IXPE Cost Trace Proposal to ORR

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CS50/Program Planning and Control Office

Background

- Imaging X-ray Polarimetry Explorer (IXPE)
  - Principal Investigator (PI) Managed Mission
  - PIMMC = $175M in FY15 $M including $50M for launch vehicle
  - Small Explorer Class (SMEX)
  - Class D
  - Proposal Submitted in December 2014
  - Dr. Martin Weisskopf (MSFC) – Principal Investigator
  - Detectors Provided by the Italian Space Agency
    - Istituto di Astrofisica e Planetologia Spaziale (IAPS) – Detector Fabrication
    - Istituto Nazionale di Fisica Nucleare (INFN) – Detector Assemblies and Calibration
    - Agenzia Spaziale Italiana (ASI) – Ground Station
  - Ball Aerospace and Technology Corporation – Spacecraft Development and System Integration

Science

- IXPE uses X-ray polarimetry to expand dramatically observation space and to provide new input to our understanding as to how X-ray emission is produced in objects such as neutron stars, pulsar wind nebulae, and stellar and supermassive black holes. The two-year mission is very low-risk, making use of mature flight elements combined in a system with conservative resource margins and run by a team with extensive mission experience, in X-ray astronomy and especially X-ray polarimetry.

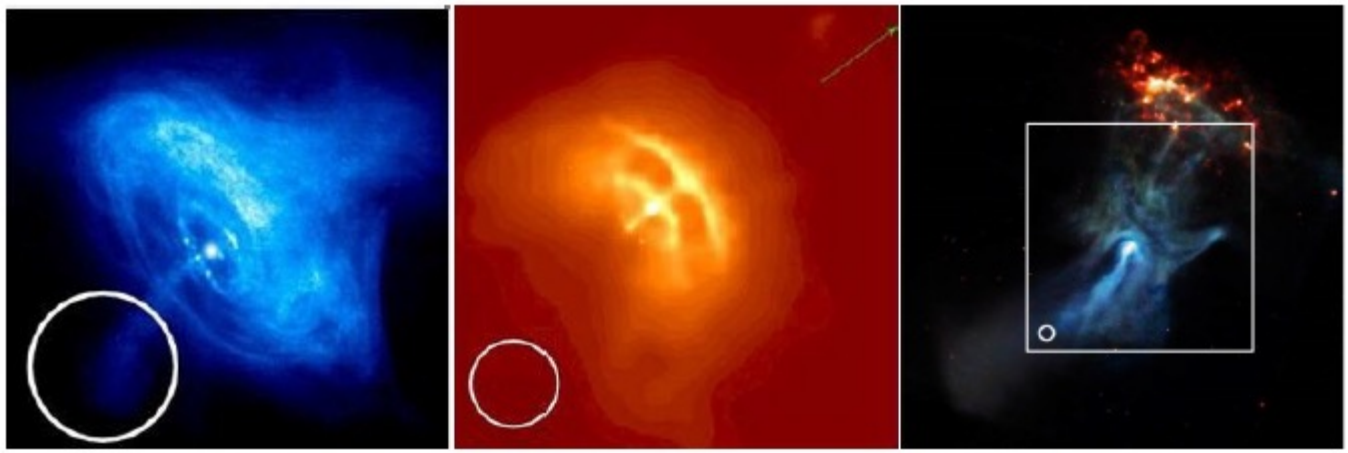


Figure D-4: Chandra images of the Crab (left), with its torus and jet; the Vela pulsar (center) and PWNe, with its peculiar double arcs; and the MSH 15-52 complex. The circles denote *IXPE*'s 30″ HPD; the square, *IXPE*'s field of view.

Approach

- Download CADRe files for IXPE milestones from One NASA Cost Engineering (ONCE) Database
  - 2014 Proposal (IXPE was originally proposed in 2008)
  - CSR (Concept Study Report)
  - SRR (System Requirements Review)
  - PDR (Preliminary Design Review)
  - CDR (Critical Design Review)
  - SIR (System Integration Review)
  - ORR (Draft cost from John Howell – IXPE Business Manager)
- Compare to Parametric Cost Estimates from the same milestones
- Check changes and data with IXPE Project
- Present findings

Ground Rules and Assumptions for Parametric Estimates

Engineering Cost Office

- COVID impact cost included in SIR cost ~ $14M (~12.5M in FY15)
- Launch Schedule change from Launch Services Provider (LSP) resulted in ~$1M increase ($0.9M in FY15)
- Launch vehicle cost not included
- Phase A not included
- Contributions not included
  - Italian Instrument Cost
- Parametric cost shown are the Most Likely estimate average from the PRICE and SEER cost models
- Reserves included
  - 30% Phase B-D
  - 15% Phase E-F

