NASA Instrument Cost Model

Impact of Mission Class on Cost

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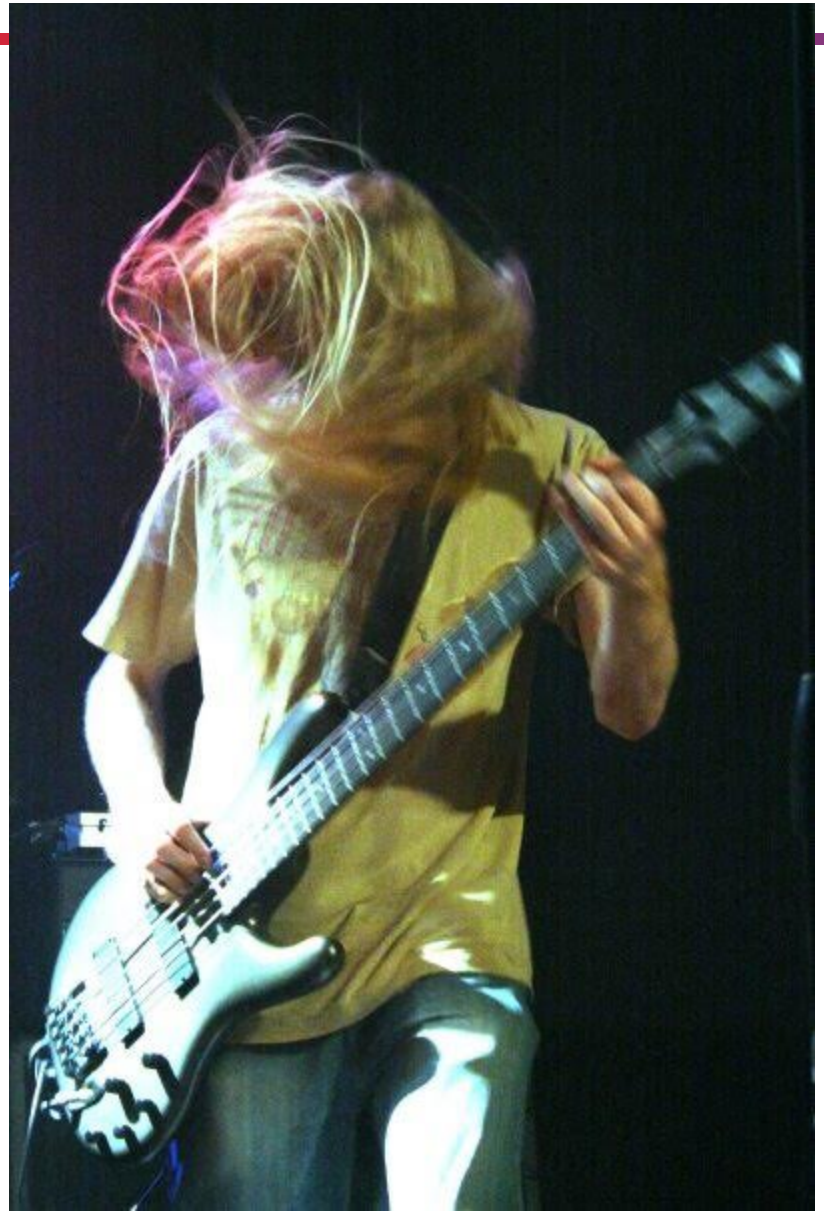
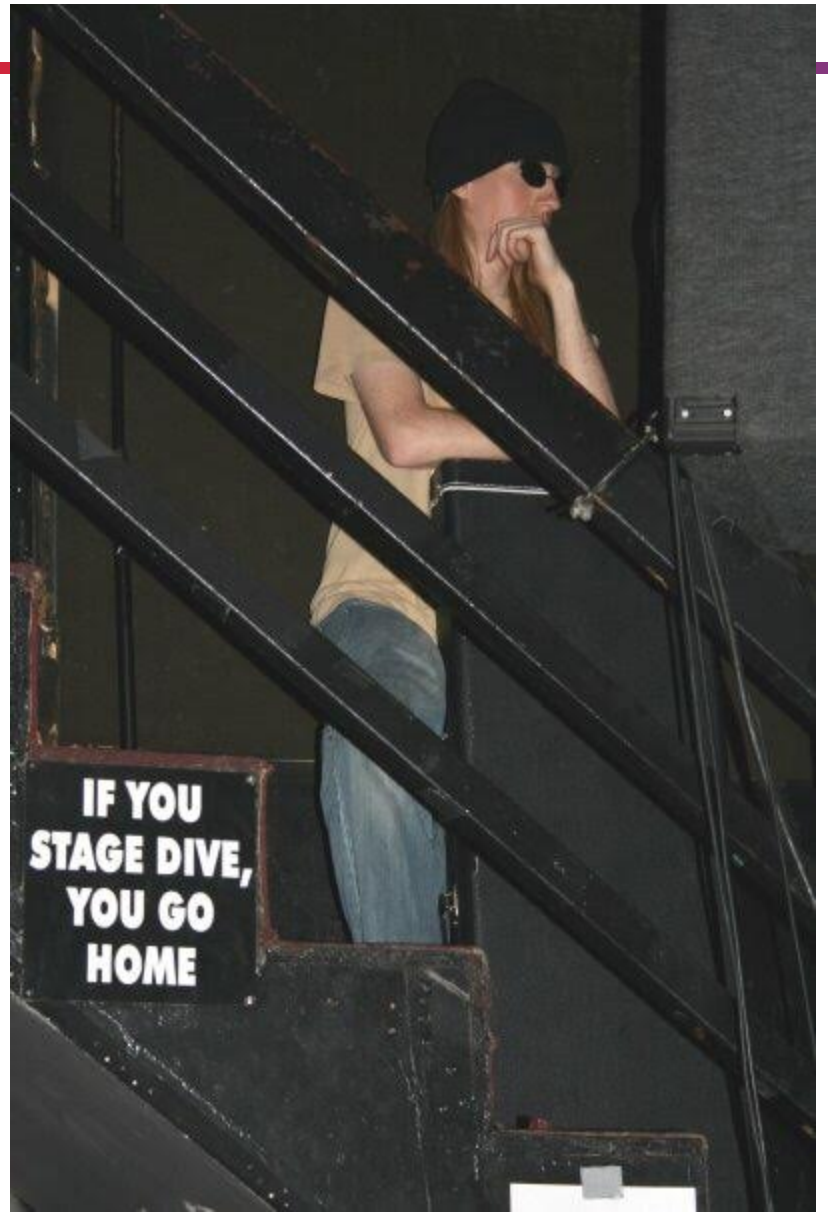
NASA Cost Symposium, August 2016

Jet Propulsion Laboratory
California Institute of Technology




IF YOU
STAGE DIVE,
YOU GO
HOME

What is NICM?

- NASA Instrument Cost Model
  - Probabilistic Cost Estimates for Space Flight Instruments
  - Used by all NASA Centers
    - And any organization proposing instruments for NASA Instruments
    - And proposal evaluators
  - Version I Released in 2007
  - Version VII Rev 2 Released 2016

What is NICM?

