

IXPE: Imaging X-Ray Polarimetry Explorer Mission

2017 IEEE Aerospace Conference Yellowstone Conference Center, Big Sky, MT • USA March 4-11, 2017 Session 2.01 Presented by: William Deininger Ball Aerospace

This work was authored by employees of Ball Aerospace under Contract No.NNM16581489R with the National Aeronautics and Space Administration. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes. All other rights are reserved by the copyright owner.



CONTENTS

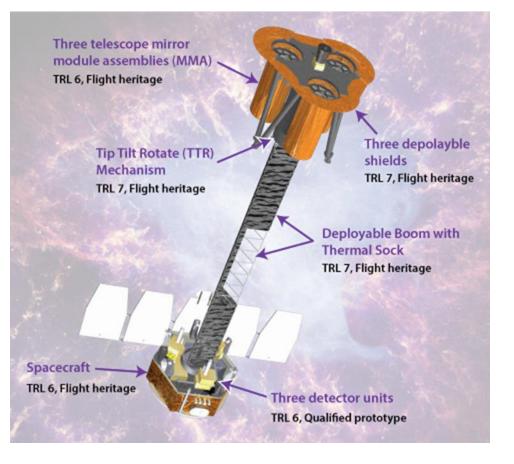
Introduction

- Overview of science
- Project partners and roles
- Technical summary
- Schedule and milestones
- Conclusions



QUICK SUMMARY OF IXPE

- NASA Explorer Mission, cost capped at \$175M (FY15)
- PI: Martin Weisskopf, MSFC
- Class D Mission managed by MSFC
- LEO observatory that measures spatial, spectral, timing, and polarization state of X-rays from 49 known astrophysical targets
- Ball Roles: Spacecraft, Payload mechanical, AI&T, and Mission Ops (with LASP)
- MSFC: Management, X-ray optics, SOC
- ASI (Italian Space Agency): Detectors Units, Ground station
- Phase B starts now; launch Nov 2020

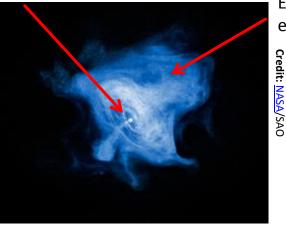




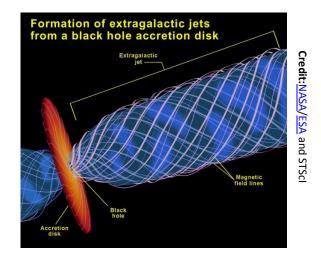
IXPE SCIENCE

- X-ray emission from energetic processes: In-fall of matter into Neutron Star or Black Hole, synchrotron or shock emission, or very hot regions
- Can originate both from point and extended sources; *Imaging* separates these sources
- Polarization of X-rays if there is anisotropy in emission geometry or mag field, plasma reflections, or general relativistic effects

Crab Pulsar



Extended X-ray emission



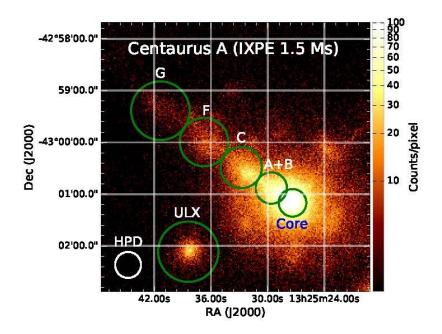
Polarization probes the source geometry and mag field strength

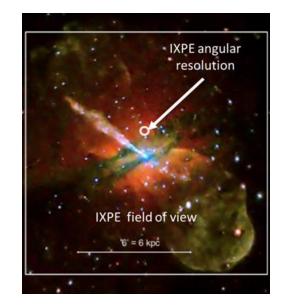
Imaging separates regions with different emission mechanisms



IXPE IMAGING LIMITS SOURCE CONFUSION

- Active galaxies are powered by supermassive Black Holes with jets
 - Radio polarization implies the magnetic field is aligned with jet
 - But other models also consistent with current observations
- *IXPE* can image the Cen A jet and separate from other sources in the field (e.g., Ultra Luminous X-ray source)