Main Comparison

Engineering Cost Office

- Engineering Cost Office
  - Proposal
    - Phase B/C/D Estimate = **$110.4M** in FY15
- Project
  - As of June 2021
    - Phase B/C/D Cost = **$136.4M** in FY15
      - Includes roughly $12.5M in COVID impacts
      - Includes a month ($0.9M) delay on the launch due to launch scheduling

- **11.4%** growth without impact increases included
- **23.6**% growth with impacts included

2014 Proposal Cost Estimate

Engineering Cost Office

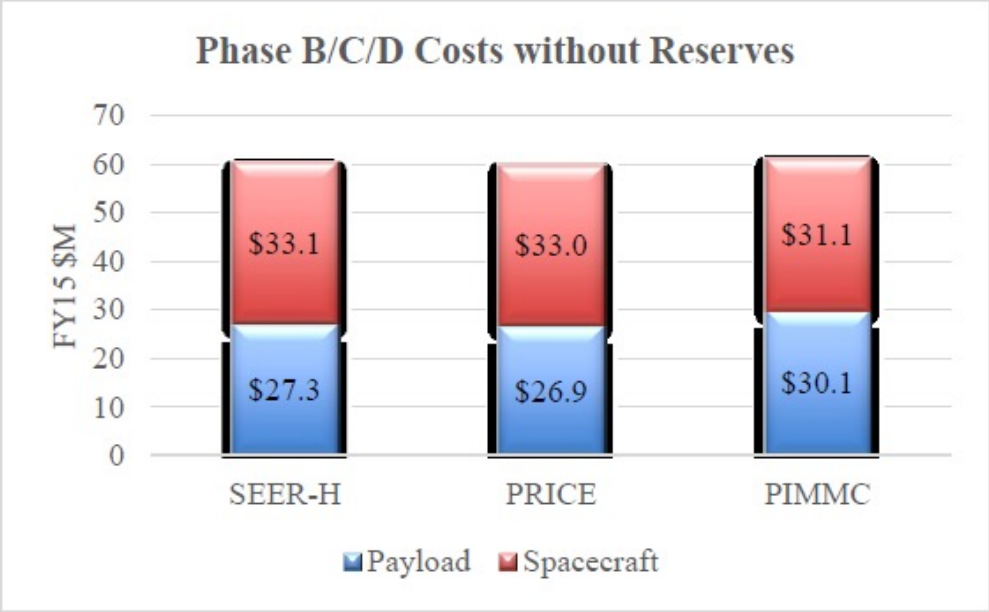


Figure H-1: *IXPE* Parametric Cost Estimates Compared to the PIMMC Estimate.

- Parametric Estimates focused on Spacecraft and Payload Cost
- The graph is from the 2014 proposal cost validation section.
- Section references a 74% mission confidence level as seen below, but no S-curve is included.

distributions. The result of the risk analysis showed the proposed Phase B/C/D cost for *IXPE*, less the cost of the launch services but including all reserves and CM&O overhead costs, is at **a confidence level of 74%.** The coefficient of variation for the probability distribution is 0.18, which is consistent with the high degree of heritage on the spacecraft combined with the more technically challenging science payload.