- NICM also:
  - Estimates schedule
  - Estimates cost and schedule phase breakdowns
  - Supports JCL
  - Contains an normalized instrument database (for civil servants)

Yes – you can get a copy of NICM

- RSVP for only training at:

Joseph.J.Mrozinski@jpl.nasa.gov

Just kidding, you'll never remember that

NICM@jpl.nasa.gov

Today's Story: Mission Class

- Once upon a time… (2007):
  - Version I of NICM was released, and lived (mostly) in the kingdom of Class B missions.
  - For many ages, NICM prospered in this land (NICM I – NICM V)…
  - …Until the denizens of Class C Missions revolted!
  - NICM VI was bestowed upon the land of Class C Missions (2014), and everybody* lived happily ever after.
  - Or so we thought…

*Everybody = C Class Missions/University Built/High Inheritance

Today's Story: Mission Class

- In order for EVERYBODY to be happy, NICM needs to be able to help out Class D missions as well.
- And it's Mike's job to make everybody happy =)

Preliminary Analysis of Mission Class on Optical Instrument Cost

Mike DiNicola

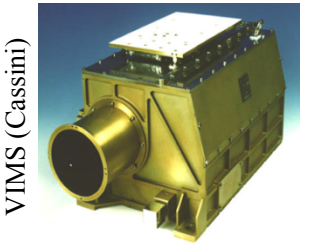
NASA Cost Symposium, August 2016

Overview

- NASA's Mission Class is way to classify acceptable risk for NASA payloads.
  - "Risk" = likelihood of not achieving mission success
- Mission Class drives the scope of work throughout development, for example:
  - Design
  - Documentation
  - Reliability
  - Requirements
  - Reviews
  - Testing, analysis, qualification

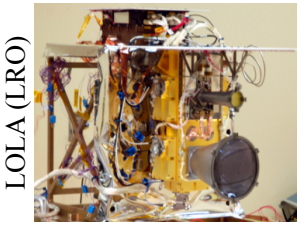
If Mission Class drives the scope of work, then shouldn't it drive cost as well?

VIMS (Cassini)



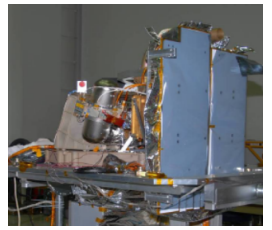
Class A

LOLA (LRO)



Class B

GSPEC (OCO)



Class C

NIS (LCROSS)

Class D

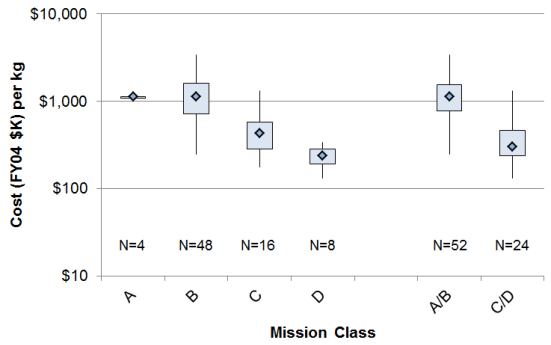
What We Are Doing

- The NICM Team is analyzing the Mission Class/ Instrument cost relationship for 76 remote sensing optical instruments flying on 42 NASA space missions.
  - Largest homogenous group of data in the NICM Database
- Review results with the NICM Team and larger cost community.
- Presented here are results of this analysis to-date, focusing on top-level observations.

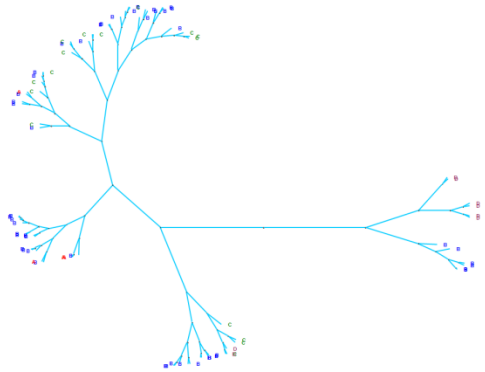
Discussion is encouraged!

Analysis Process

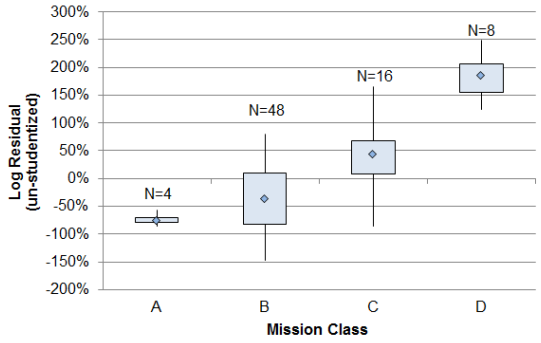
1 Cost-per-kg



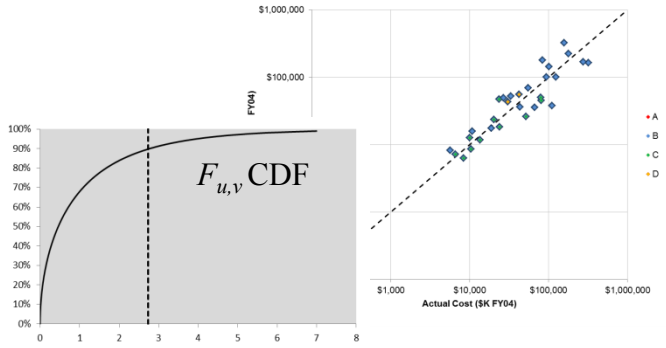
2 Cluster Analysis



3 Model Residuals



4 Preliminary CERs & Formal Analysis of Covariance

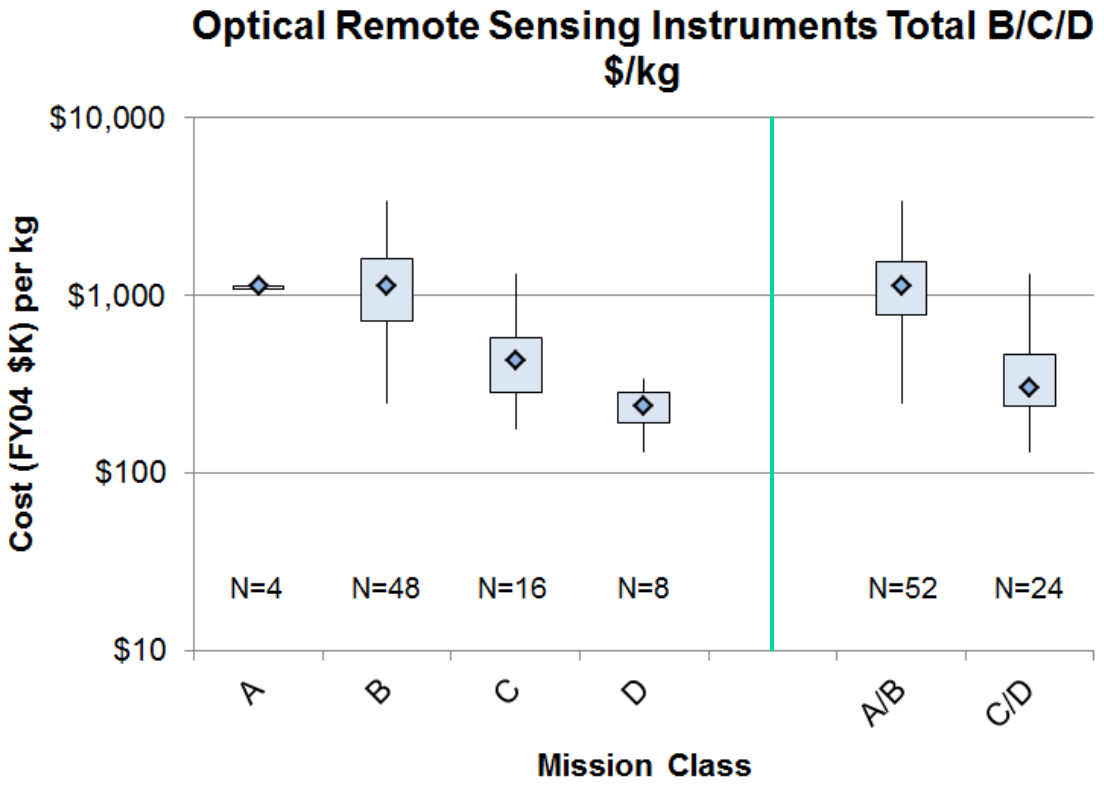


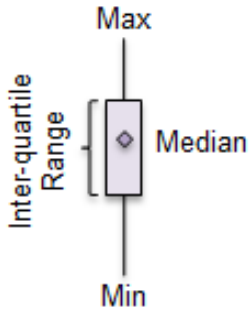
Normalized Data Used in this Analysis

(Remote Sensing Optical Instruments Only)