IXPE SCIENTIFIC OBJECTIVES

Science Objectives:

- Enhance our understanding of the physical processes that produce X-rays from and near compact objects such as neutron stars and black holes
- Explore the physics of the effects of gravity, energy, and electric and magnetic fields at their extreme limits
- IXPE addresses key questions in High Energy Astrophysics
 - What is the spin of a black hole?
 - What are the geometry and magnetic-field strength in magnetars?
 - Was our Galactic Center an Active Galactic Nucleus in the recent past?
 - What is the magnetic field structure in synchrotron X-ray sources?
 - What are the geometries and origins of X-rays from pulsars?

Polarimetry of X-ray sources largely unmeasured Opens a new window on the X-ray Universe



PRINCIPAL TEAM MEMBERS



- Principal Investigator
- Project Management
- Systems Engineering & SMA
- Mirror Module Design, Fabrication, & Calibration
- Science Operations Center (SOC)
- Science Data Analysis and Archiving
- Spacecraft
- SE and SMA Support
- Payload Structure
- S/C, Payload, Observatory I&T
- Mission Ops Management



- Detector System Funding
- Ground Station (Malindi)
- Mission Assurance (Italian contribution)





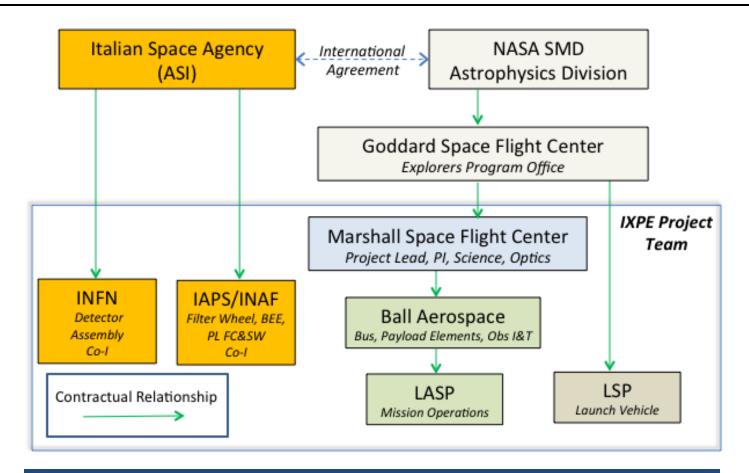
- Italian PI (IPI)
 Polarization-Sensitive Detector System
- Payload Computer



• Mission Operations Center



INTERNATIONAL RELATIONSHIPS



CLEAR INSTITUTIONAL ROLES, WITH WELL-DEFINED INTERFACES



SCIENCE TEAM

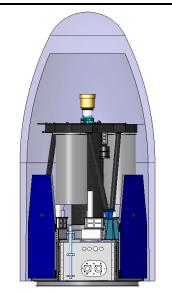
- Martin Weisskopf, PI
- Brian Ramsey, Deputy PI
- Paolo Soffitta, Italian Pl
- Ronaldo Bellazzini, Italian Co-PI
- Enrico Costa, Senior Co-I
- Steve O'Dell, Project Scientist
- Allyn Tennant, Co-I
- Fabio Muleri, Co-I

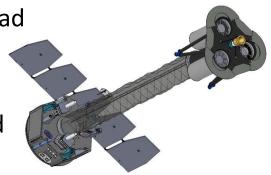
- Jeffrey Kolodziejczak, Co-I
- Roger Romani, Co-I
- Giorgio Matt, Co-I
- Vicky Kaspi, Co-I
- Ronald Elsner, Co-I
- Luca Baldini, Co-I
- Luca Latronico, Co-I