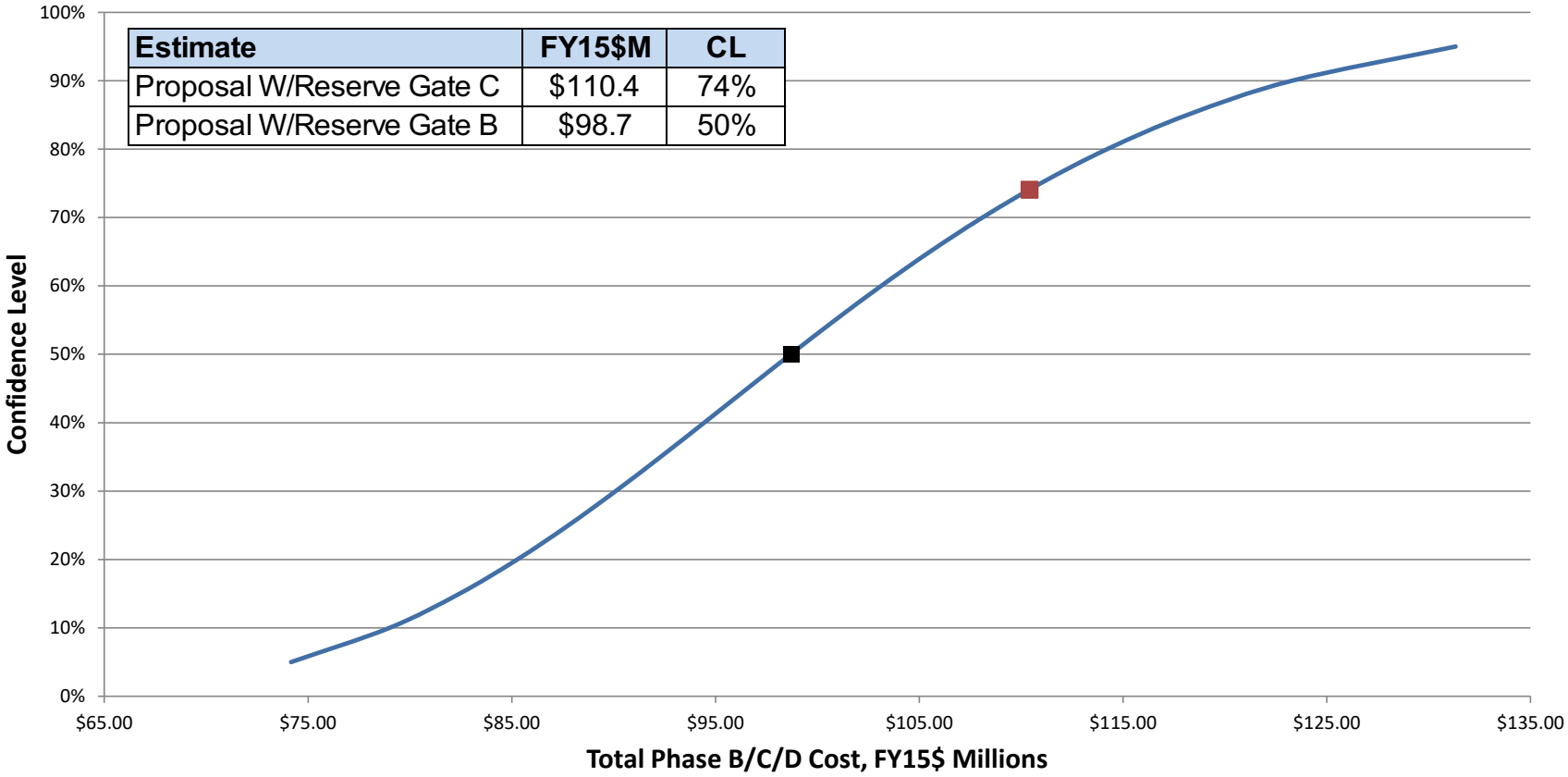
IXPE-II Mission CL Results

Gate C Presentation – Dec 2014

Engineering Cost Office

IXPE-II Total B/C/D Cost Confidence Level Analysis

Estimate	FY15$M	CL
Proposal W/Reserve Gate C	$110.4	74%
Proposal W/Reserve Gate B	$98.7	50%



Cost does not include Launch Vehicle Services.

