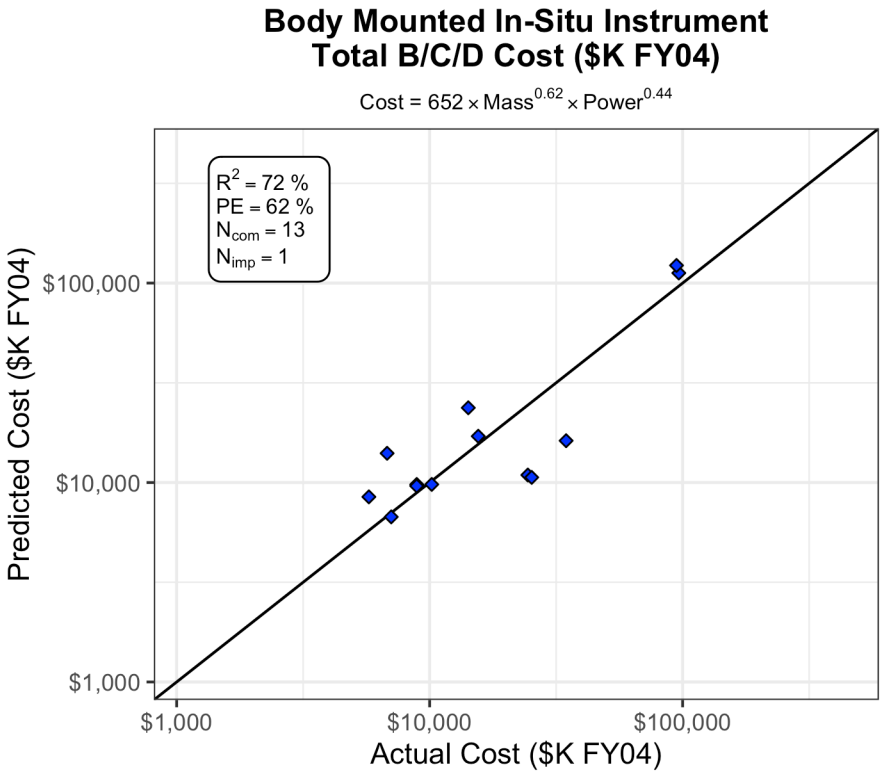
where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Probe Mounted In-Situ CER



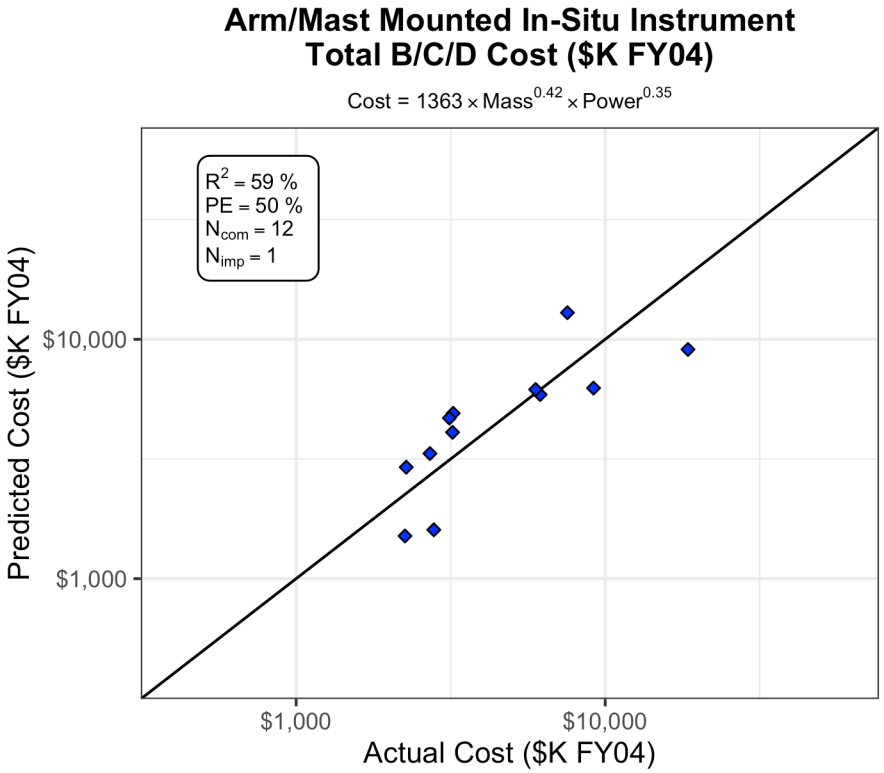
Instruments used in this CER:			Imputed instruments used:
ASI_GalileoProbe	ENose	GCMS	
GIM	GSWC	LDEX	
NEP	NFR	NGIMS_MAVEN	
NMS_LADEE	NMS-Galileo_Probe	VCAM ISS	

Body Mounted In-Situ CER



Instruments used in this CER:			Imputed instruments used:
CheMin	IDD	MECA-Phoenix	APSS
MECA-Surveyor	MFEX	MIP	
RA-MPL	RA-Phoenix	SAM	
SA-SPaH	TEGA-MPL	TEGA-Phoenix	
TLS			

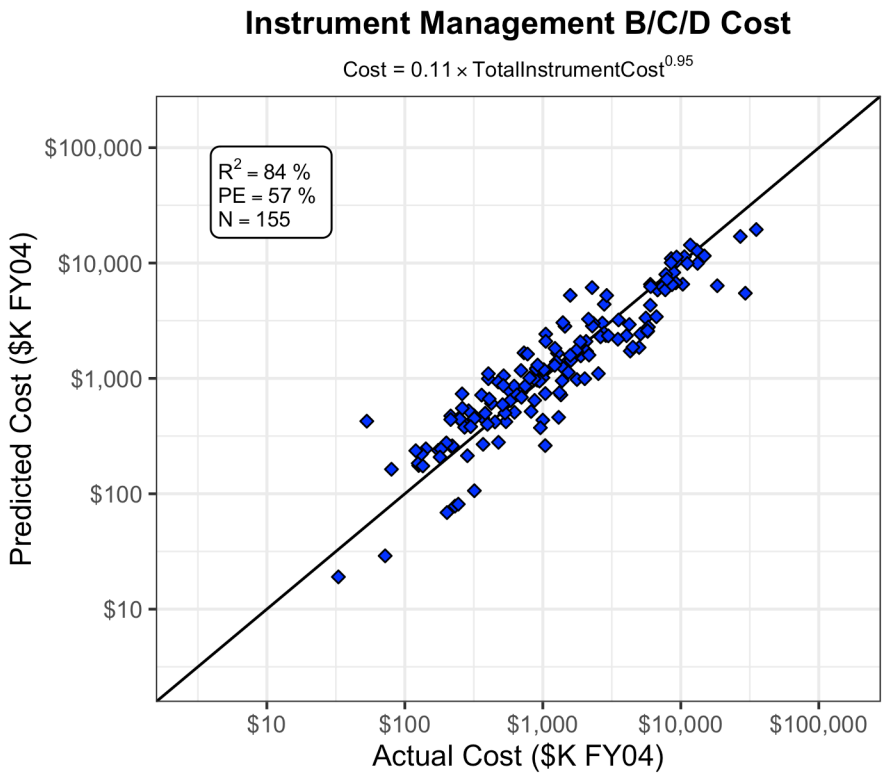
Arm/Mast Mounted In-Situ CER



Instruments used in this CER:			Imputed instruments used:
ASI_MET	IMP	MAHLI	RAC-Phoenix
MARDI-MPL	MARDI-MSL	MastCam	
MET-MPL	MiniTES	RAT	
SSI-MPL	SSI-Phoenix	TES Electrometer	