IXPE HAS A STRAIGHT FORWARD MISSION CONCEPT

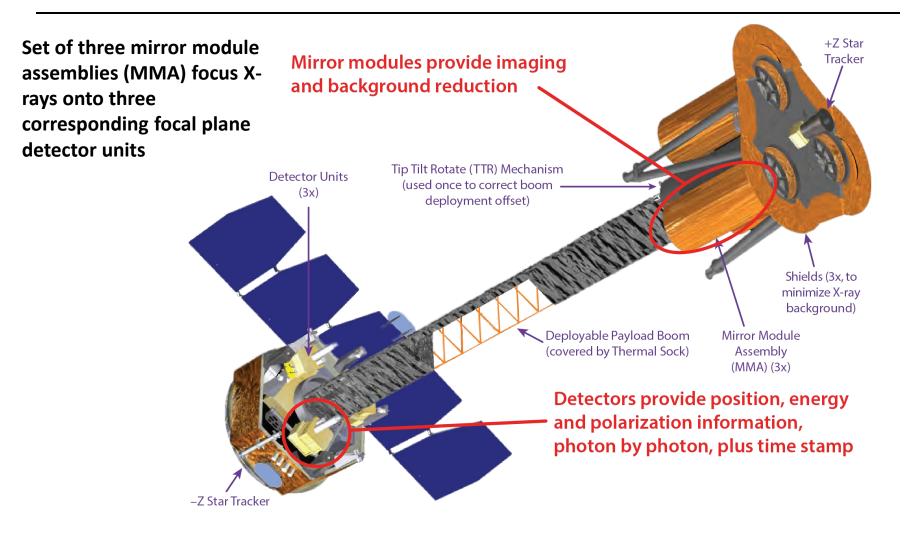
- IXPE Observatory is a single flight element
- Observatory launched to a 540 km, 0° orbit
- Pegasus XL launch vehicle is baselined
- 3 critical events occur within ground or TDRSS contact
 - Separation from launch vehicle (TDRSS) free flying S/C
 - Solar array deployment (TDRSS) full power available
 - Payload boom deployment (Malindi) ready for payload commissioning
- Observatory comm via S-band link
 - Half of available Malindi contacts meet data download requirements for high data rate targets (e.g. The Crab)
 - Most targets require only 2 (of 15 available) contacts per day