CSR Estimates FY15 $M

Engineering Cost Office

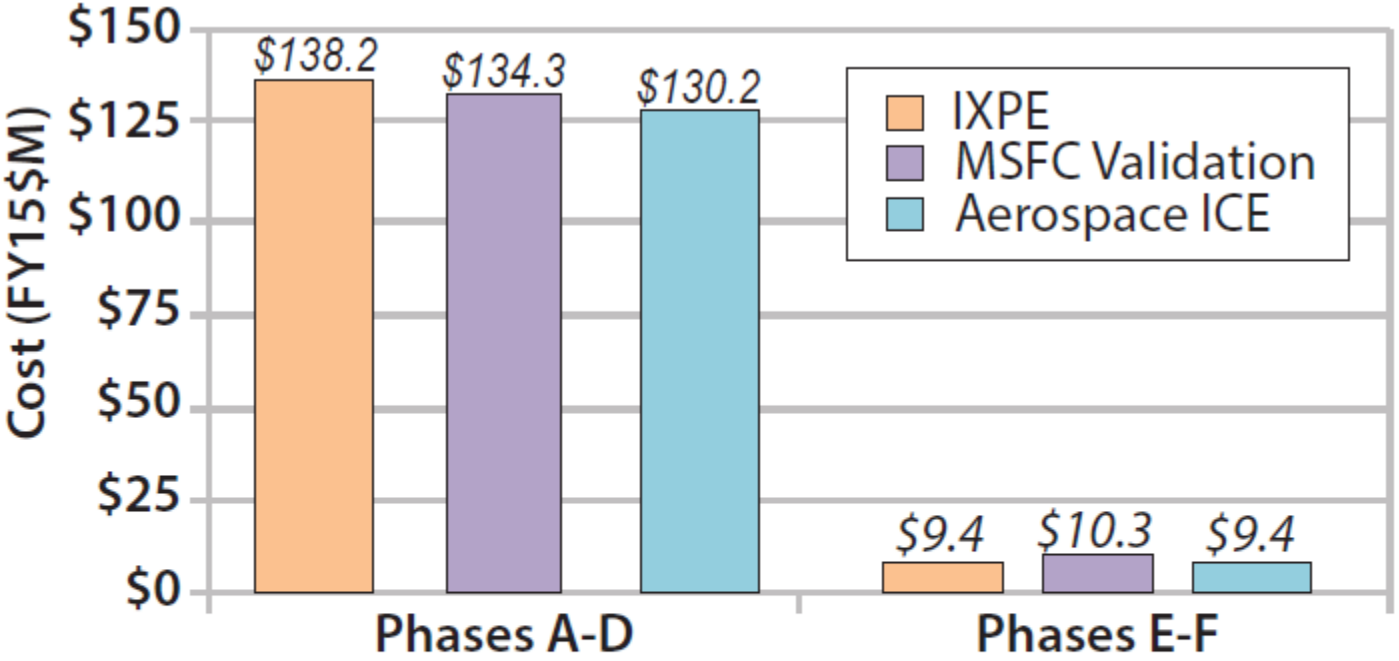


Figure K–1e *IXPE PIMMC (excluding reserves) was validated by MSFC internal analyses and by Aerospace Corporation ICE. See Table K–2.*

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Technical Changes from Proposal to SIR

- Updated Design Feature:
  - Launch Locks on Inverted Bipods
  - Solar Arrays received iterative design changes
    - Proposal - 2.2m^2 generating 534W EOL
    - SIR - 1.7m^2 generating 306W EOL
  - Spacecraft Shear Panels
  - X-ray Shields
- New Design Feature:
  - Mirror Module Assembly (MMA) TSS Ring
  - Thermal shield for MMA
  - Coarse Sun Sensor (CSS) on solar array panel
  - DU Adaptor Plate
  - 2nd GPS Antenna
  - Hinges for the Inverted Bipods
- Moved Components:
  - Inverted Bipods – from payload deck to spacecraft
  - Magnetometer – from spacecraft to payload deck