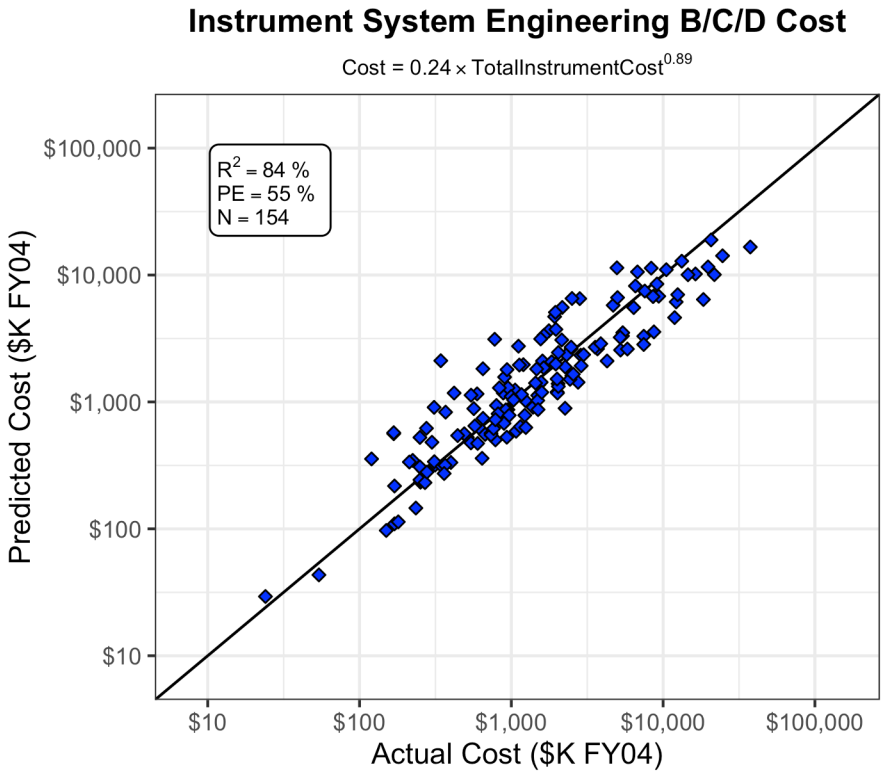
WRAP CERs

Management CER



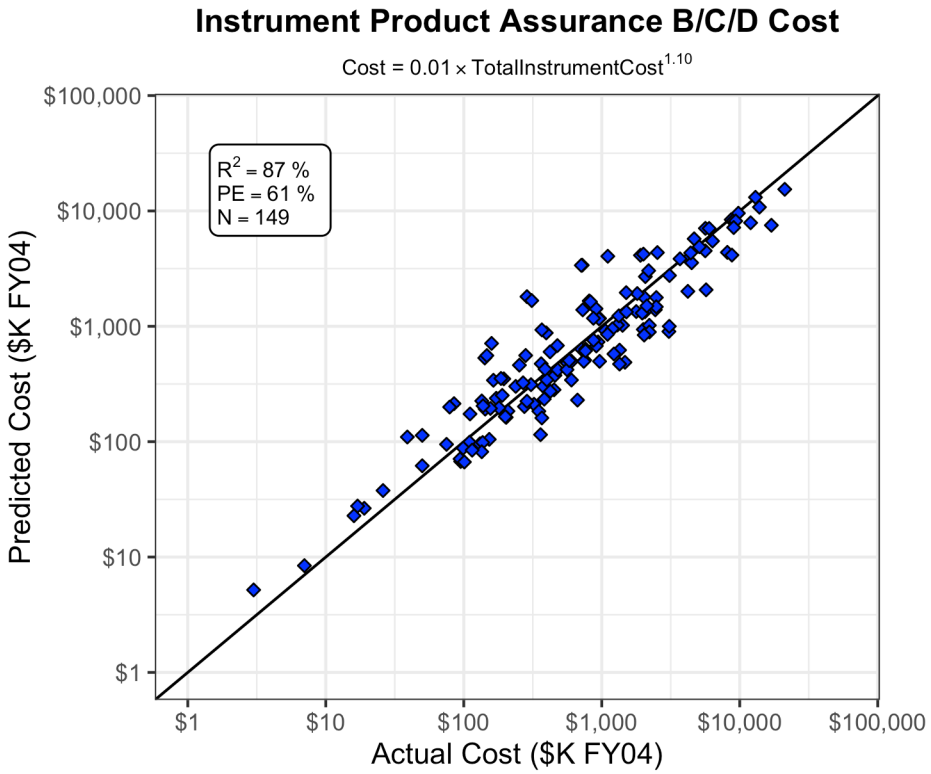
Instruments used in this CER:			
ACIS	ACRIM III	ACS	AIA
AIRS	AMR	AMSU-A	ASI_MET
CAPS	Cassini Radar	CFI	CheMin
CIPS	CIRS	CPR	CRISM
CRISP	CTX	DLRE	EFI_Polar
EFPE	EMLS	ENose	EPPS
ESA_FAST	FGM-ASC	FUSE	GALEX
GCMS	GFO Radiometer	GFO-Alt	GIM
GLAS	GMI	Grace Instrument	GRAND
GRNS	GRS_MO	GRS_Odyssey	GSPEC-OCO
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-Surveyor
MECA-TECP	MER Camera	MET-MPL	MFEX
MFI	MICAS	MIMI	MiniTES
MIP	MIPS	MIR	MIRO
MISR	MLA	MLS	MOC-MO
MODIS	MOLA-MO	MRI	MSI
MWR	NavCam	NGIMS_MAVEN	NICMOS
NIR	NIS	NSCAT	NSP
NuStar	OLI	ONC	PEPE
PEPSSI	PMIRR	RAD	RA-MPL
RA-Phoenix	RAT	RBSPICE	RHESSI
RPWS	SAM	SA-SPaH	SeaWinds
SMAP	SOFIE	SSI-MPL	SSI-Phoenix
STIS	SWAP	TEAMS	TEGA-MPL
TEGA-Phoenix	TES Electrometer	TES_Aura	TES_MO
THEMIS	TLP	TLS	TMR
TOMS	TOPEX ALT	UVIS	UVS - Juno
VCAM ISS	VIMS	VIS_LCROSS	VSP
WAVES_Juno	WAVES_STEREO	WFPC1	WFPC2
WISE	XRS-GRS	XRS-MESSENGER	

Systems Engineering CER



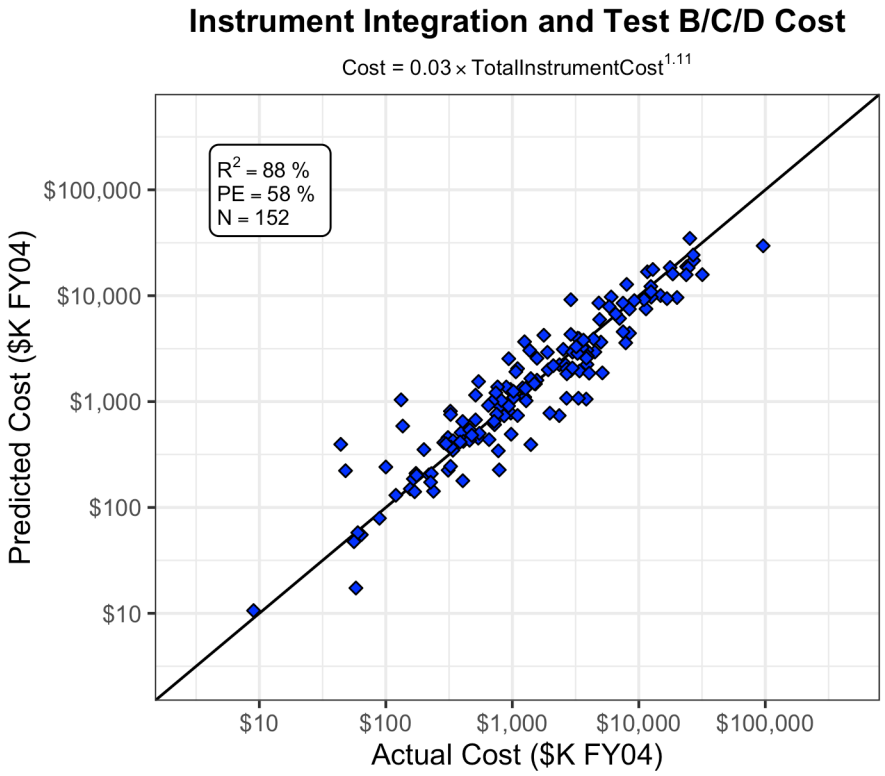
Instruments used in this CER:			
ACIS	ACRIM III	ACS	AIA
AIRS	AMR	AMSU-A	ASI_MET
CAPS	Cassini Radar	CFI	CheMin
CIPS	CIRS	CPR	CRISM
CRISP	CTX	DLRE	EFI_Polar
EFPE	EMLS	ENose	EPPS
ESA_FAST	FGM-ASC	FUSE	GALEX
GCMS	GFO Radiometer	GFO-Alt	GIM
GMI	Grace Instrument	GRAND	GRNS
GRS_MO	GRS_Odyssey	GSPEC-OCO	GSWC
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-Surveyor	MECA-TECP
MER Camera	MET-MPL	MFEX	MFI
MICAS	MIMI	MiniTES	MIP
MIPS	MIR	MIRO	MISR
MLA	MLS	MOC-MO	MODIS
MOLA-MO	MRI	MSI	MWR
NavCam	NGIMS_MAVEN	NICMOS	NIR
NIS	NSCAT	NSP	NuStar
OLI	ONC	PEPE	PEPSSI
PMIRR	RAD	RA-Phoenix	RAT
RBSPICE	RHESSI	RPWS	SAM
SA-SPaH	SeaWinds	SMAP	SOFIE
SSI-MPL	SSI-Phoenix	STIS	SWAP
TEAMS	TEGA-MPL	TEGA-Phoenix	TES Electrometer
TES_Aura	TES_MO	THEMIS	TLP
TLS	TMR	TOMS	TOPEX ALT
UVIS	UVS - Juno	VCAM ISS	VIMS
VIS_LCROSS	VSP	WAVES_Juno	WAVES_STEREO
WFPC1	WFPC2	WISE	WMAP
XRS-GRS	XRS-MESSENGER		