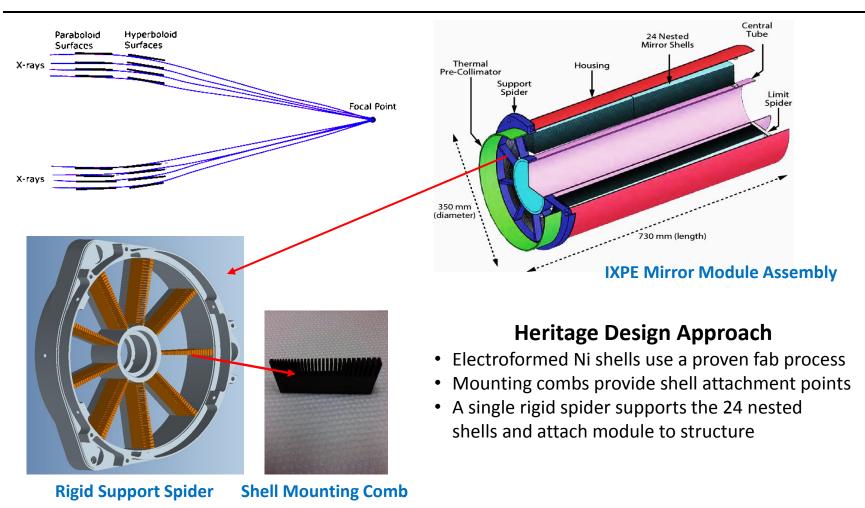


PAYLOAD OVERVIEW





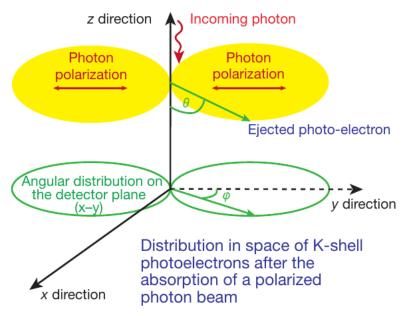
MIRROR MODULE DESIGN

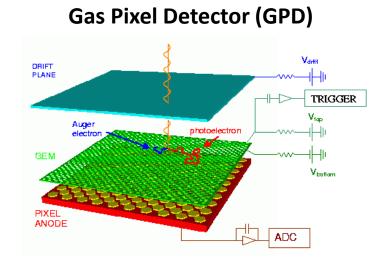




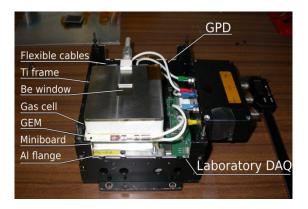
DETECTOR A CONTRIBUTION FROM ASI

- Detection uses photoelectric effect
- X-rays absorbed in detector fill gas
- Photoelectron emission aligned with X-ray polarization vector
- Electron multiplier with pixelated detector



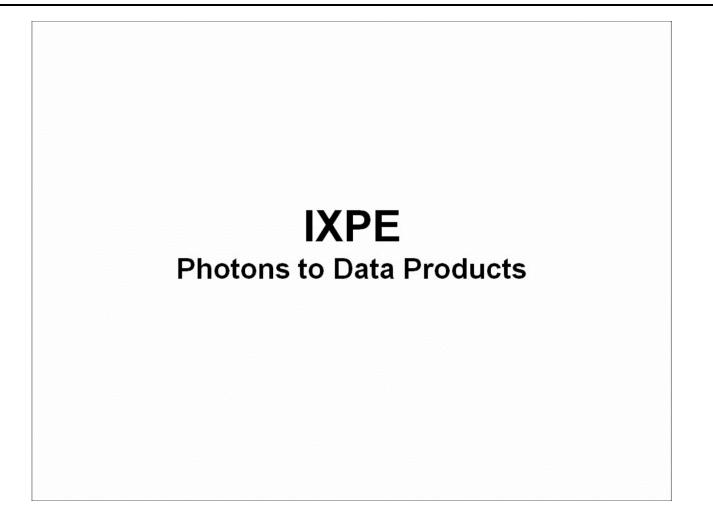


TRL 6 Prototype same form/function as FM





END-TO-END FLOW FROM DETECTED PHOTON TO SCIENTIFIC DATA PRODUCTS





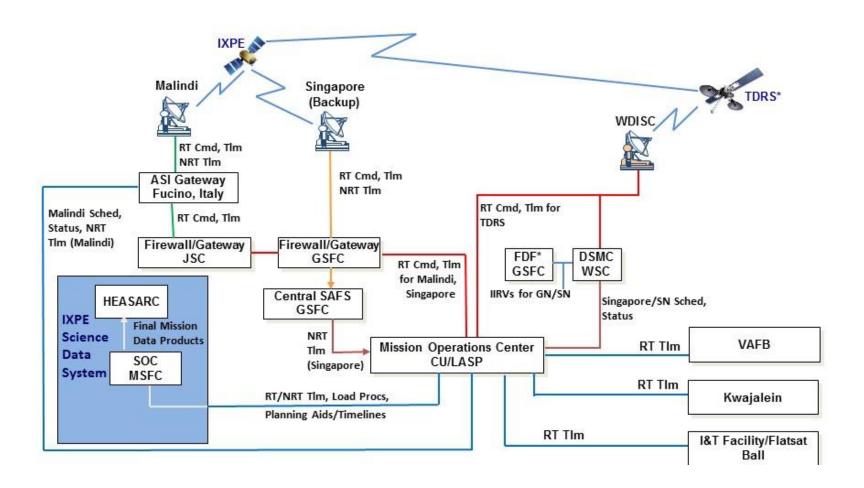
IXPE HAS SUBSTANTIAL TIMELINE AND TECHNICAL MARGINS

- Design Reference Mission (DRM) targets studied in detail during Year 1
 - Year 2 is available for follow up observations, targets of opportunity, survey of additional sources
- IXPE also has high technical margins