Mission Class	Instrument (Mission) *Earth Orbiting = Blue; Planetary = Black	Count
Class A	CIRS, ISS, UVIS, VIMS (all Cassini)	4
Class B	ACIS (Chandra), ACRIM II (UARS), ACRIM III (ACRIMSAT), AIA (SDO), AIRS (Aqua), ALICE (Rosetta), APS-Glory (Glory), CERES (TRMM), CFI (CONTOUR), CRISM (MRO), CRISP (CONTOUR), CTX (MRO), DLRE (LRO), EVE (SDO), HIRDLS (Aura), HiRISE (MRO), HMI (SDO), HRC (Chandra), HRI (Deep Impact), IRAC (Spitzer), IRS (Spitzer), ITS (Deep Impact), JunoCam (Juno), LAC (EO-1), LOLA (LRO), LORRI (New Horizons), LROC (LRO), M3 (Chandrayaan 1), MARCI (MRO), MASCS (MESSENGER), MCS (MRO), MDIS (MESSENGER), MICAS (Deep Space 1), MIPS (Spitzer), MISR (Terra), MLA (MESSENGER), MOC (Mars Observer), MODIS (Terra), MOLA (Mars Observer), MRI (Deep Impact), OLI (LDCM), ONC (MRO), PHOTO (Kepler), PMIRR (Mars Observer), TES (Aura), TES_MO (Mars Observer), TOMS (EP - Earth Probe Satellite), UVS (Juno)	48
Class C	CHIPS, CIPS (AIM), FUV (IMAGE), GALEX, GSPEC-OCO (OCO), GUVI (TIMED), IRIS, MSI (NEAR), NavCam (Stardust), NIS (NEAR), NLR (NEAR), SABER (TIMED), SOFIE (AIM), THEMIS (Mars Odyssey), TRACE, WISE	16
Class D	MIR, NIR, NSP, TLP, VIS, VSP (all LCROSS), NuStar, RHESSI	8
Total		**76**

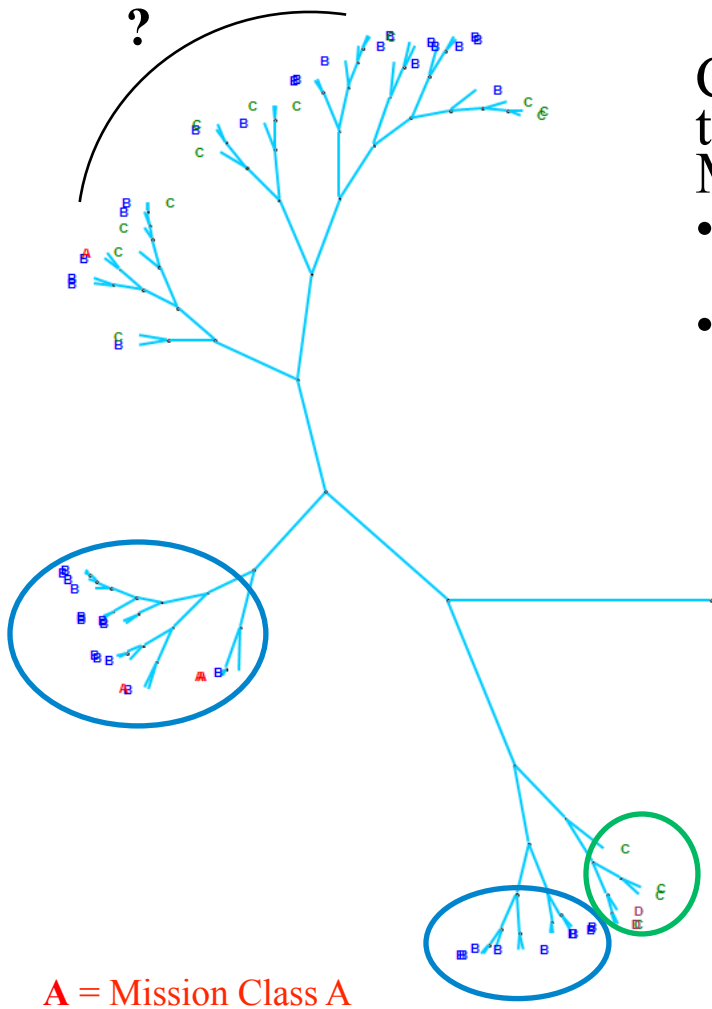
Data Exploration: Cost-per-kg
Mission Class





Tapering down of the cost-per-kg is evident as Mission Class moves from A/B to C/D.

Data Exploration: Cluster Analysis
Mission Class



Cluster analysis performed to visualize how the data may group itself according to Mission Class

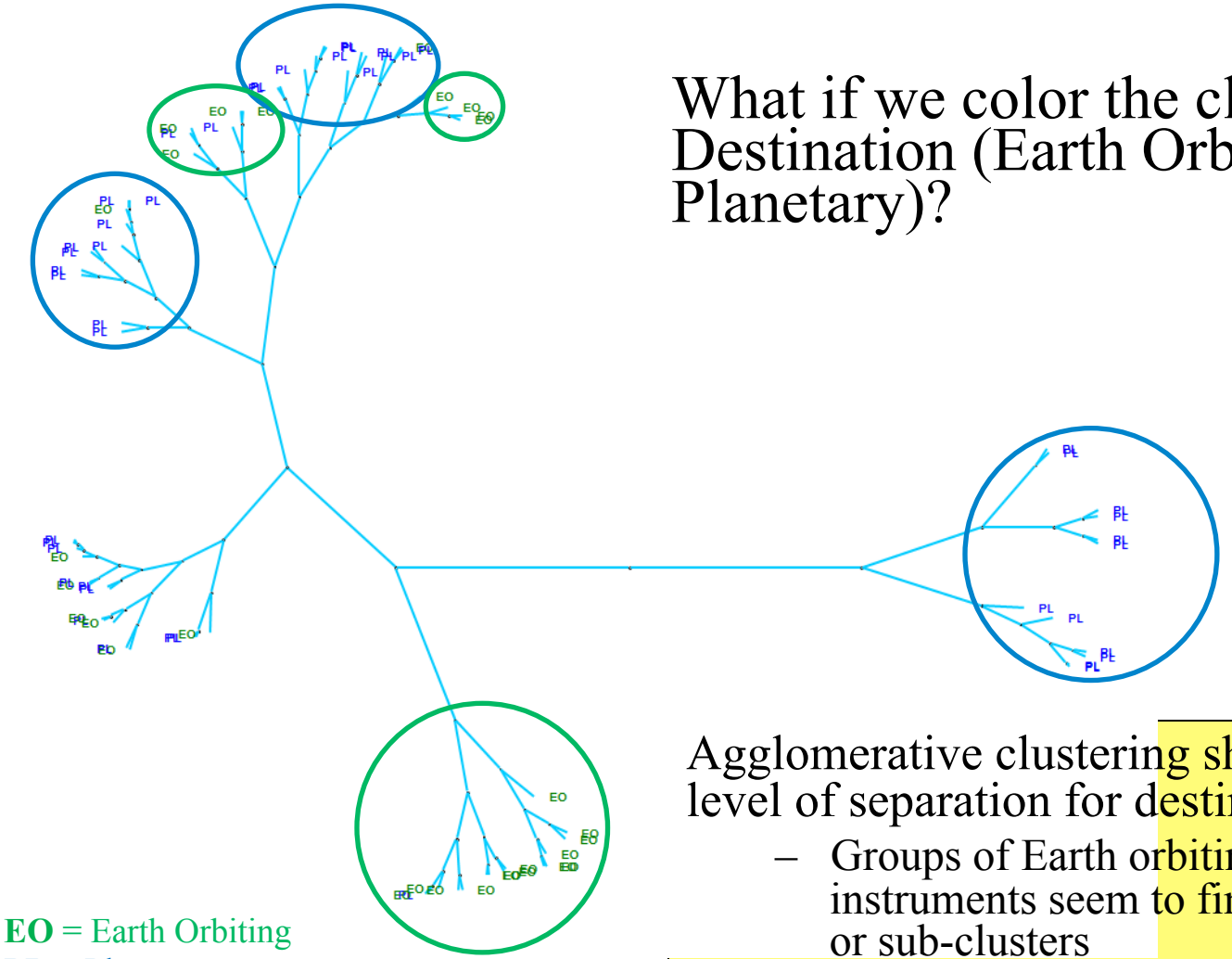
- Utilized cost and quantitative cost drivers (mass, power, design life, schedule)
- Mission Class is not an input to cluster algorithm