Product Assurance CER



Instruments used in this CER:			
ACIS	ACRIM III	ACS	AIA
AIRS	AMR	AMSU-A	ASI_MET
CAPS	Cassini Radar	CFI	CheMin
CIPS	CIRS	CPR	CRISM
CRISP	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
MARDI-MPL	MARDI-MSL	MARIE	MARSIS
MASCS	MastCam	MCS	MDIS
MECA-Phoenix	MECA-Surveyor	MER Camera	MET-MPL
MFEX	MFI	MIMI	MiniTES
MIP	MIPS	MIR	MISR
MLA	MLS	MOC-MO	MODIS
MOLA-MO	MRI	MSI	MWR
NavCam	NGIMS_MAVEN	NICMOS	NIR
NIS	NSCAT	NSP	NuStar
OLI	ONC	PEPE	PEPSSI
PMIRR	RAD	RA-Phoenix	RAT
RBSPICE	RHESSI	RPWS	SAM
SA-SPaH	SeaWinds	SMAP	SOFIE
SSI-MPL	SSI-Phoenix	STIS	SWAP
TEAMS	TEGA-MPL	TEGA-Phoenix	TES Electrometer
TES_Aura	TES_MO	THEMIS	TLP
TLS	TMR	TOPEX ALT	UVIS
UVS - Juno	VCAM ISS	VIMS	VIS_LCROSS
VSP	WAVES_Juno	WAVES_STEREO	WFPC1
WFPC2	WISE	WMAP	XRS-GRS
XRS-MESSENGER			

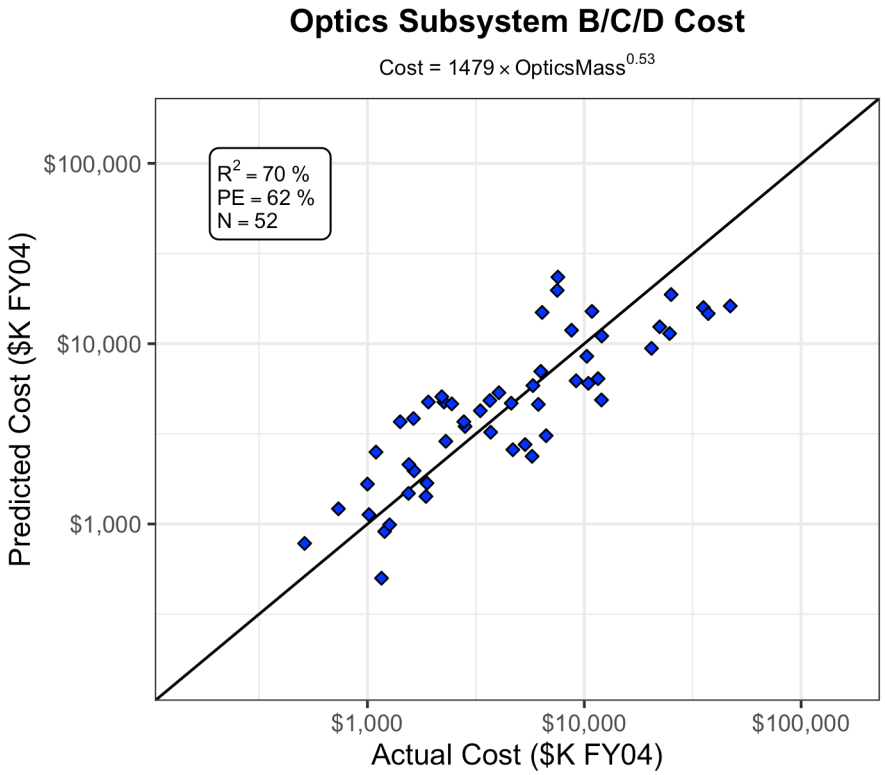
Integration & Test CER



Instruments used in this 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	MAHLI
MARCI	MARDI-MPL	MARDI-MSL	MARIE
MARSIS	MASCS	MastCam	MCS
MDIS	MECA-Phoenix	MECA-Surveyor	MECA-TECP
MER Camera	MET-MPL	MFEX	MFI
MICAS	MIMI	MiniTES	MIP
MIPS	MIR	MIRO	MISR
MLA	MLS	MOC-MO	MODIS
MOLA-MO	MRI	MWR	NavCam
NGIMS_MAVEN	NICMOS	NIR	NSCAT
NSP	NuStar	OLI	ONC
PEPE	PEPSSI	PMIRR	RAD
RA-MPL	RA-Phoenix	RAT	RBSPICE
RHESSI	RPWS	SAM	SA-SPaH
SeaWinds	SMAP	SOFIE	SSI-MPL
SSI-Phoenix	STIS	SWAP	TEAMS
TEGA-MPL	TEGA-Phoenix	TES Electrometer	TES_Aura
TES_MO	THEMIS	TLP	TLS
TMR	TOMS	TOPEX ALT	UVIS
UVS - Juno	VCAM ISS	VIMS	VIS_LCROSS
VSP	WAVES_Juno	WAVES_STEREO	WFPC1
WFPC2	WISE	WMAP	XRS-MESSENGER

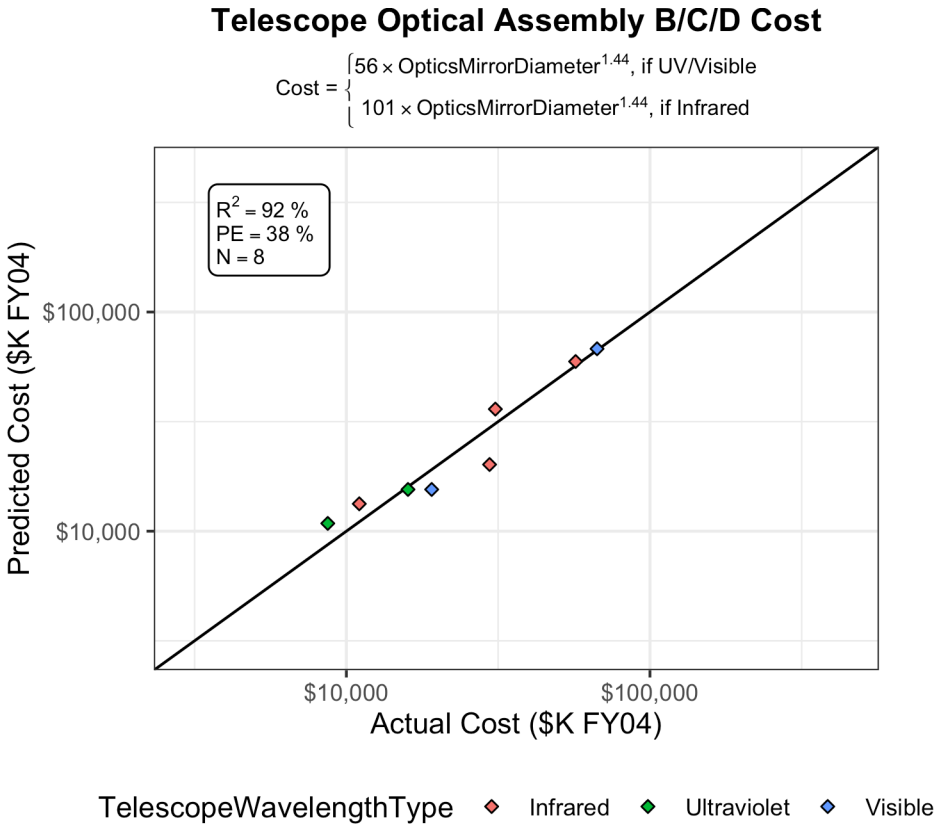
Subsystem Level CERs

Optics Subsystem CER



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

Telescope Optical Assembly Subsystem CER (for Apertures >= 30 cm)



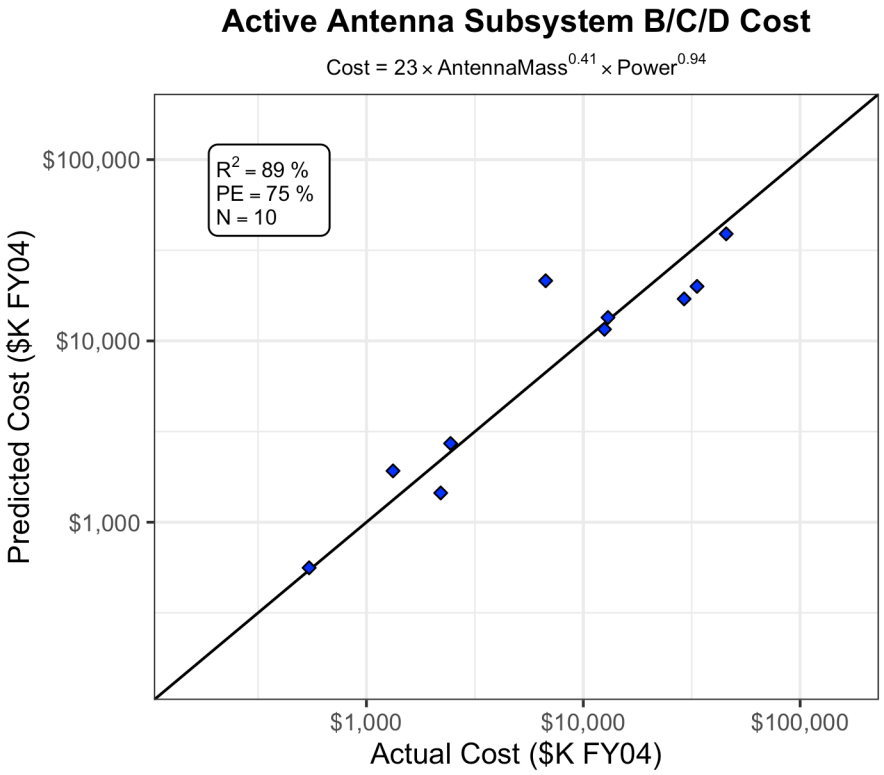
Instruments used in this CER:		
FUSE Telescope	GALEX Telescope	HiRISE Telescope
IRAS_Telescope	Kepler Telescope	Spitzer Telescope
WIRE_Telescope	WISE Telescope	