- Changed from Pegasus XL to SpaceX Falcon 9
- Orbit changed from 540km to 600km

Configuration by Milestone

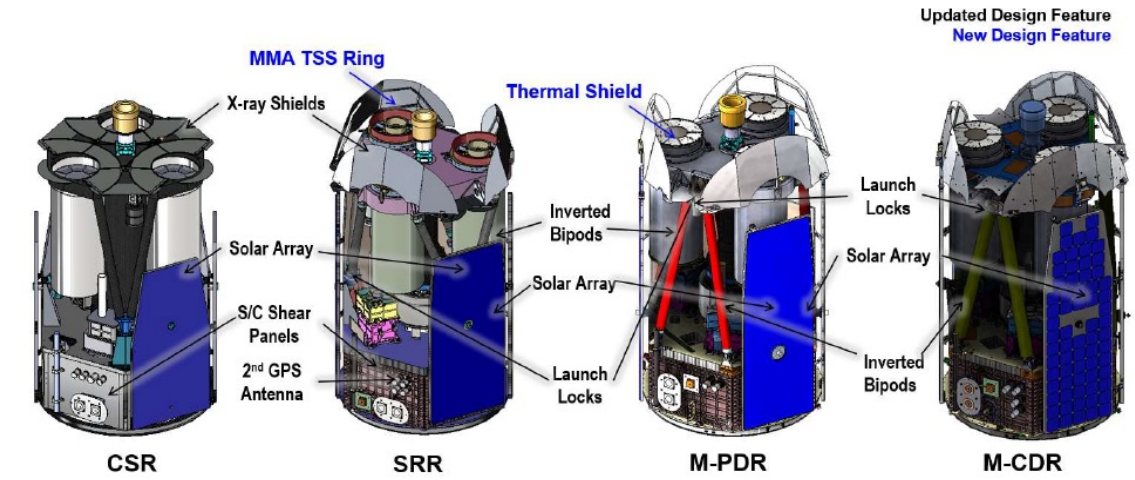


Figure 12: IXPE Observatory Stowed View Comparison CSR to SRR to PDR

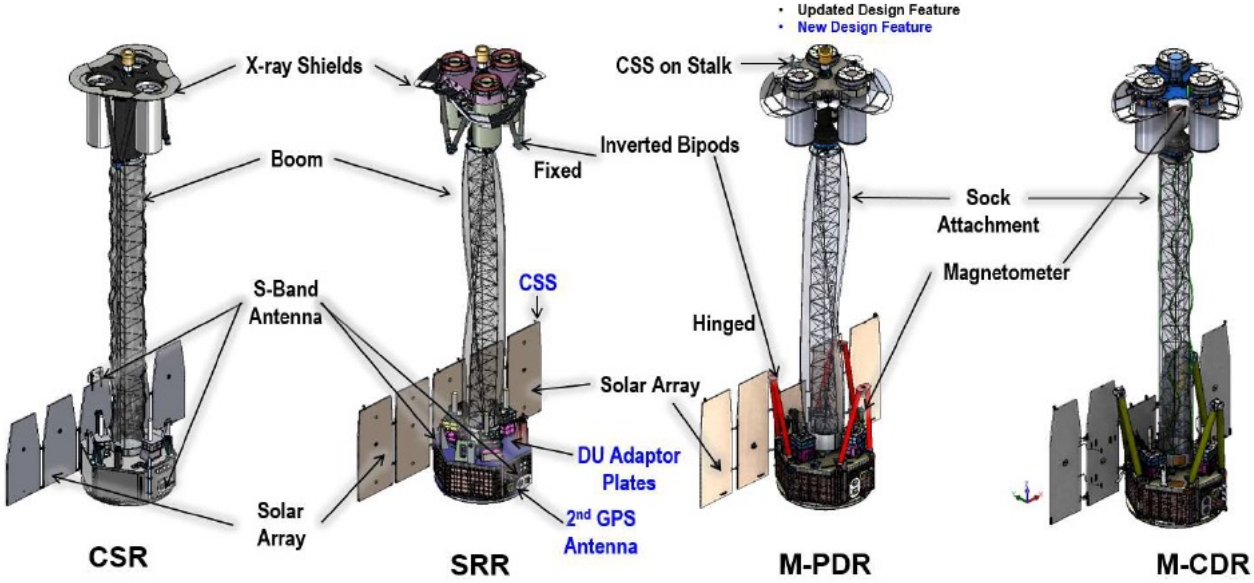


Figure 13: IXPE Observatory Deployed View Comparison CSR to SRR to PDR

SIR

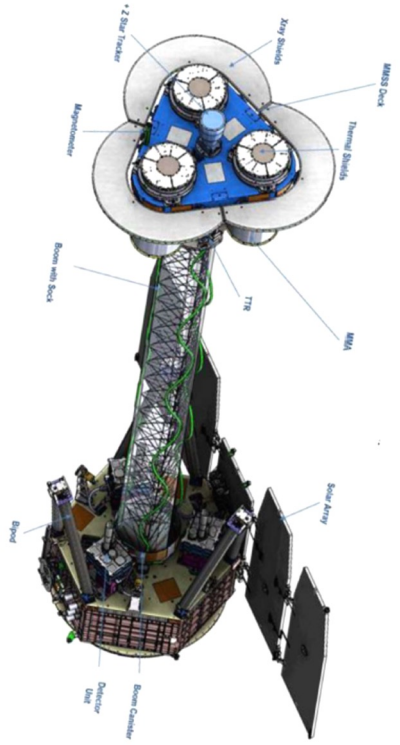
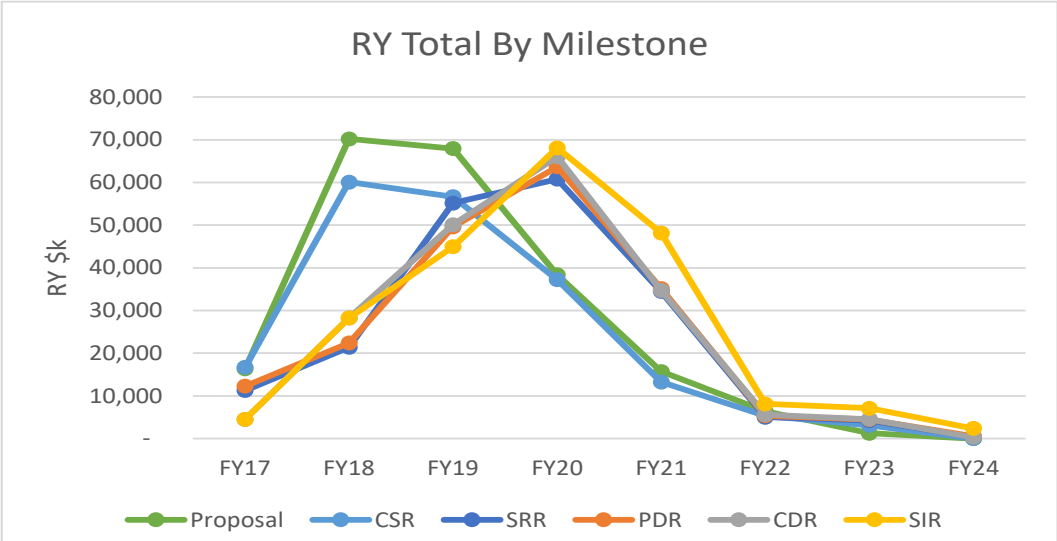
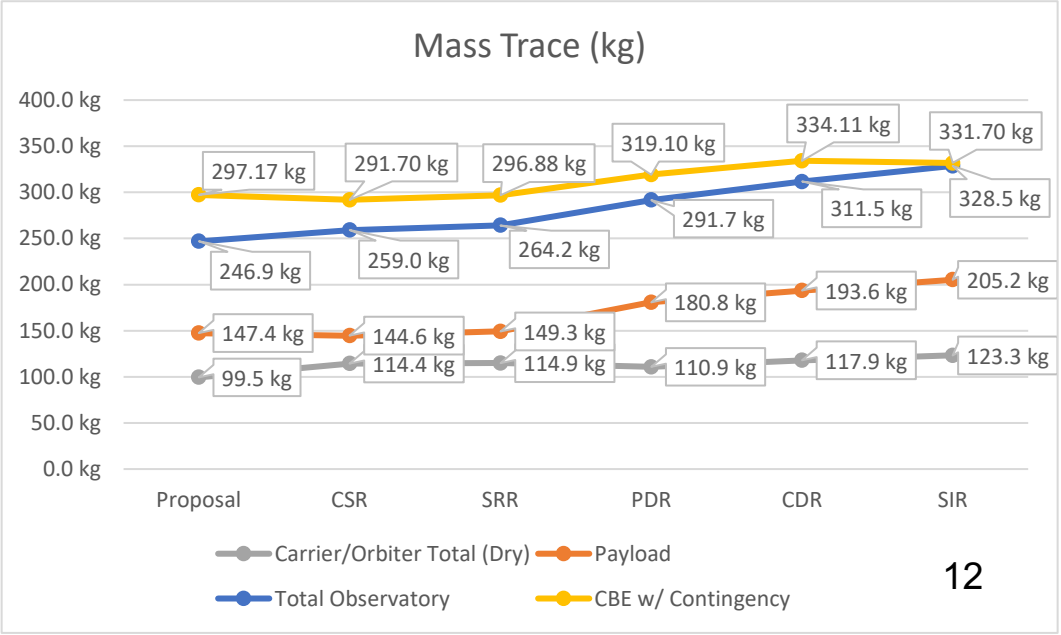


Figure 10: IXPE Spacecraft Layout Showing Major Elements [17]

Project Results

- Total Mission RY $M (including LV)
  - Proposal = $216.1M
  - CSR = $192.3M
  - SRR = $192.7M
  - PDR = $193.4M
  - CDR = $194.0M
  - SIR = $211.6M
  - Draft ORR = $212.6M
- Mass Growth of Current Best Estimate (CBE) from Proposal to SIR:
  - Total Observatory = 81.6kg (33%)
  - Payload = 57.8kg (39%)
  - Spacecraft = 23.8kg (24%)
- SIR Mass 10.5% above Proposal with mass margin