A = Mission Class A
B = Mission Class B
C = Mission Class C
D = Mission Class D

Agglomerative clustering shows some (but not strong) separation for Mission Class

- Class D data does show some separation
- Class B and C separation not apparent in some branches, more evident in others
- Other clustering algorithms will also be investigated
- Mission Class still may be a useful or significant parameter for a model.

Data Exploration: Cluster Analysis
How about Destination?



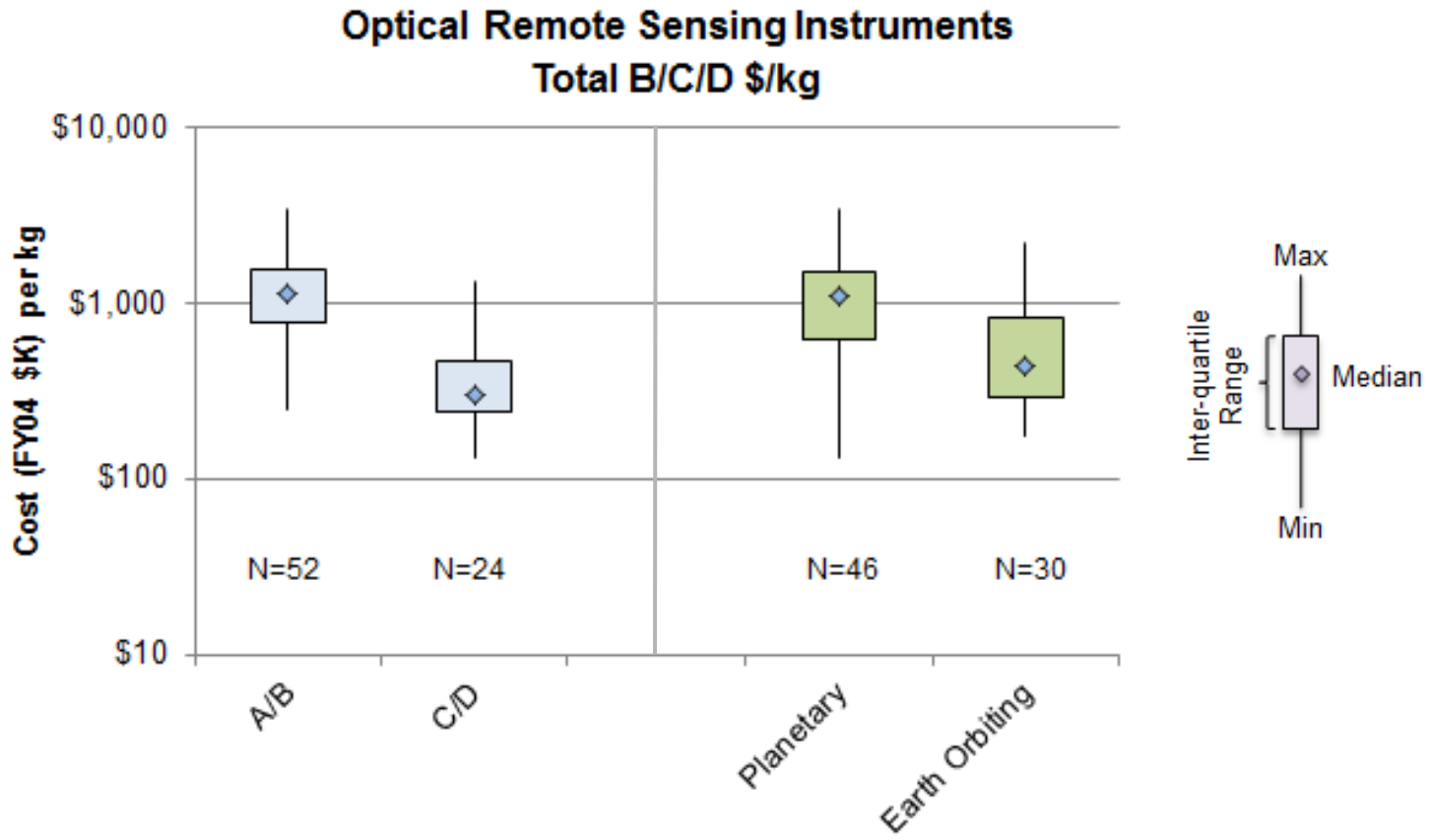
EO = Earth Orbiting
PL = Planetary

What if we color the clusters by Destination (Earth Orbiting or Planetary)?

Agglomerative clustering shows a moderate level of separation for destination.

- Groups of Earth orbiting and Planetary instruments seem to find their own clusters or sub-clusters

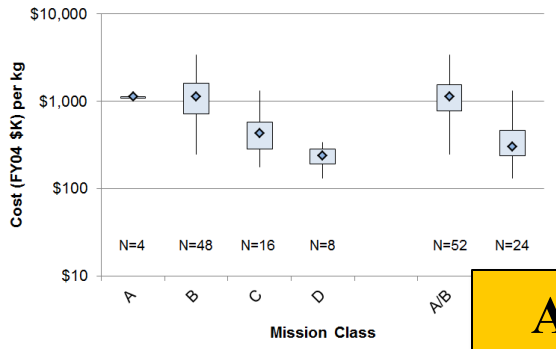
Data Exploration: Cost-per-kg
Mission Class vs. Destination



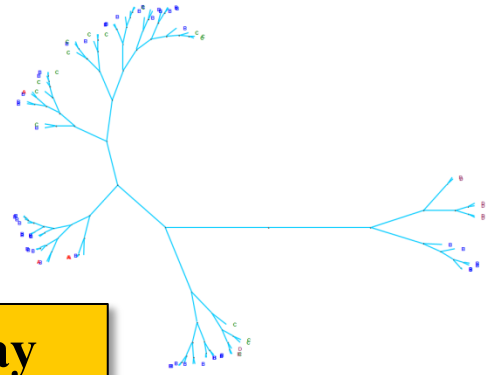
Grouping data according to Mission Class vs Destination results in similar changes in cost-per-kg; this is slightly more apparent when grouped by Mission Class.