Alternative form of equation:

$$Cost = 56\ OpticsMirrorDiameter^{1.44}\ exp(TelescopeWavelengthType)^{0.58}$$

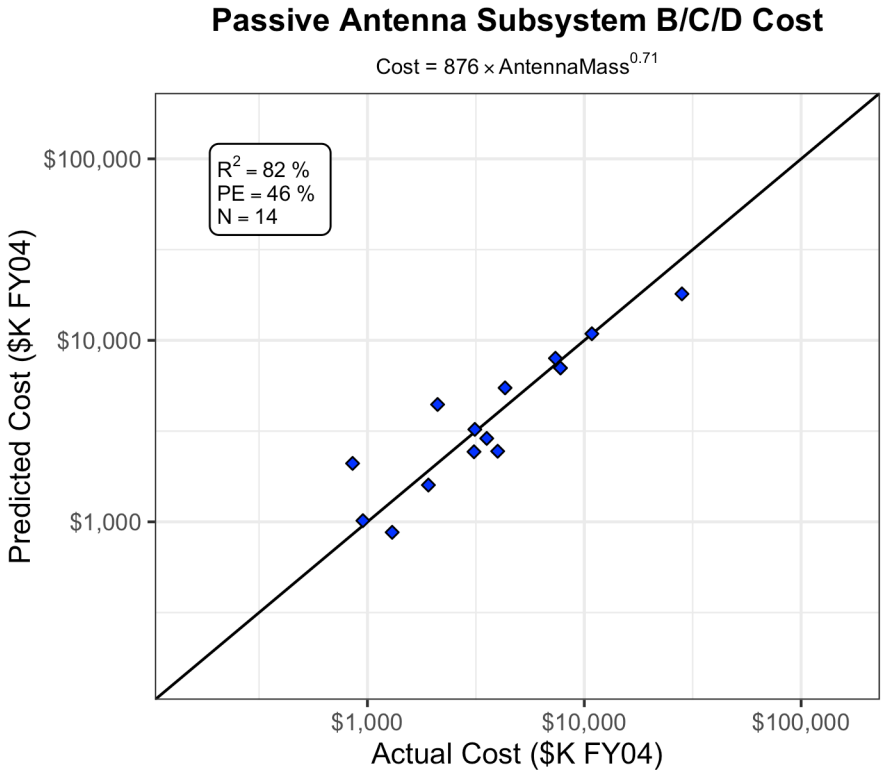
where TelescopeWavelengthType = 0 if Visible/Ultraviolet, & TelescopeWavelengthType = 1 if Infrared

Active Microwave Antenna Subsystem CER



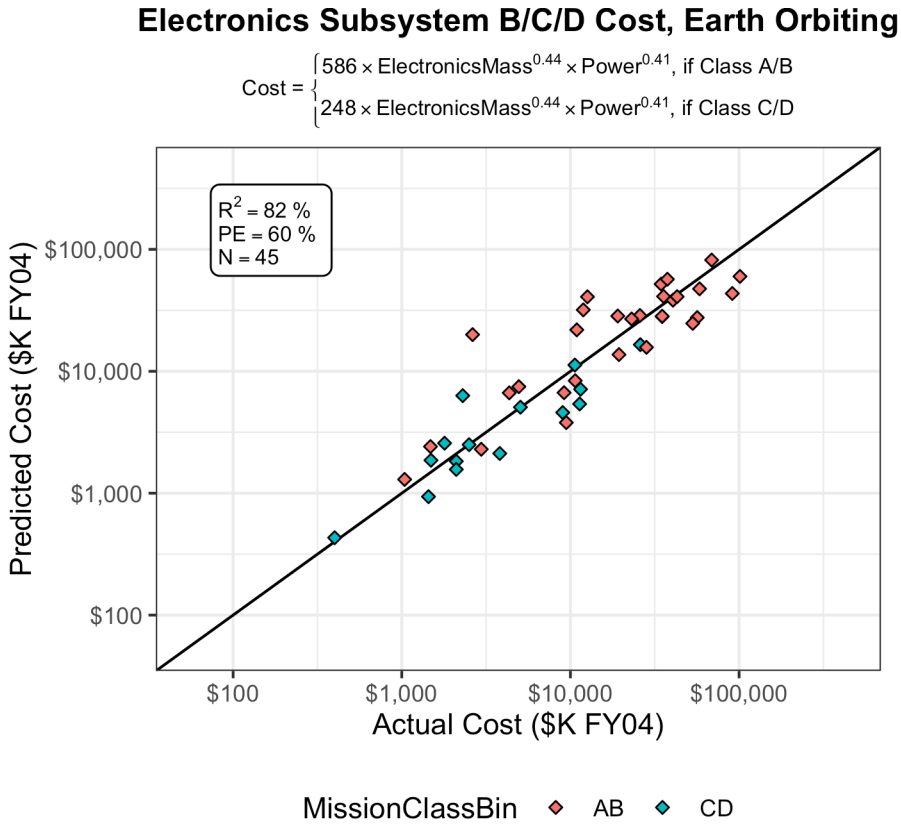
Instruments used in this CER:		
Cassini Radar	CPR	GFO-Alt
Grace Instrument	LGRS	MARSIS
NSCAT	SeaWinds	SMAP
TOPEX ALT		

Passive Microwave Antenna Subsystem CER



Instruments used in this CER:		
AMR	EMLS	FGM-ASC
GFO Radiometer	GMI	JADE
JMR	MIRO	MLS
MWR	RPWS	SWICS_Ulysses
TMR	WAVES_Juno	

Electronics Earth Orbiting Subsystem CER



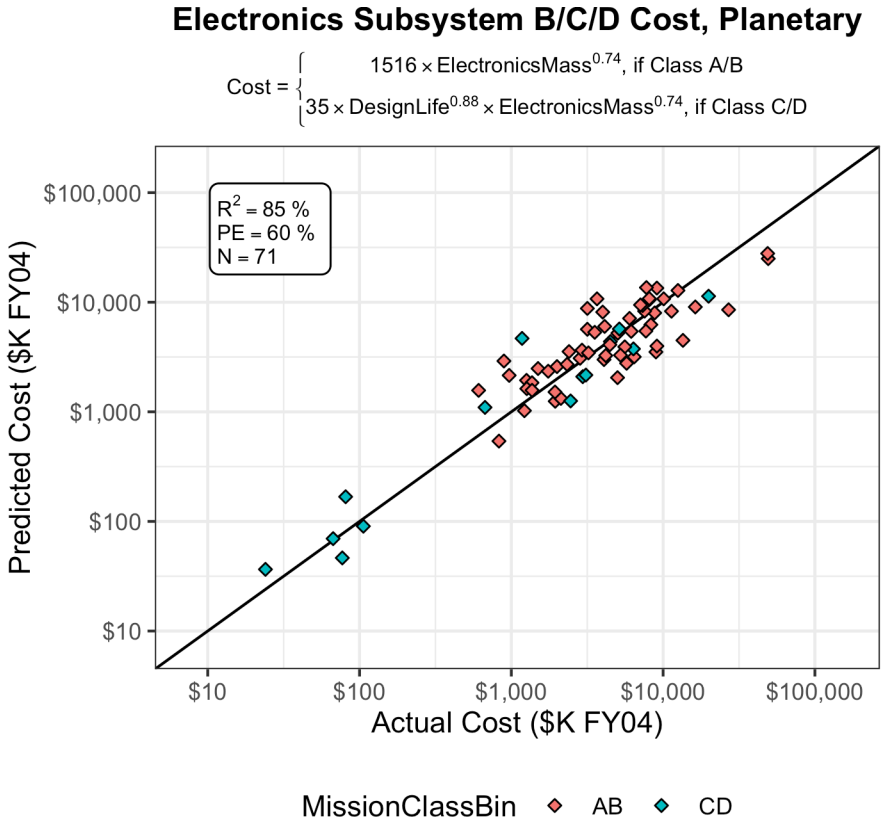
Instruments used in this CER:				
ACIS	ACRIM III	ACS	AIA	AIRS
AMR	CIPS	CPR	EFI_Polar	EFPE
EMLS	ESA_FAST	FUSE	GALEX	GFO Radiometer
GFO-Alt	GLAS	GMI	Grace Instrument	GSPEC-OCO
GUVI	HYDRA	IBEX	JMR	MAG FAST
MISR	MLS	MODIS	NICMOS	NSCAT
NuStar	OLI	RHESSI	SeaWinds	SMAP
SOFIE	STIS	TEAMS	TES_Aura	TMR
TOMS	TOPEX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

Alternative form of equation:

$$Cost = 586\ ElectronicsMass^{0.44}\ Power^{0.41}\ exp(MissionClassBin)^{-0.86}$$

where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Electronics Planetary Subsystem CER