Characteristic	Requirement	Capability	Margin
Launch Mass	291.7 kg	380.0 kg	30.3%
Science Data Storage	4 GB	6 GB	50%
EOL Science Mode Power Generation	188 W	257 W	37%
w/30° offset			
LOS Pointing Accuracy	53.1 arcsec (3σ)	25.2 arcsec (3σ)	110%
LOS Co-alignment Accuracy, X-axis	19.8 arcsec (3σ)	9.5 arcsec (3σ)	107%
LOS Co-alignment Accuracy, Y-axis	26.7 arcsec (3σ)	12.8 arcsec (3σ)	109%
LOS Pointing Knowledge	34.5 arcsec (3σ)	17.3 arcsec (3σ)	100%
Link Margins	>3 dB	>3.9 dB	>3 dB



IXPE USES HERITAGE GROUND DATA SYSTEM





IXPE INTEGRATED MASTER SCHEDULE

			FY20	16		FY2017		FY2018		FY2019		FY2020			FY2021		FY2022		FY2)23
		201		2016		2017		2018		201			2020		2021			2022		2023
		ASO			SOND.		ASONDJF	MAMJJA	SOND			DJFMAM	JJASO	NDJ	FMAMJJ			JJASO		
	Mission Phases		Phase A (11 m				B (13 mo)			Phase C	:/D (34 mo)					Phase E	24 mo)			Phase F
	Major Milestones/Reviews	8/31/15 Ph A Select		7/19/16 Submit CSR	Site Visit	2/1/17 6/30/13 Flight SRR/MD Select KDP-B)	PDR PDR 3/	1/18	11/1/18 CDR		10/8/19 IIRR	1/9/20 4/30/2 SIR ORR 2/10/20	Y	MRR 10	/30/20 AR/KDP-E 12/15/20	0			2/1/22 DR 12/14/22	
WBS	WBS Title/Task				-			KDP-C				KDP-D		🔶 La	unch 11/20/20				KDP-F	
1.01	Project Management		CSR Developm		V Prep	Program	n Planning			Project N	lanagement					Operations N	anagement		C	loseout
			CSR Developm		V Prep															
1.02	System Engineering				nts Developn		Verification Plans	Verification	Matrix			erification Sell-of	t				F			
						es/Mission System El				Mission Syste	em Engineerin	Ig				Mission Systen	n Engineering			
				P Developme	aft ICDs	Detailed MA	ns/Final ICDs	Parte A	Antorials Subs	ontract Support										
1.03	Safety and Mission Assurance		IVIAI	PDevelopme	int	Detailed WA	rians	Parts, N	laterials, Subc	ontract support	Inspect	ions, MRB, Sell-of	f							
	Colon on Investigation								▼MOC/SO		MOC/SOC CD									
	Science Investigation Science Ops Center (SOC)						Reat's		SOC Design			Documentation	and Training			Sc	ence User Sup	oort		
	Science Ops Center (SOC) Science Data Analysis						neque	Calibration SW		t S		re Development					ight Data Proce			
1.04	Science Data Analysis														Science Mi	ission Planning				
	Science Team and Support						Science Oversight			Science	Oversight					Science	Research and F	Reporting		
																			SEC	D(1yr) 🗕
	Payload		Optics /	ssembly Desi	ign	EM Manufac	turing and Test	Flight N	lirror Mod Ass	y Test										
	Optics/Mirror Modules						Flight Optics	Manufacturing		▼Calibration Re		w								
									Calibration P		Cal									
	Payload Harness						Reqt's	Design	Mockup	Fabrication/	Test							h Margin (wor		
	Detector System									t							Phase	Margin/day		
	Detector Units		Detector					ght Units Mfg Tes	t/Cal								PDR to SIR	109	5.	
			Davide and Car	Prototype		Contracts	EM Qual Unit EM Unit										SIR to PSR	51	2.	
1.05	Payload Computer		Payload Co	nputer Desigr	n	Contracts		imulator									PSR to Launch	15	0.	
	Payload Computer							Computer Fabrica	tion/Test								Total Critical	175	8.	3
	Payload Structure and Mech					Pa	yload Struct Design			sign/Fab 🗕 🗕 To B	us Structure A	ssembly					Path Margin>			
	Deployable Boom						Studies Spec		cure Deployal								Note: 1 month	= 21 work day	s	
	Tip/Tilt Mechanism							Requirements		Fab/Assy/Test										