Analysis Process (Revisited)

1 Cost-per-kg

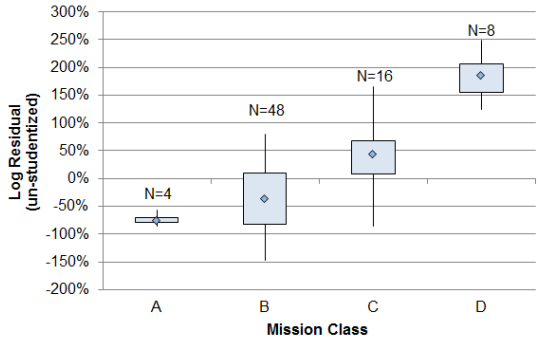


2 Cluster Analysis

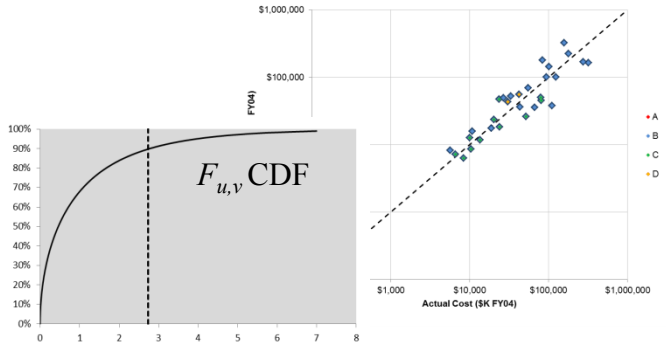


Assess interplay between Mission Class & Destination

3 Model Residuals



4 Preliminary CERs & Formal Analysis of Covariance

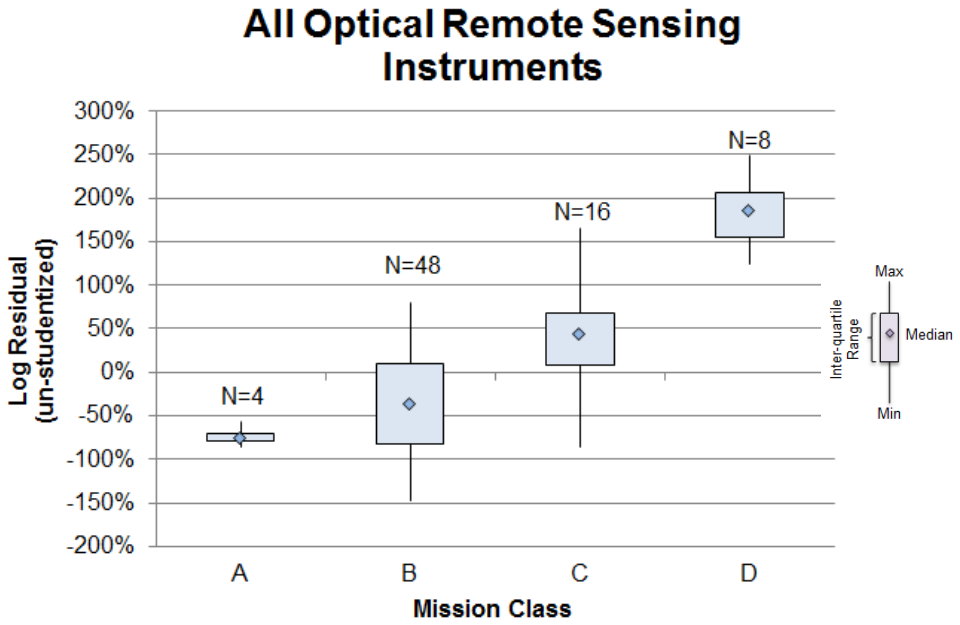


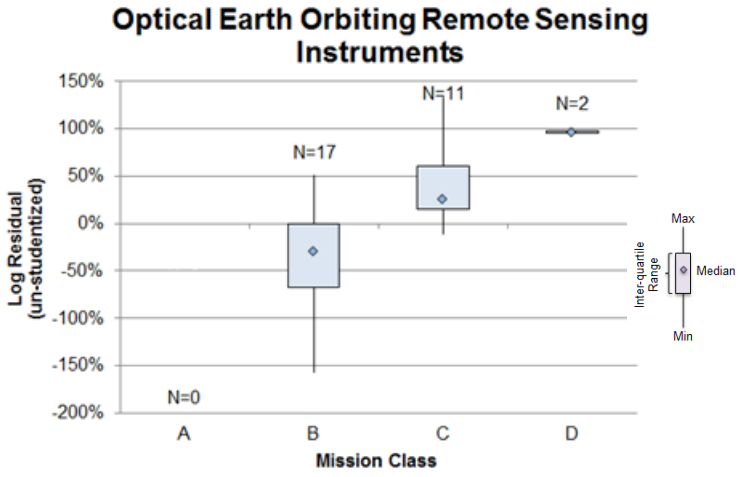
Model Evaluation – Mission Class

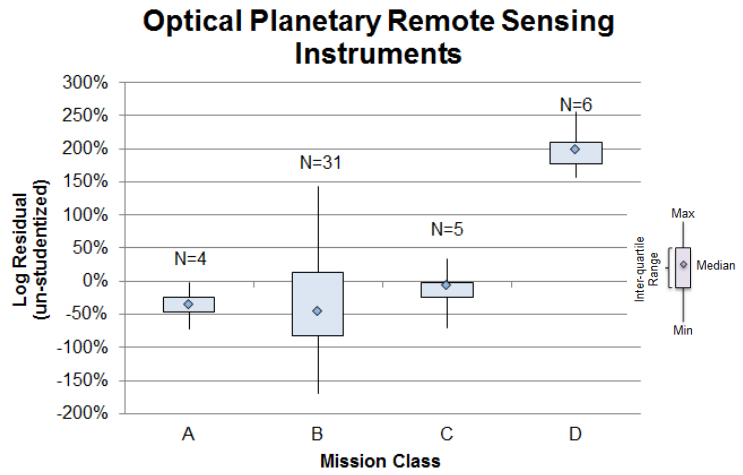
Place the power model:

$$Cost \approx \alpha Mass^{\beta} Pwr^{\gamma}$$

on the data and assess residuals*







* For this initial analysis, Total Mass and Max Power were used based on significance testing done for NICM VII. Other variables are currently being investigated.

Analysis Summary

Method	Mission Class	Destination
Clustering (Agglomerative)	Some evidence for split by Mission Class in sub-clusters	Moderate evidence for split by Destination (Earth Orbiting / Planetary)
Dollar-per-kg	Visible $/kg trend downward from Mission Class A/B to C/D	Visible $/kg decrease from Planetary to Earth Orbiting
Model 1-way AnCoVa (in progress)	*Mission Class is a significant discriminator ($p<0.001$)*	*Destination is a borderline significant discriminator ($0.05<p<0.1$)*

Method	No Grouping by Destination	Group Data by Destination
Model Residuals	Moderate to Strong visible trend in residuals for Mission Class	Some trend visible in residuals for Mission Class (more for Earth Orbiting instruments).
Model 2-way AnCoVa	*TBD: Will be testing both nested and un-nested models as well as interactions*	

Analysis Results To-date

Clustering favors a Destination split – Earth Orbiting vs. Planetary

When we place a model on the data, significance testing seems to favor Mission Class as a parameter