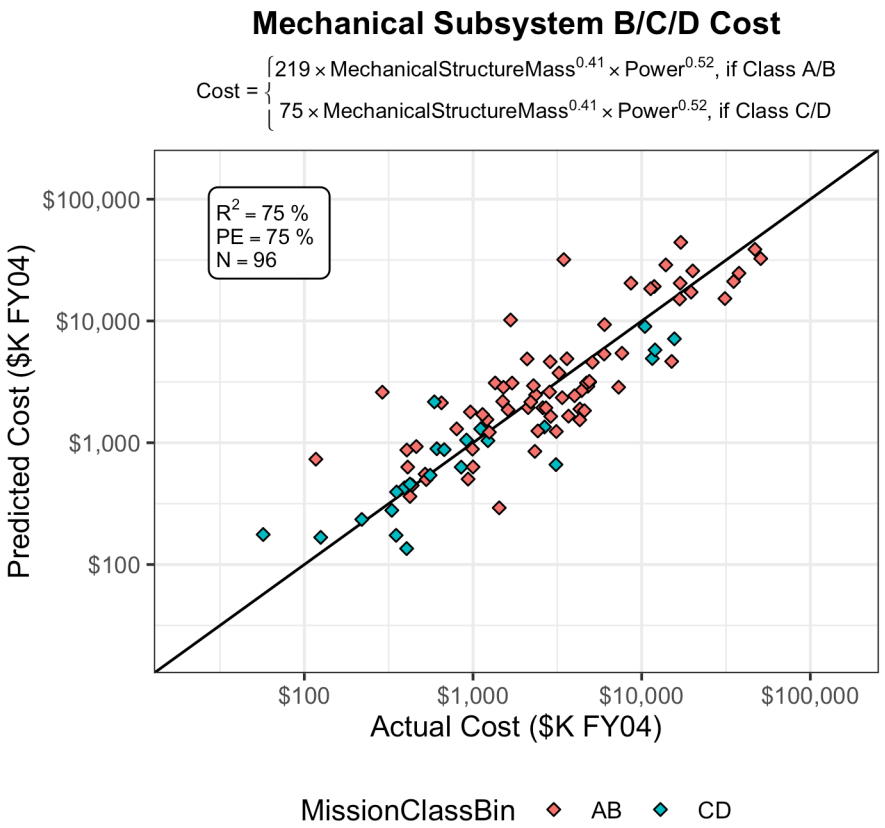
Instruments used in this CER:			
CAPS	Cassini Radar	CFI	CIRS
CRISM	CRISP	CTX	DLRE
EPPS	FGM-ASC	GRAND	GRNS
GRS_MO	GRS_Odyssey	HiRISE	HISCALE
HRI_Deep_Impact	INMS	IRAC	IRS
ISS	ITS	JADE	JEDI
JunoCam	Kepler	LGRS	LOLA
LORRI	M3	MAG MESSENGER	MAG NEAR
MARCI	MARIE	MARSIS	MASCS
MCS	MDIS	MFI	MICAS
MIPS	MIR	MIRO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

Alternative form of equation:

$$Cost = 1516\ ElectronicsMass^{0.74}\ (DesignLife)^{0.88 \times MissionClassBin}\ exp(MissionClassBin)^{-3.78}$$

where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Mechanical/Structures Subsystem CER



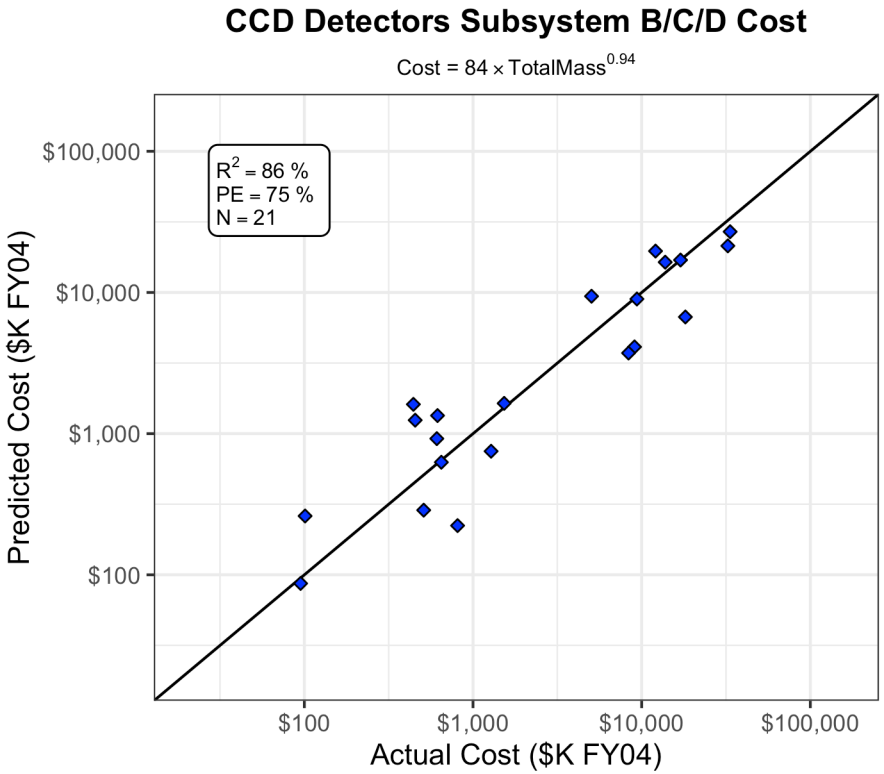
Instruments used in this CER:			
ACIS	ACRIM III	ACS	AIA
AIRS	AMR	CAPS	CFI
CIPS	CIRS	CPR	CRISM
CRISP	CTX	DLRE	EFPE
EMLS	EPPS	ESA_FAST	GLAS
GMI	Grace Instrument	GRAND	GRNS
GRS_MO	GRS_Odyssey	GSPEC-OCO	GUVI
HISCALE	HYDRA	INMS	IRAC
IRS	ISS	ITS	JADE
JEDI	JMR	JunoCam	LGRS
LOLA	LORRI	M3	MAG FAST
MAG MESSENGER	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	SOFIE
STIS	SWAP	SWICS_Ulysses	TEAMS
TES_Aura	TES_MO	THEMIS	TLP
TMR	TOMS	UVIS	UVS - Juno
VIMS	VIS_LCROSS	VSP	WAVES_Juno
WFPC1	WFPC2	XRS-GRS	XRS-MESSENGER

Alternative form of equation:

$$Cost = 219\ MechanicalStructureMass^{0.41}\ Power^{0.52}\ exp(MissionClassBin)^{-1.07}$$

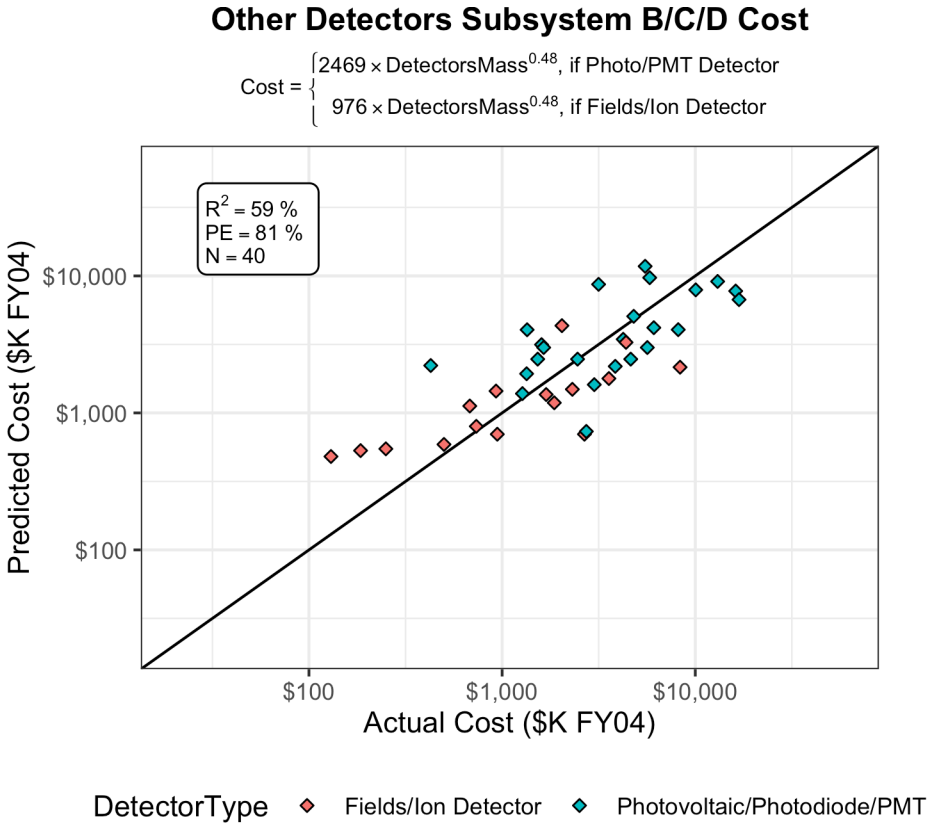
where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

CCD Detectors Subsystem CER



Instruments used in this CER:			
ACIS	ACS	AIA	CFI
CIPS	CTX	HiRISE	ISS
ITS	JunoCam	Kepler	LORRI
MARCI	MICAS	MISR	MOC-MO
MRI	ONC	STIS	WFPC1
WFPC2			