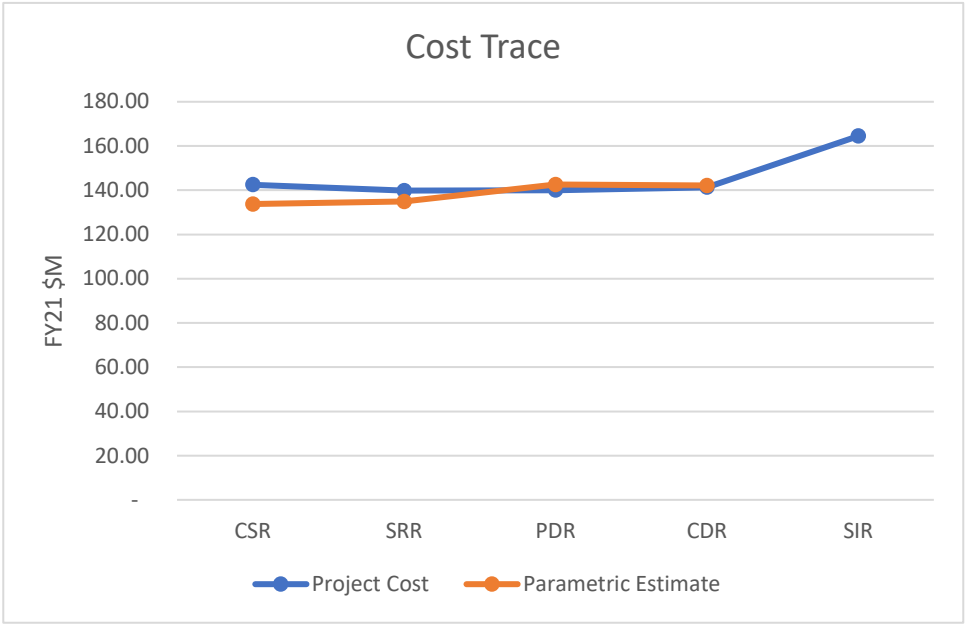




Parametric vs Project Results

Engineering Cost Office

- Percentage project cost growth from CSR:
  - To CDR = -0.83%
  - To SIR = 15.43%
- Percentage parametric cost growth from CSR:
  - To CDR = 6.32%
  - To SIR = Not Estimated



Conclusions

- Growth of 11% without COVID impacts.
  - From Andy's Paper "Being Certain about Uncertainty Part 2":
    - Median Cost Growth seen by NASA projects is 35.1%
    - Mean Cost Growth seen by NASA projects is 56.2%
- Great Leadership Team!
- Congratulations to MSFC, Ball, and Italian Space Agency!

BACKUP

Mass Trace Breakdown

Engineering Cost Office

CBE	Proposal	CSR	SRR	PDR	CDR	SIR
	CBE Mass	CBE Mass	CBE Mass	CBE Mass	CBE Mass	CBE Mass
Payload Total	**147.40 kg**	**144.60 kg**	**149.25 kg**	**180.80 kg**	**193.58 kg**	**205.21 kg**
Imaging X-Ray Polarimetry Explorer (IXPE)	147.40 kg	144.60 kg	149.25 kg	180.80 kg	193.58 kg	205.21 kg
Mirror Module Support	13.40 kg	20.83 kg	22.00 kg	34.93 kg	42.42 kg	39.30 kg
Mirror Module Assembly	83.10 kg	84.99 kg	85.59 kg	92.19 kg	93.69 kg	93.10 kg
Deployable Boom Assembly	12.70 kg	4.90 kg	7.83 kg	8.96 kg	8.67 kg	8.20 kg
Detector Units (DU)	23.50 kg	15.11 kg	15.11 kg	18.63 kg	18.78 kg	29.97 kg
Detector Service Unit (DSU)		4.00 kg	4.00 kg	5.86 kg	6.20 kg	
MMSS Launch Lock	0.90 kg	1.73 kg	1.73 kg			1.60 kg
Thermal Control		3.90 kg	3.86 kg	11.17 kg	12.45 kg	18.44 kg
Metrology Assembly	4.20 kg	1.16 kg	1.16 kg	1.52 kg		
Payload Electronics Box	3.00 kg	2.00 kg	2.00 kg			
DU Adapter Plates	4.90 kg					5.10 kg
Deployable X-Ray Shield Assembly						3.80 kg
Payload Cabling	6.00 kg	5.98 kg	5.98 kg	7.55 kg	11.36 kg	5.60 kg
Carrier/Orbiter Total (Dry)	**99.50 kg**	**114.40 kg**	**114.91 kg**	**110.87 kg**	**117.95 kg**	**123.30 kg**
Structures & Mechanisms	41.18 kg	47.10 kg	51.44 kg	46.74 kg	35.96 kg	62.85 kg
Thermal	3.10 kg	3.70 kg	3.70 kg	3.70 kg	3.70 kg	3.11 kg
Electrical Power Subsystem	20.51 kg	15.10 kg	11.47 kg	12.02 kg	26.82 kg	44.20 kg
Guidance, Navigation & Control	23.01 kg	28.10 kg	27.86 kg	26.51 kg	27.10 kg	0.00 kg
Propulsion (not incl. Propellant & Pressurant)	0.00 kg	0.00 kg	0.00 kg	0.00 kg	0.00 kg	0.00 kg
Telecommunications	5.47 kg	4.90 kg	4.92 kg	6.07 kg	6.93 kg	7.06 kg
Command and Data Handling	6.20 kg	6.00 kg	6.02 kg	6.33 kg	6.33 kg	6.08 kg
Wire Harness Assembly		9.50 kg	9.50 kg	9.50 kg	11.10 kg	
Propellant & Pressurant	**0.00 kg**	**0.00 kg**	**0.00 kg**	**0.00 kg**	**0.00 kg**	**0.00 kg**
Carrier/Orbiter Propellant & Pressurant	0.00 kg	0.00 kg	0.00 kg	0.00 kg	0.00 kg	0.00 kg
Total Mass (Dry)	**246.90 kg**	**259.00 kg**	**264.16 kg**	**291.67 kg**	**311.53 kg**	**328.51 kg**
Total Mass (Wet)	**246.90 kg**	**259.00 kg**	**264.16 kg**	**291.67 kg**	**311.53 kg**	**328.51 kg**
LV Capability	380.00 kg	380.00 kg	380.00 kg	371.00 kg	371.00 kg	371.00 kg
Launch Mass Margin	133.10 kg	121.00 kg	115.84 kg	79.33 kg	59.47 kg	42.50 kg
% Launch Mass Margin	35.03%	31.84%	30.48%	16.26%	#REF!	11.00%