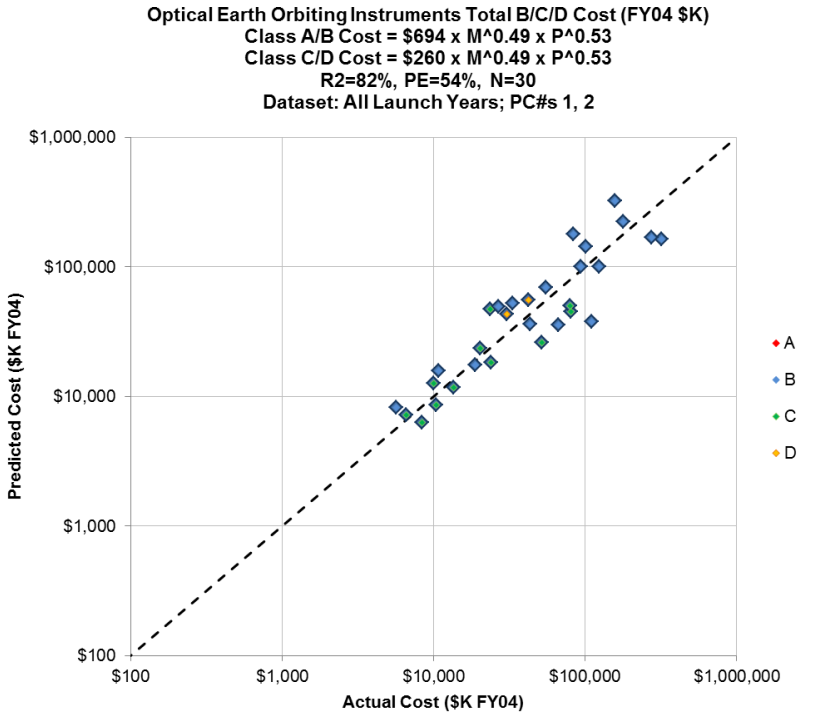
Potential Models

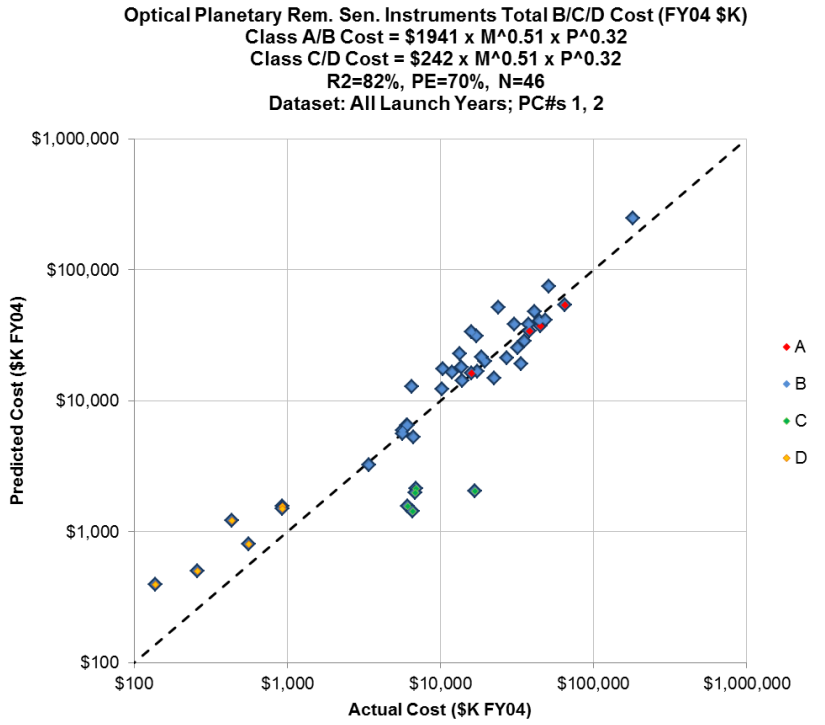
1. Group data by Destination, then fit a model using Mission Class and other cost driving variables
2. Group data by Mission Class A/B and Mission Class C/D, then fit model using other cost driving variables

In-work CERs

- The following slides show in-work CERs to illustrate potential results
- CERs are not intended for use by the Community at this point in time

In-work CERs: 1
Group by Destination, then Fit Class



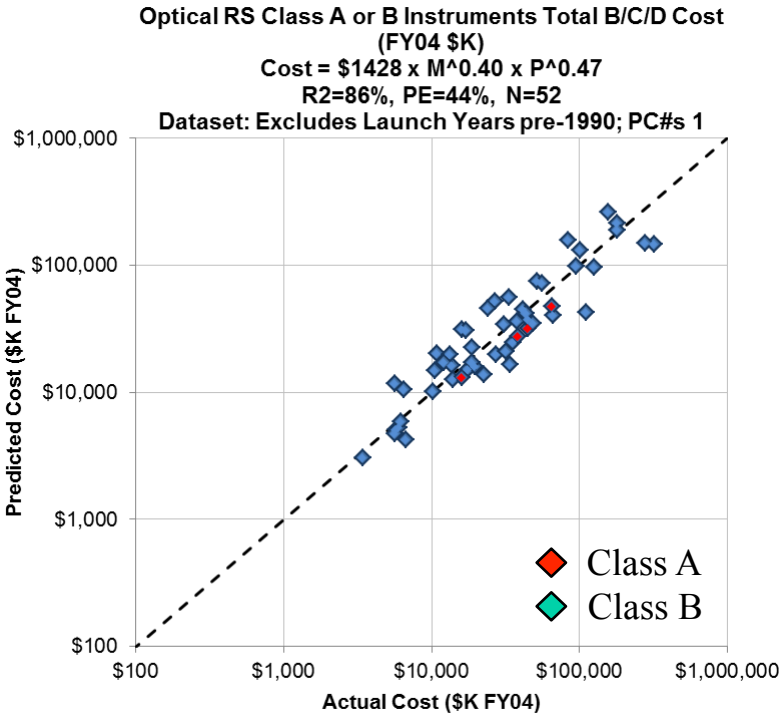


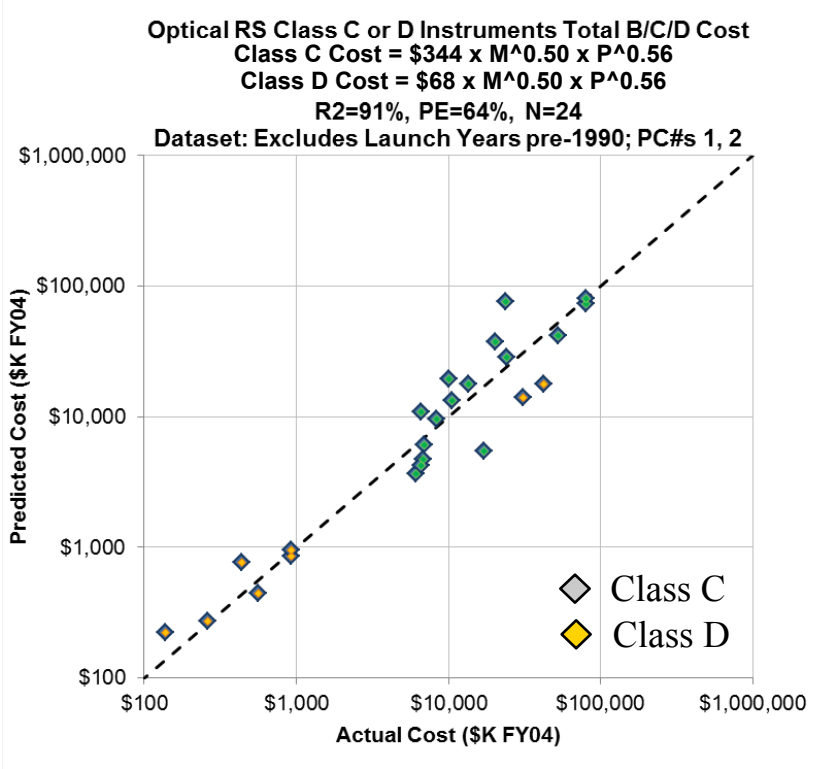
Earth Orbiting

Planetary

*Other models / variables may show significance with future analysis

In-work CERs: 2
All Destinations, Group by Class





Class A or B

Class C or D

*Other models / variables may show significance with future analysis

Next Steps

- Collect more data
- Continue data analysis and model evaluation
  - Complete formal Analysis of Covariance
  - Explore other potential variables to incorporate in CERs

Thank you!

- Questions?