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



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

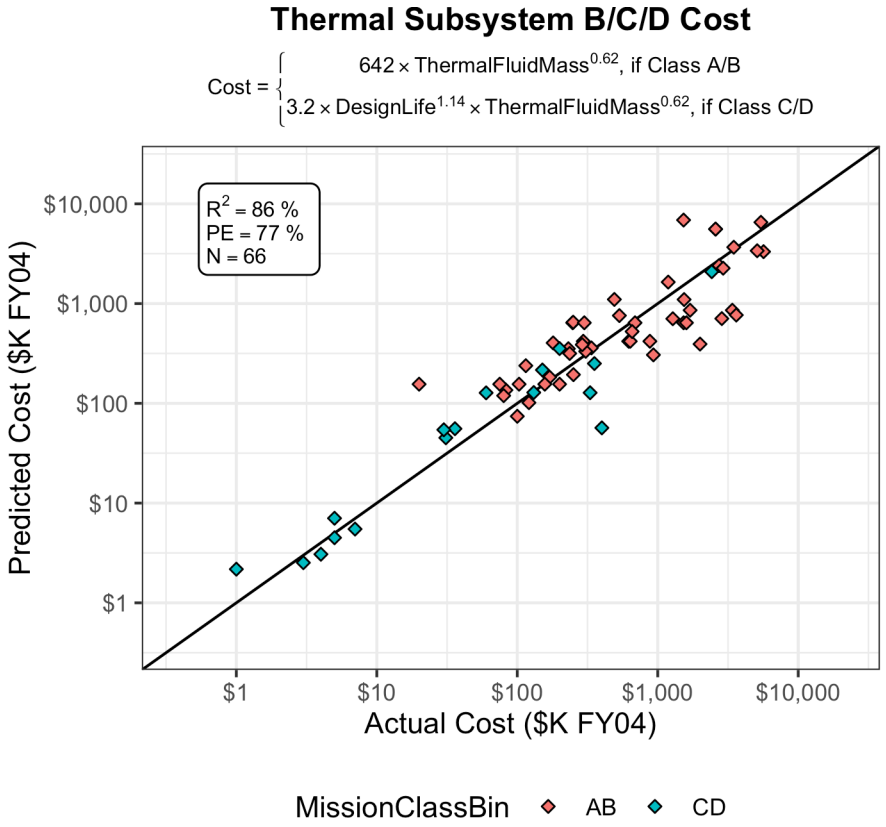
Alternative form of equation:

$$Cost = 2469\ DetectorsMass^{0.48}\ exp(DetectorType)^{-0.93}$$

where DetectorType = 0 if Fields/Ion Detector, & DetectorType = 1 if Photovoltaic/Photodiode/PMT

Thermal/Fluid Subsystem CER

(non-Cryocooler/cryostat/dewar)



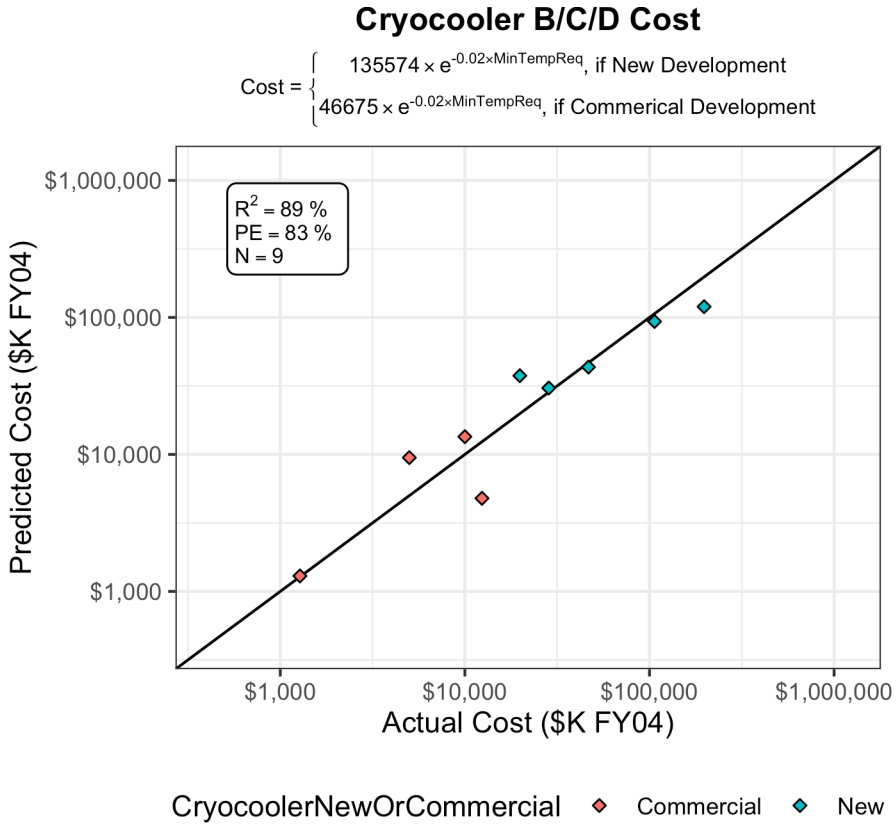
Instruments used in this CER:			
ACIS	ACS	AMR	CFI
CIPS	CIRS	CTX	DLRE
EFPE	EMLS	EPPS	FGM-ASC
GLAS	GMI	Grace Instrument	GRAND
GRNS	GRS_MO	GRS_Odyssey	HISCALE
INMS	IRAC	IRS	ISS
ITS	JADE	JEDI	JunoCam
LOLA	M3	MARCI	MARIE
MASCS	MDIS	MICAS	MIPS
MIR	MLA	MODIS	MOLA-MO
MRI	NavCam	NIR	NSP
NuStar	OLI	PEPE	PMIRR
RPWS	SMAP	SOFIE	SWICS_Ulysses
TEAMS	TES_MO	THEMIS	TLP
TOMS	UVIS	UVS - Juno	VIMS
VIS_LCROSS	VSP	WAVES_Juno	WFPC1
WFPC2	XRS-MESSENGER		

Alternative form of equation:

$$Cost = 642\ (DesignLife)^{1.14 \times MissionClassBin}\ ThermalFluidMass^{0.62}\ exp(MissionClassBin)^{-5.29}$$

where MissionClassBin = 0 if Class A or B, & MissionClassBin = 1 if Class C or D

Cryocooler Assembly Subsystem CER



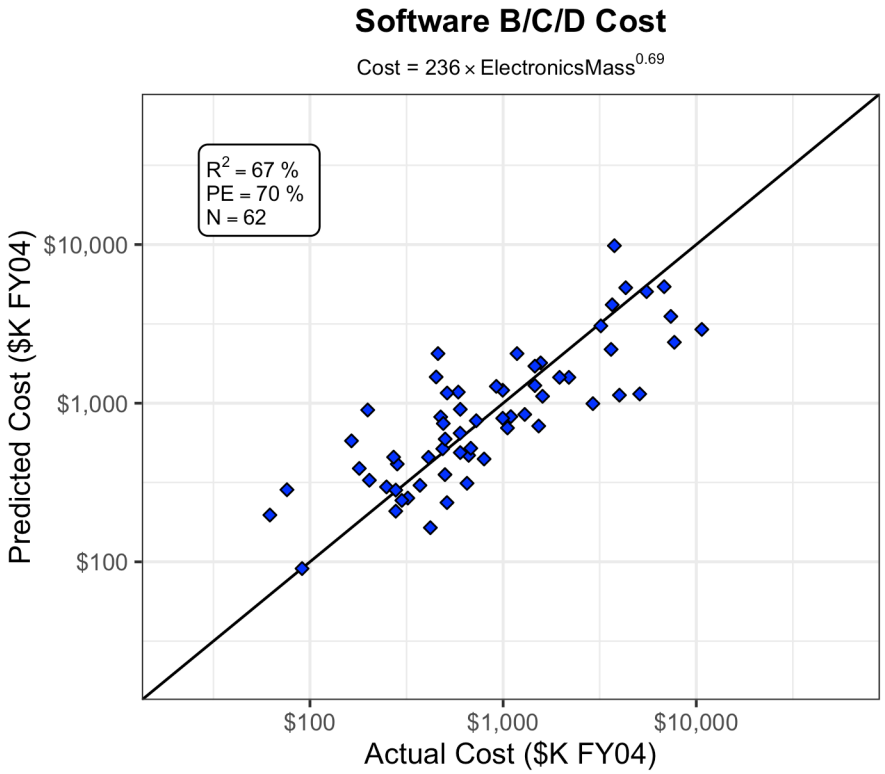
Instruments used in this CER:		
ABI_Cryocooler	AIRS_Cryocooler	AMS-02_Cryocooler
CheMin_Cryocooler	MIRI_Cryocooler_Full_System	MIRI_Cryocooler_PT_Assembly
NICMOS_Cryocooler	OCO_2_Cryocooler	TES_Aura_Cryocooler

Alternative form of equation:

$$Cost = 135574\, e^{\{-0.02 \times MinTempReq + 1.07 \times CryocoolerNewOrCommercial\}}$$

where CryocoolerNewOrCommercial = 0 if Commercial, & CryocoolerNewOrCommercial = 1 if New