*Interesting Note: Spacecraft with contingency is relatively unchanged through milestones, and final product is near predicted mass with contingency. Instrument is where the growth seems to be, mainly around Mirror Module Support and Thermal Subsystems.

IXPE
Imaging
X-Ray
Polarimetry
Explorer

Marshall Space Flight Center

agenzia spaziale italiana

VALIDATION RESULTS ARE CONSISTENT WITH PROPOSED COSTS

Table K-2 *IXPE Cost Validation Results Summary (FY15 $M)*

WBS Number	WBS Element	PIMMC Project Estimate[1]	PIMMC MSFC Validation[2]	PIMMC Aerospace ICE Excluding Contributions	Contributions	Total Mission Cost Project Estimate + Contributions	Total Mission Cost MSFC Validation[2]	Total Mission Cost Aerospace ICE[3]
Phase A		$ 1.0	$ 1.0	$ 1.0	$ 1.4	$ 2.4	$ 2.4	$ 2.4
Phases B, C/D		$ 137.2	$ 133.3	$ 129.2	$ 26.3	$ 163.5	$ 159.5	$ 155.5
01, 02, 03	PM, SE, SMA	$ 10.0	$ 8.4	$ 12.0		$ 10.0	$ 8.4	$ 12.0
04	Science	$ 4.3	$ 4.3	$ 4.3	$ 2.0	$ 6.3	$ 6.3	$ 6.3
05	Payload	$ 28.6	$ 28.8	$ 22.2	$ 21.9	$ 50.5	$ 50.7	$ 44.1
06, 10	Spacecraft & Sys I&T	$ 37.8	$ 35.2	$ 35.5	$ 1.3	$ 39.1	$ 36.5	$ 36.8
07, 09	MOS/GDS	$ 6.1	$ 6.1	$ 4.8		$ 6.1	$ 6.1	$ 4.8
08	Launch Vehicle	$ 50.0	$ 50.0	$ 50.0		$ 50.0	$ 50.0	$ 50.0
11	E&PO	$ 0.4	$ 0.4	$ 0.4	$ 1.1	$ 1.5	$ 1.5	$ 1.5
Phases E, F		$ 9.4	$ 10.3	$ 9.4	$ 6.3	$ 15.7	$ 16.6	$ 15.7
01, 02	PM, SE	$ 1.1	$ 10.1	$ -		$ 1.1	$ 13.4	$ -
04	Science	$ 4.4		$ 4.4	$ 1.4	$ 5.8		$ 5.8
07	Mission Ops	$ 3.7		$ 4.8		$ 3.7		$ 4.8
09	Ground System	$ -		$ -	$ 1.9	$ 1.9		$ 1.9
05	Payload	$ -	$ -	$ -	$ 2.4	$ 2.4	$ 2.4	$ 2.4
11	E&PO	$ 0.2	$ 0.2	$ 0.2	$ 0.6	$ 0.8	$ 0.8	$ 0.8
Total Cost (excl. Reserves)		$ 147.6	$ 144.5	$ 139.6	$ 34.0	$ 181.6	$ 178.5	$ 173.7
Reserves		$ 27.4	$ 27.4	$ 29.0	$ -	$ 27.4	$ 27.4	$ 29.0
Total Cost (incl. Reserves)		$ 175.0	$ 171.9	$ 168.6	$ 34.0	$ 209.0	$ 205.9	$ 202.7

1. Including CM&O
2. Mean of validation results. Details in §K.3.2.2 and §K.3.2.3.
3. Includes Contributions
4. Values may not sum to totals due to rounding

Validation Methodology	
Pass-through	Models & Analogies
Wrap Factor	