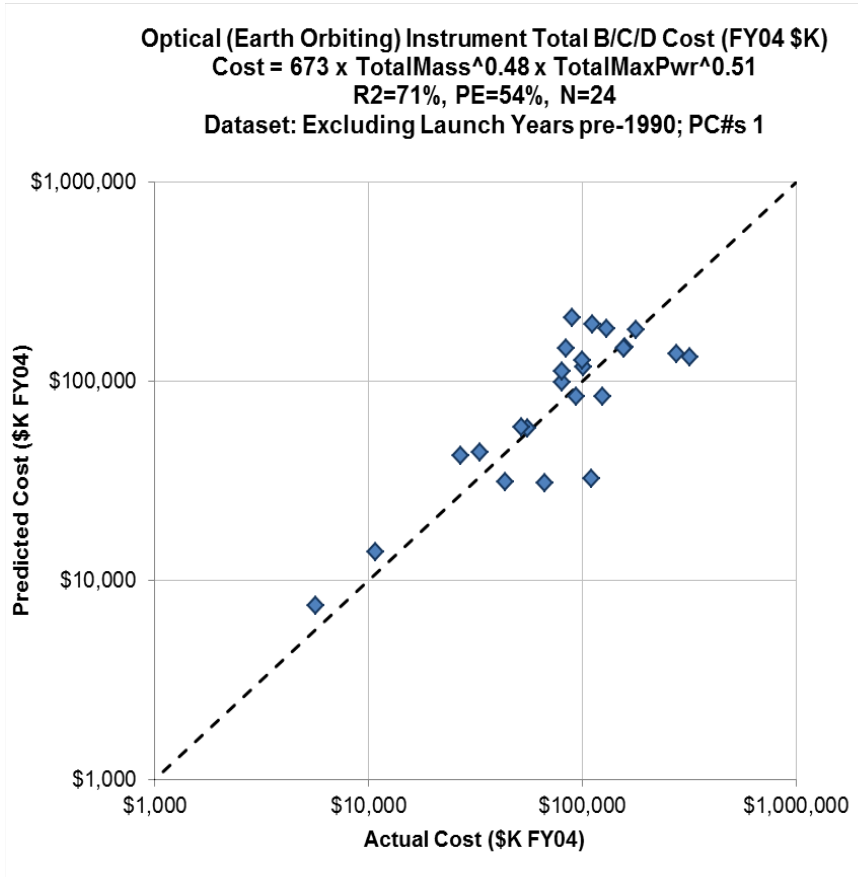
Backup

- NPR 8705.4, Appendix B
- Current Remote Sensing Optical CERs in NICM VII
- Current NICM-E CER
- Clustering vs. Fit
- Preliminary Analysis of Covariance (AnCoVa)

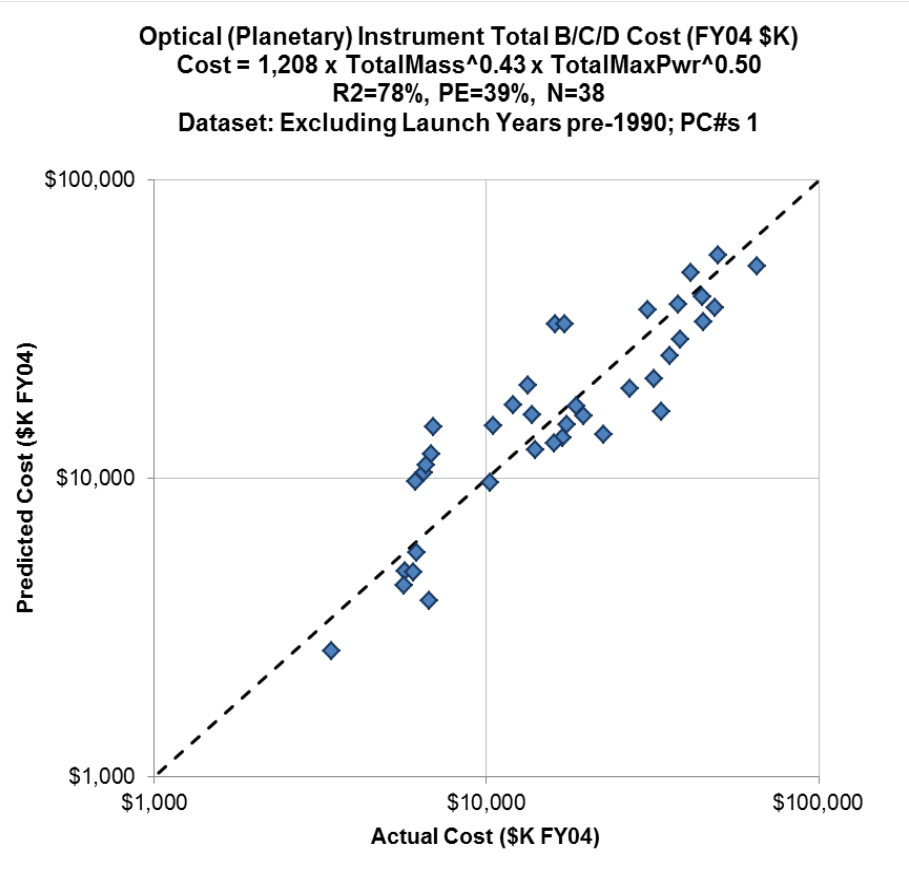
NPR 8705.4, Appendix B

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan)	High priority	High priority	Medium priority	Low priority
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, > 5 years	Medium, 2-5 years	Short, < 2 years	Short, < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints		Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX

Current NICM VII Optical RS CERs

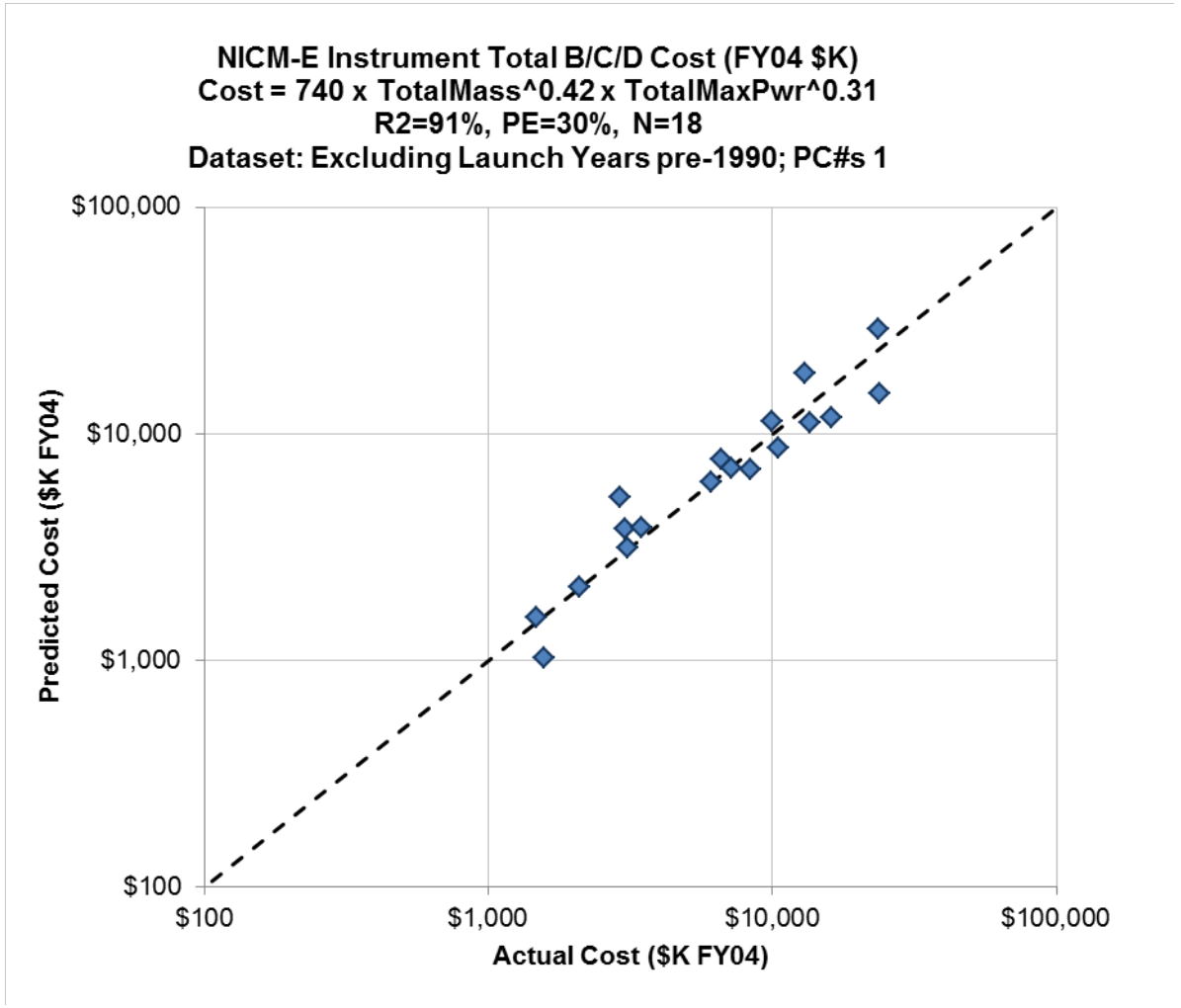


Earth Orbiting

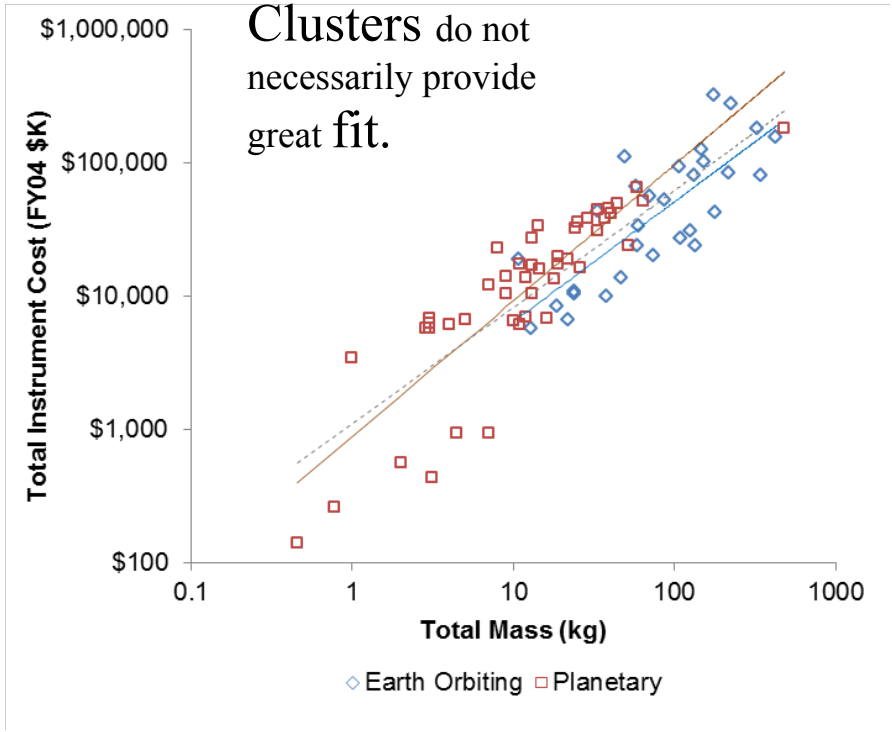


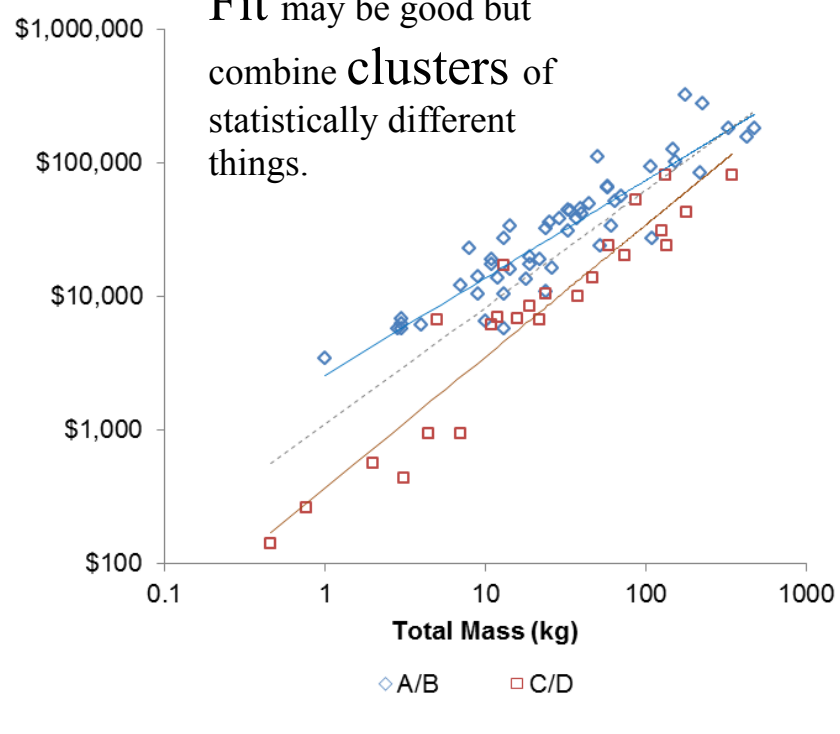
Planetary

Current NICM-E CER



Clustering vs. Fit



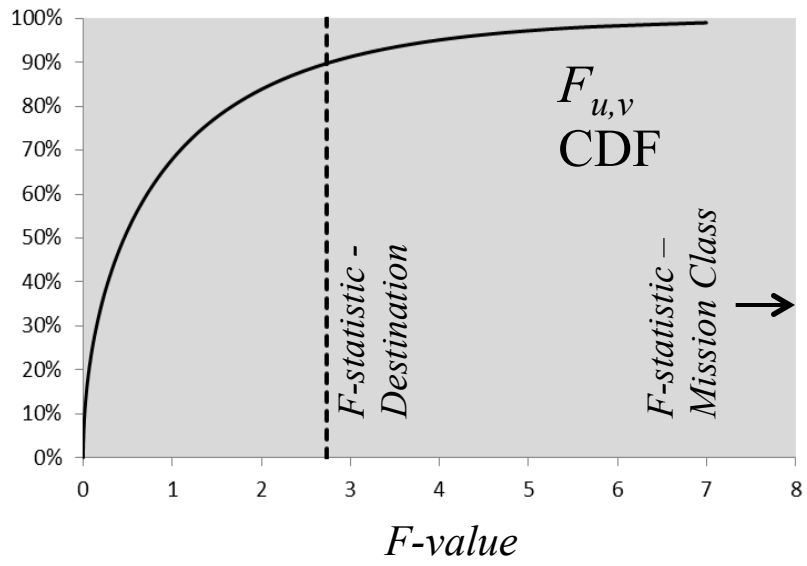


Model Evaluation – Analysis of Covariance (AnCoVa)

- What are questions we would like to answer?
  - Is there a significant shift in instrument cost due to Mission Class?
  - Is Mission Class a more significant factor than Destination (Earth Orbiting or Planetary)?
  - How does Destination affect our perception of cost when we look at Mission Class?
- We will use these questions to guide our development of hypotheses to be tested.

1-way AnCoVa Preliminary Results

- Significant mean-shift between Mission Classes
  - Null Hypothesis H_0: The scaler shift between Class A&B is the same as Class C&D
  - Null hypothesis rejected (p-value << 0.001)
- Mean-shift for Mission Class is more significant than that for Destination
  - Null Hypothesis H_0: The scaler shift between Earth Orbiting instruments is the same as Planetary instruments
  - Null hypothesis not rejected (p-value = 0.10)
- 2-way tests for nested models and interactions currently underway
  - Interactions and the order in which we group the data may have a significant impact on analysis results



References

- Shayle R. Searle, *Linear Models for Unbalanced Data,* New York: Wiley Interscience, 2006.