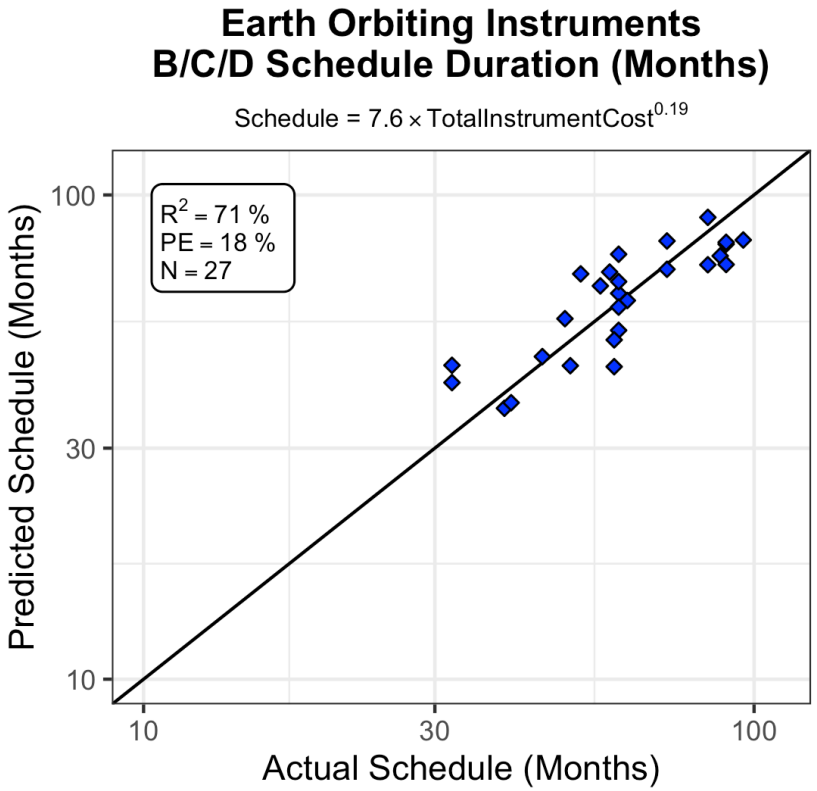
Software Subsystem CER



Instruments used in this CER:				
ACIS	ACS	AIA	AIRS	CAPS
CFI	CRISM	CRISP	CTX	DLRE
EFI_Polar	EMLS	EPPS	ESA_FAST	GALEX
GMI	GRAND	GRNS	GRS_MO	GRS_Odyssey
HiRISE	HRI_Deep_Impact	HYDRA	IBEX	INMS
IRS	ISS	ITS	JunoCam	Kepler
LGRS	LOLA	LORRI	M3	MAG MESSENGER
MAG NEAR	MARCI	MARIE	MASCS	MCS
MDIS	MICAS	MIPS	MIRO	MOC-MO
MOLA-MO	MRI	MSI	MWR	NICMOS
NIS	OLI	PEPE	RPWS	SOFIE
STIS	SWAP	TES_Aura	TOMS	VIMS
XRS-GRS	XRS-MESSENGER			

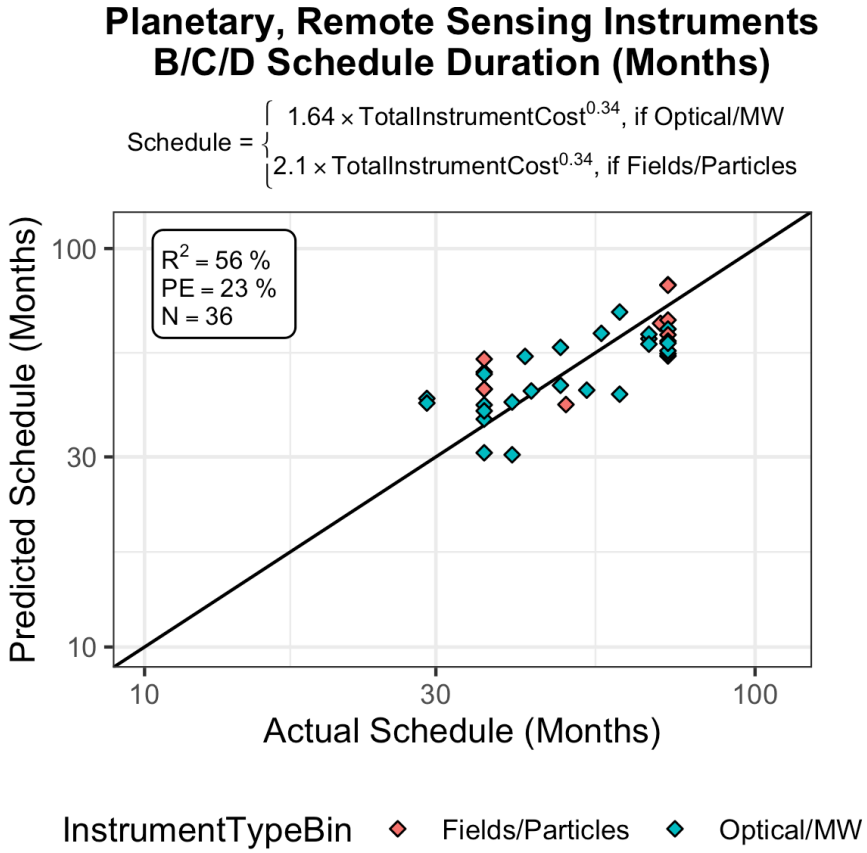
Schedule Estimating Relationships (SERs)

Earth Orbiting SER



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

Planetary Remote Sensing SER



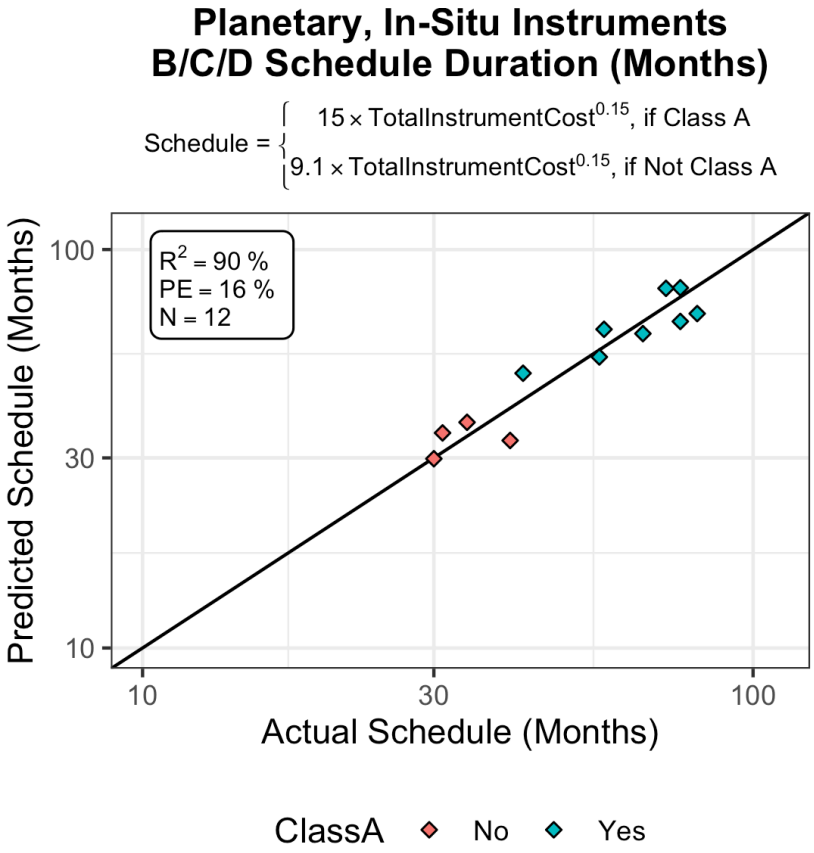
Instruments used in this CER:				
CAPS	Cassini Radar	CRISM	CRISP	CTX
DLRE	EPPS	GRNS	GRS_MO	HISCALE
IRAC	IRS	ISS	ITS	M3
MASCS	MCS	MDIS	MICAS	MIMI
MIPS	MLA	MOC-MO	MOLA-MO	MRI
MWR	PMIRR	RPWS	SWAP	TES_MO
THEMIS	URAP	UVIS	UVS - Juno	VIMS
XRS-MESSENGER				

Alternative form of equation:

$$Cost = 1.64\ TotalInstrumentCost^{0.34}\ exp(InstrumentTypeBin)^{0.26}$$

where InstrumentTypeBin = 0 if Optical/MW, & InstrumentTypeBin = 1 if Fields/Particles

Planetary In-Situ SER



Instruments used in this CER:				
CheMin	IDD	MAHLI	MARDI-MSL	MastCam
MER Camera	RAD	RA-Phoenix	SAM	SA-SPaH
SSI-Phoenix	TLS			