	Mirror Module Support/Shields							Requirement		Fab										
i i	Payload Metrology					LEDs/Lens	s		n/Fabrication		_									
	Payload Thermal Control						Preliminary Design		Heat	ers/Temp Sensors										
	Payload I&T					I&T P	lanning		Plans/Proce	edures	I&T									
	Spacecraft Development (Ball)																			
	Spacecraft Program Management		CSR Developm	ent S	V Prep		n Planning				lanagement									
	Spacecraft Mission Assurance					Detailed MA		Varification		ials, Subcontract S								Funde	d Schedule	wargin
	Spacecraft System Engineering ADCS			R	equirements		Verification Plans reliminary Design	Verification	Matrix ar Trackers, Ro		quirements Ve	er fication/Sell-of							ule Slack y Critical Pa	+h
	C&DH						reliminary Design		ar Trackers, Ro M and Flight I										dary Critical Pa	
1.06	Flight Software					caprincqt3/ri	Requirements	FSW Docum		FSW Build	FQT								any critica	
	RF and Communications					Telecom Regt's/	Preliminary Design			Cables, Switches		1								
	EPDS						eliminary Design		Solar Array, B	attery										
	Spacecraft Harness						Req'ts	De	esign Mock	-up Fab/Test										
	Spacecraft Structure and Mech						Preliminary Design	Design	Fabrica		st									
	Spacecraft Thermal Control						Preliminary Design	Design		b/Assembly	-++									
	Spacecraft I&T					I&T P	lanning		Plans/Proced		I&T									
	Mission Operations								▼MOC/SD	DC PDR V	MOC/SOC CD									
1.07	Mission Ops Development Commissioning					MOC Planning	g/Requirements		MOC Design		Develop N	ICC HW/SW s. Training, Rehe	aveals MCT-							
	Mission Operations (LASP)										Doc	.s, fraining, Rehe	arsais, MS Is Commissioni	ing		Mission Opera	tions (LASP)		Do	comm
1.08	Launch Vehicle					LV Select	tion	Initial ICD			Final ICD		commissioni	ing		wission opera	ILIOIIS (LASP)		De	comm
1.00	Ground Operations					Ly Selec		minial ICE			marico									
1.09	Network Development			Network I	Planning	Requirements	SDRLs/Plans	ICDs, Database	es, Command/	Telemetry Validati	on Net	work Tests								
	Malindi Stations							, is the second second		, india, india	110		iness Support			Operations/Ma	intenance		De	comm
1.10	Observatory I&T					Observator	y I&T Planning		Plans, Pro	ocedures, GSE		Obs I&T		ch Site Pr						
1.10	Launch Site Operations						Drft MSPSP, ICD			lans, Procedures, N										
1.11	Education and Public Outreach						EPO Planning			Media, Events, Wel					Website Maint	tenance, Missio	n/Science Med	lia Events		
	MIT Student Collaboration							Track Anal	ysis	Algorithms for 2	X-ray Data Ana	lysis	Training							
																				A12567



CONCLUSIONS

- IXPE Project Phase B Kicked off in February 2017
- SRR planned mid-September 2017
- PDR planned February 2018
- Observatory built up from heritage elements
- X-ray optics build starts at MSFC 2017
- Gas-pixel detector fabrication starts 2017
- Launch planned November 2020



- The Ball Aerospace IXPE Project Team would like to thank NASA Marshall Space Flight Center for their support of this work under contract number NNM16581489R. Weare grateful for the support.
- The work described in this presentation is a culmination of efforts from teams at NASA MSFC, Ball Aerospace, ASI, INFN, IAPS, LASP, Stanford, McGill, Roma TRE