Alternative form of equation:

$$Cost = 15\ TotalInstrumentCost^{0.15} exp(ClassA)^{-0.51}$$

where ClassA = 0 if Class A, & ClassA = 1 if not Class A

Agenda

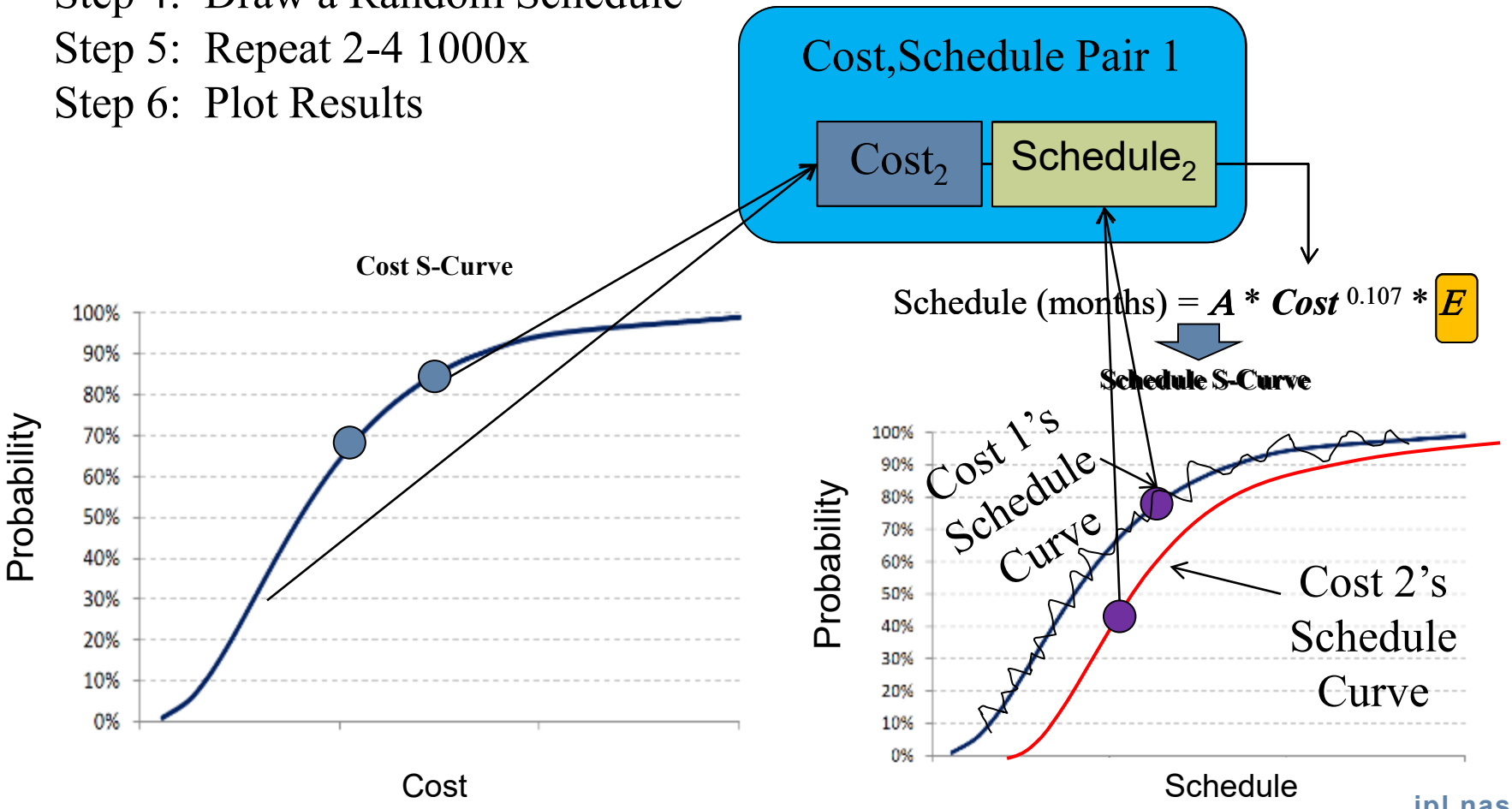
- Acknowledgements
- NICM 101
  - Introduction
  - Instrument Data
  - Modeling Methodologies
  - Models
  - **JCL**
  - Tool Demonstration

JCL Simulation

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

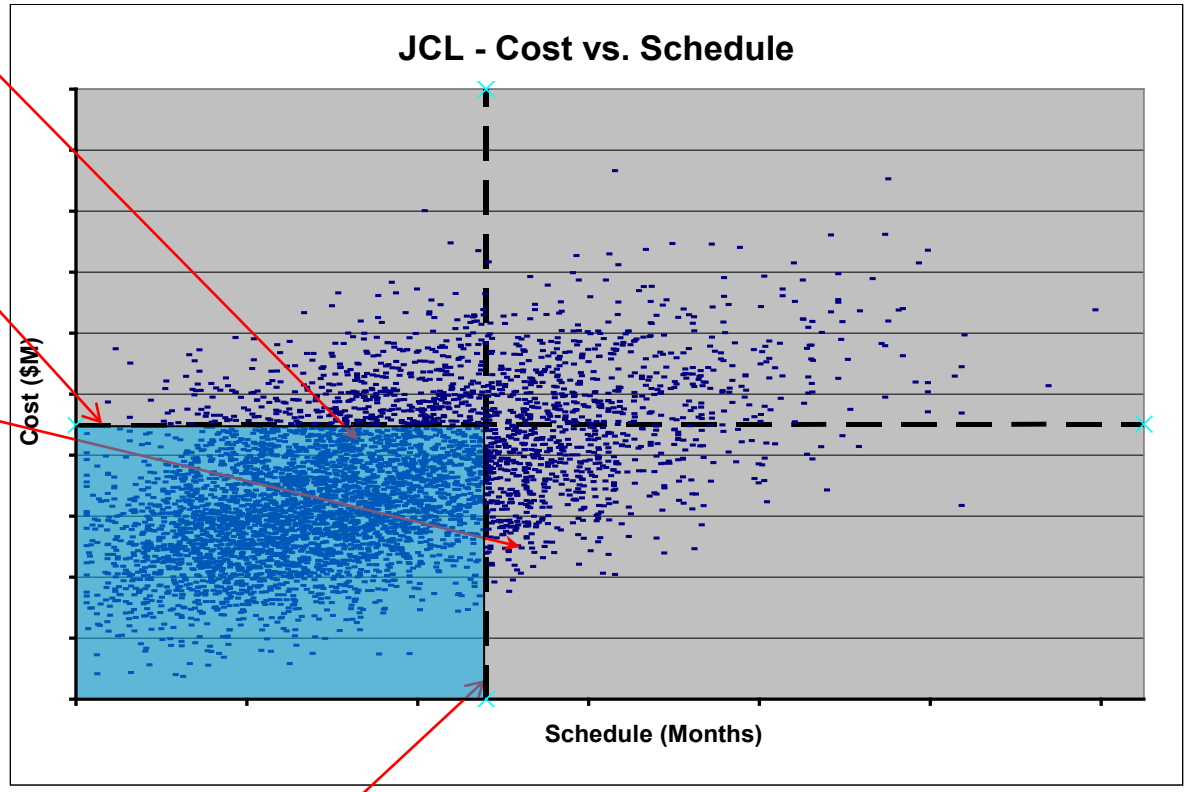
JCL Simulation

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



(Schedule$_2$, Cost$_2$)

Cost Cap

(Schedule$_1$, Cost$_1$)

Percentage of Cost,Schedule Pairs = JCL%

Schedule Cap

Agenda

- Acknowledgements
- NICM 101
  - Introduction
  - Instrument Data
  - Modeling Methodologies
  - Models
  - JCL
  - **Tool Demonstration**

NICM Publications & Presentations

1. IEEE Aerospace

- Upcoming accepted paper: “Salvaging Data Records with Missing Data: Data Imputation using the Multivariate t Distribution,” 2021 Aerospace Conference, Virtual, March 2021, M. Hooke, J. Mrozinski, M. DiNicola
- “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.

2. 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.
- “NICM Schedule & Cost Rules of Thumb,” 2009 Aerospace Conference, Pasadena, CA, September, 2009, H. Habib-Agahi, G. Fox, G. Ball.

3. 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, CO, June 2014, H. Habib-Agahi, J. Mrozinski, G. Fox.

NICM Publications & Presentations

NASA Cost and Schedule Symposium Presentations

- 2020: NICM 9 announced 2020 NASA Cost & Schedule Virtual Gathering.
- 2019: “NICM 8.5,” Johnson Space Center, J. Mrozinski, M. Ramirez.
- 2018: “NASA Instrument Cost model: Version VIII Major Improvements,” Goddard Space Flight Center, J. Mrozinski, J. Johnson.
- 2017: “NICM – Cryocooler,” NASA Headquarters, J. Mrozinski, M. DiNicola.
- 2017: “The Silent “S” in NICM – NICM Schedule Capabilities”, NASA Headquarters, J. Mrozinski, M. DiNicola.
- 2016: “NASA Instrument Cost Model Impact of Mission Class on Cost,” Glenn Research Center, August 2016, J. Mrozinski, M. DiNicola, H. Habib-Agahi.
- 2015: “NICM Version VII,” Ames Research Center, H. Habib-Agahi, J. Mrozinski, M. DiNicola.
- 2014: “Telescope Cost Estimating,” Langley Research Center, H. Habib-Agahi, J. Mrozinski.
- 2013: “NASA Instrument Cost Model for Explorer-like Mission Instruments,” Jet Propulsion Laboratory, H. Habib-Agahi, J. Mrozinski, G. Fox, G. Ball.
- 2012: “NASA Instrument Cost Model,” Applied Physics Laboratory, H. Habib-Agahi, J. Mrozinski.
- 2011: “NICM,” Johnson Space Center, J. Mrozinski.

Presented at the 2022 ICEAA Professional Development & Training Workshop: www.iceaaonline.com/pit2022

Questions?

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Jet Propulsion Laboratory
California Institute of Technology

November 2, 2020

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov