



LA MISSIONE EXTP E REDSOX

RIVELATORI AL SILICIO PER LO SPAZIO: DAL R&D ALLA MISSIONE SPAZIALE

MARCO FEROCI

INAF/IAPS, ROMA

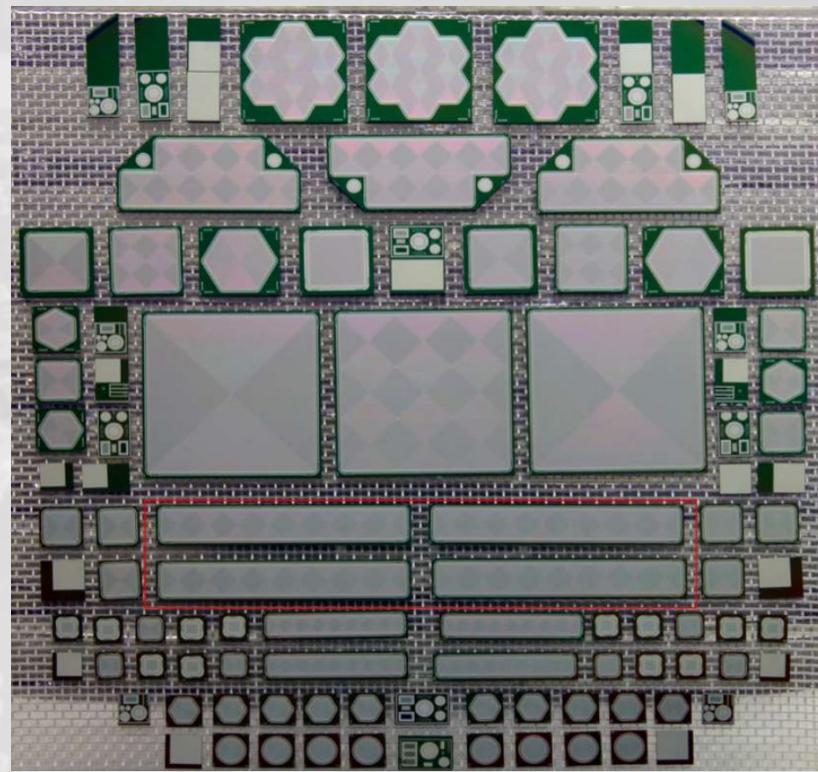
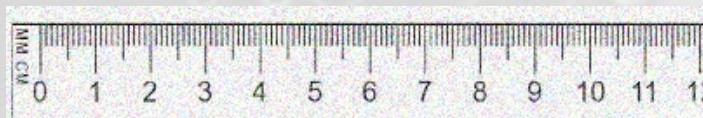
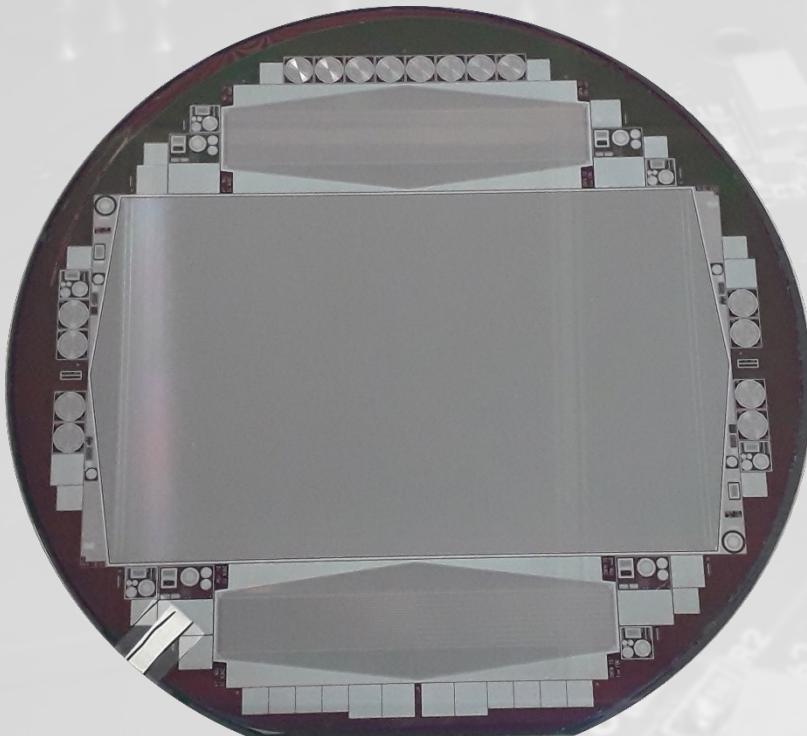
IN RAPPRESENTANZA DEI TEAM EXTP & REDSOX



REDSOX in breve:

- Collaborazione nata circa 13 anni fa da una iniziativa INAF-INFN, come sigla INFN (CSN 5), sotto il coordinamento di INFN-Ts
- Forte complementarietà e sinergia tra i gruppi
- Partecipazione gruppi (limitatamente alla parte spaziale): INFN, INAF, Fondazione Bruno Kessler, Politecnico di Milano, Università di Pavia, Karlsruhe Institute of Technology
- Supporto INFN, ASI, FBK, INAF, EU, ESA

Sviluppo di sistemi di rivelazione innovativi basati sul Silicon Drift Detectors ed elettronica di lettura integrata (ASICs) per Astronomia X (ed altre applicazioni...).





INFN sez. Trieste & TIFPA Trento – Coordinatore: A. Vacchi

Detector design, trade-off analysis, simulations, bench-test, detector-FEE integration.



INAF – Coordinatori: M. Feroci, C. Labanti

Science drivers and requirements. Experiment and system concept, design and development. FEE design and trade-off, production, integration and test. Test equipment, functional and physical tests, qualification tests.



Fondazione Bruno Kessler Trento – Coordinatore: P. Bellutti

Detector technology development, production and test. Detector design.



Politecnico di Milano – Coordinatore: G. Bertuccio

Analogue front-end development, ASIC design, trade-off analysis, bench-test.



Università di Pavia – Coordinatore: P. Malcovati

Digital front-end development, ASIC design, trade-off analysis, bench-test.



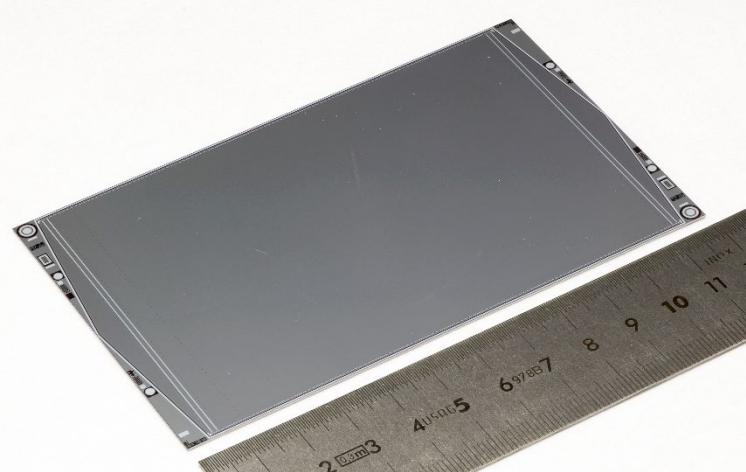
KIT Karlsruhe – Coordinatore: M. Caselle

Detector-ASIC flip-chip interconnection.

RISULTATI: RIVELATORI ABILITANTI PER MISSIONI SPAZIALI



LOFT/
eXTP/
STROBE-X
(Medium/
Large)



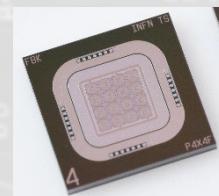
THESEUS
(ESA M)



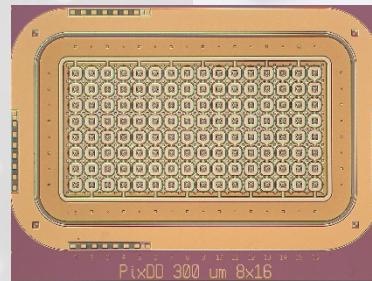
HERMES
(cubesat)



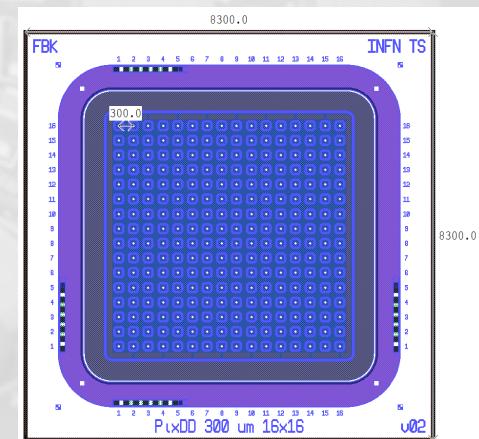
4x4



16x8



16x16

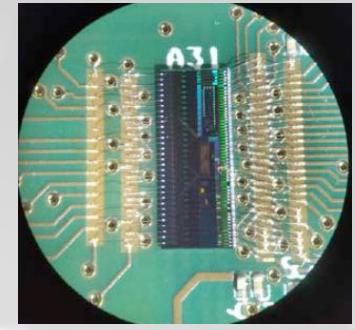
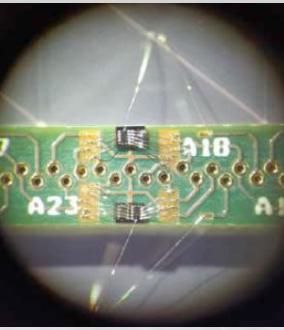
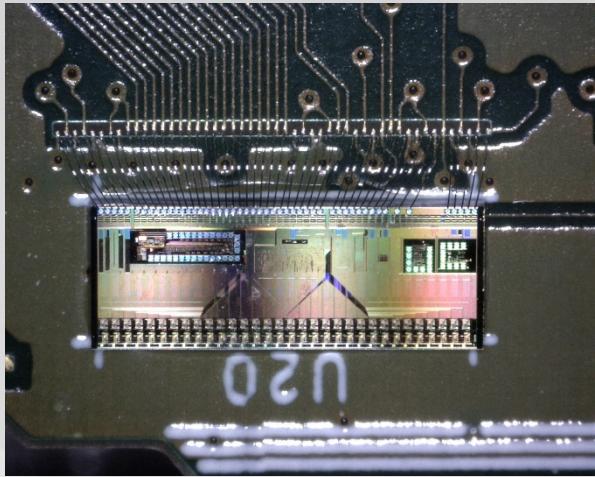


PixDD (LAMP, Small)

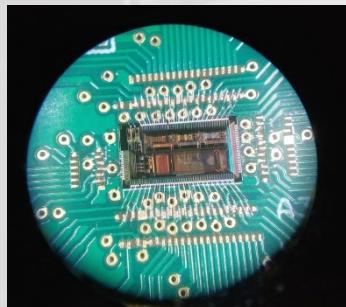
RISULTATI: ELETTRONICA A BASSISSIMO RUMORE E BASSO CONSUMO



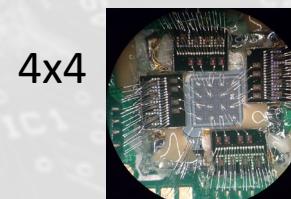
VEGA
(LOFT/eXTP/
STROBE-X)



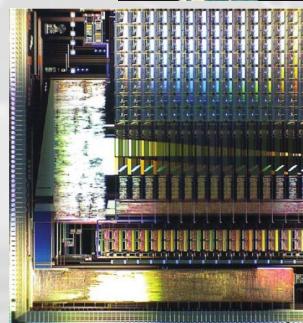
LYRA FE/BE (HERMES)



ORION
(THESEUS)

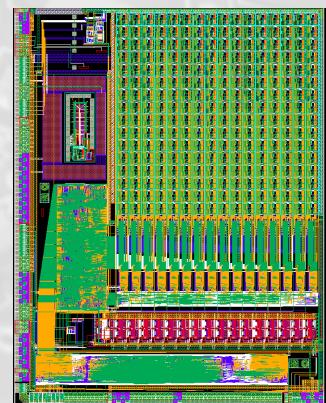


16x8

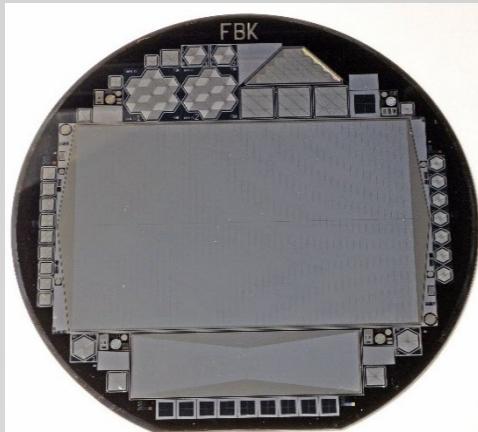


4x4

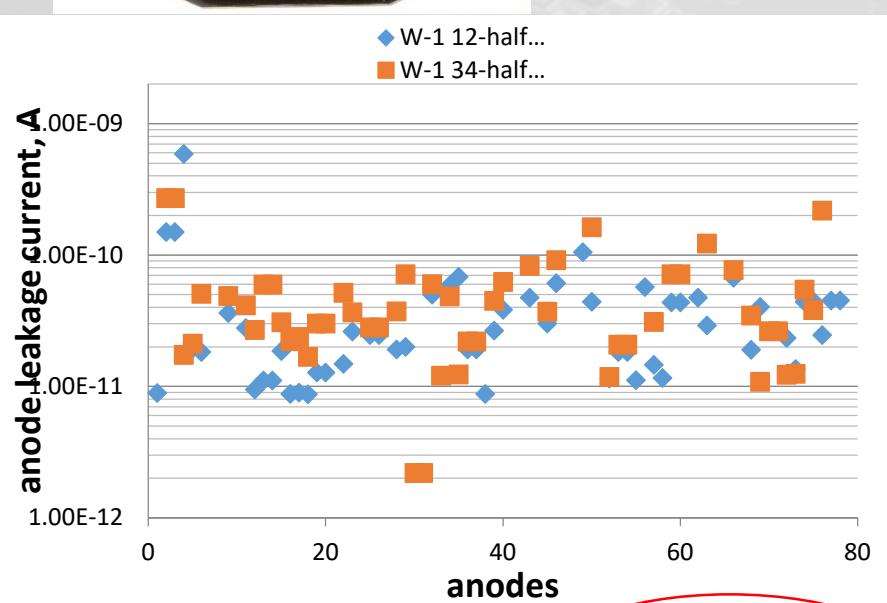
16x16



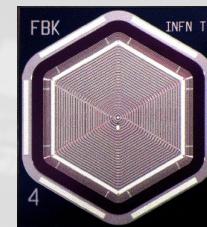
RIGEL/SIRIO (PixDD)



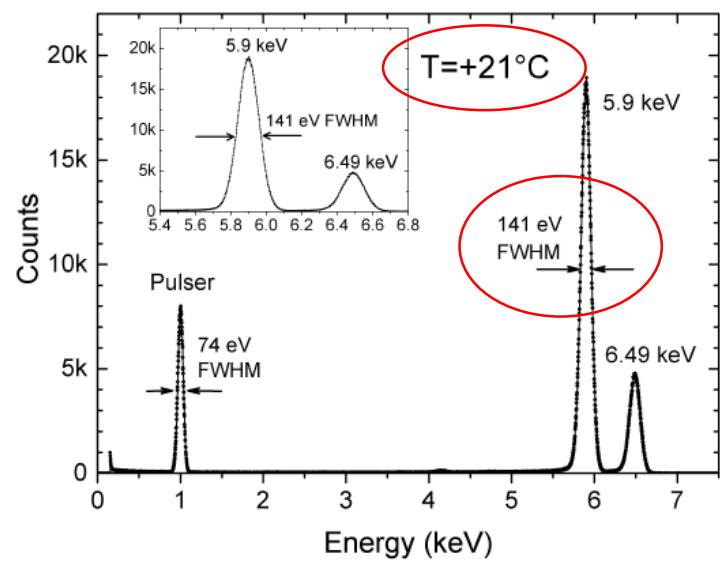
Detector area 76 cm²
Strip area 34 mm²



Mean value 12-half: 14.6 pA/anode (**44 pA/cm²**) at 20° C;
Mean value 34-half: 24.9 pA/anode (**75 pA/cm²**) at 20° C;



Detector area 13 mm²
SIRIO pre-amp



Detector leakage current: **25 pA/cm²** at 20° C;

Le attività REDSOX sono sostenute attraverso progetti R&D e studi di missione, da bandi competitivi:

Ente	Bando	Progetto	Periodo
ASI	“Bando Svelto”	Architetture Compton	2008-2010
	ESA-M3	LOFT	2011-2014
	TECNO-2016	PixDD	2015-2017
	Premiale 2015	ADAM	2018-2021
	ESA-M3	FBK Rivelatori eXTP	2018-2020
	MoO	eXTP Fase A	2018-2019
	MoO	eXTP Fase B1	2019-2021
	MoO	eXTP Fase B2	2021-2022
	TECNO-2016	HERMES-Tecno	2016-2021
	Premiale 2015	HERMES-TP	2018-
	Premiale 2016	HERMES-SP	2020-
	ESA-M5	THESEUS	2019-2021
INAF	Idee Missioni _ Anno I	ASM	2007
	Idee Missioni _ Anno II	ASM	2008
	Idee Missioni _ Anno III	ASM	2009
	Idee Missioni – Anno III	LOFT	2009
	TECNO-2014	PixDD	2015-2017
INFN	CSN5	XDXL	2009-2012
	CSN5	REDSOX	2013-2017
	CSN5	REDSOX2	2018-2019
	CSN2	XRO	2021-
EU	Horizon-2020	HERMES-SP	2018-2022

Nome	Ruolo
Ambrosino, Filippo	Ricercatore TD
Campana, Riccardo	Ricercatore TI
Ceraudo, Francesco	Assegnista
Del Monte, Ettore	Tecnologo TI
Di Cosimo, Sergio	CTER, Associato
Evangelista, Yuri	Ricercatore TI
Feroci, Marco	Dirigente di Ricerca TI
Fiore, Fabrizio	Dirigente di Ricerca
Fiorini, Mauro	Ricercatore TI
Fuschino, Fabio	Ricercatore TI
Labanti, Claudio	Primo Ricercatore, Associato
Marchesini, Ezequiel	Assegnista
Piazzolla, Raffaele	Tecnologo TD
Rapisarda, Massimo	Dirigente di Ricerca, Associato
Virgilli, Enrico	Ricercatore TI

FTE 2021 formali
in scheda: 1.0

- ❑ Il Gruppo REDSOX nasce da una collaborazione INAF-INFN con l'obiettivo di applicare all'Astrofisica spaziale i rivelatori sviluppati dall'INFN per esperimenti di Fisica delle Alte Energie. Ciascun team di ciascun ente porta all'interno di REDSOX la propria expertise: la complementarietà e completezza di queste sono il punto di forza della collaborazione.
- ❑ Nei progetti ai quali si applicano le tecnologie sviluppate nell'ambito di REDSOX il coordinamento è effettuato dal gruppo che li propone e/o ha la migliore expertise specifica.
- ❑ L'INAF coordina i progetti PixDD, ADAM, ASM, HERMES, LOFT, eXTP, THESEUS. (Ad esempio, l'INFN coordina invece le applicazioni alla luce di sincrotrone o le applicazioni medicali, che sono tra le applicazioni non-spazio di REDSOX).

Il team REDSOX rappresenta una **filiera nazionale unica** costituita da autonomi gruppi di ricerca di INAF, INFN, FBK ed Università, coordinati nel proporre ed affrontare sfide specifiche in risposta a bandi ESA, ASI, INAF o INFN. Dal punto di vista progettuale e tecnologico REDSOX è una eccellenza nazionale, in alcuni casi in posizione di leadership europea o mondiale.

Tuttavia, la collaborazione soffre ad oggi la mancanza di una **«stabilità istituzionale»** e di una efficiente infrastruttura per l'ingegnerizzazione e la spazializzazione (e.g., **laboratorio nazionale inter-ente**), che potrebbe rendere la presenza dei dispositivi integrati (rivelatore e front-end) sul mercato scientifico meno occasionale e più strutturata, permettendo un flusso di sviluppo organico e continuo.

Una tale infrastruttura nazionale potrebbe poi aprire facilmente la strada a spin-off per la commercializzazione di questi dispositivi per le numerose potenziali applicazioni anche in settori non specificamente scientifici.



- ❑ A flagship X-ray observatory mission, being developed by the Chinese Academy of Sciences, with a large contribution by a European Consortium. ESA is studying a MoO participation.
- ❑ Currently in Phase B1. The launch date is planned in late 2027, for a minimum mission lifetime of 5 years (goal 8 years).
- ❑ eXTP is proposed as an observatory open to the worldwide scientific community through a Core Program and a Guest Investigator Program.



eXTP PI Institute: IHEP/CAS, Beijing

CAS



CNSA



IHEP Beijing



Institute of High Energy Physics
Chinese Academy of Sciences

Tsinghua University



清华大学
Tsinghua University

Tongji University



同济大学
TONGJI UNIVERSITY

CAST Beijing



中国空间技术研究院
China Academy of Space Technology

IAMC Shanghai



Italy



Spain



Germany



France



Switzerland



Czech Republic



Poland



Denmark



The Netherlands

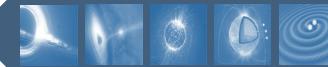


Austria



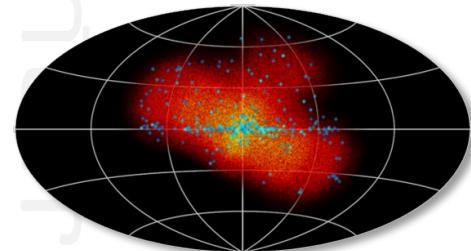
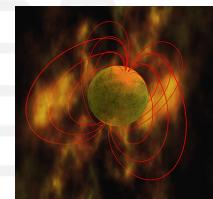
Turkey





Study of matter under extreme conditions of gravity, density and magnetism. For the first time: simultaneous, high-throughput spectral, timing and polarimetry observations.

- Constrain the **Equation of state** of the supra-nuclear density matter in the interior of neutron stars.
- **Accretion** physics in the **strong-field** regime of **gravity** and tests of General Relativity in neutron stars and black holes over the mass scale.
- Physics of light and matter in the presence of **ultra-strong magnetic fields** in magnetars and X-ray pulsars.
- Multi-purpose **observatory** and wide-field monitoring for transients (and e.m. counterparts of GWs). Rapid follow-up.



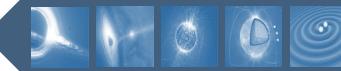


Science Case study and scientific simulations for the enhanced X-ray Timing and Polarimetry mission eXTP (A. De Rosa)

Studi di Astrofisica delle Alte Energie e di Fisica Astroparticellare. Bando 2019.
Accordo ASI - INAF 2017-14-H.0

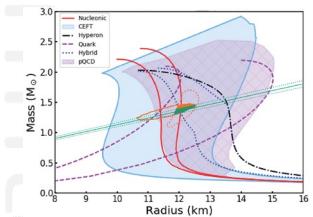
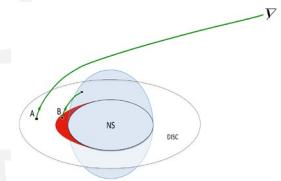
Composing team

- UdR 1. Alessandra De Rosa - INAF/IAPS/OA Roma/OA Arcetri/OAS. U La sapienza, U Roma Tre, U Tor Vergata
- UdR 2. Fiorella Burgio - INFN-Catania/Ferrara, U Ferrara, U Pisa
- UdR 3. Tiziana Di Salvo - U Palermo, U Cagliari, INAF/OA Brera, IASF-Pa, OAS, IRA, OA Capodimonte



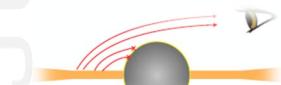
O1: NS Equation of State

- Measuring the M/R ratio of NSs through the observation of the very broad FeK α emission line. Occultation techniques
- Theory: phenomenological consequences of the existence of two families of compact stars. evaluate eXTP ability to discriminate models.



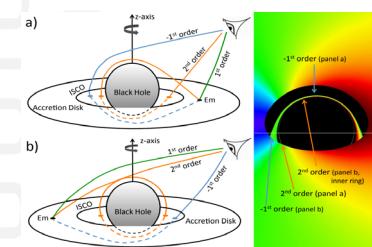
O2: BH (AGN and XRB) disc-corona

- Spectral (occultation) and Spectral-timing properties (time lag) of outflowing coronae: constraining the corona location; polarimetric signature: constraining the geometry of the emitting corona



O3: millisecond X-ray Pulsar

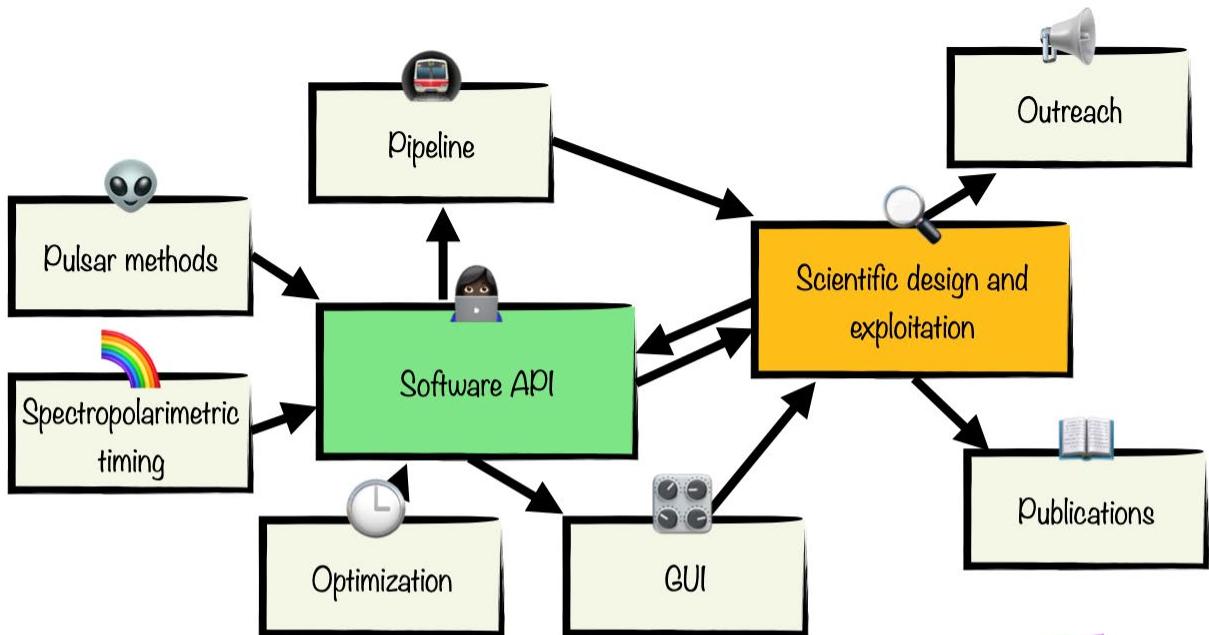
- modelling the fast X-ray variability of the accretion flows in binary systems hosting a NS. Timing noise. MW+X-ray mock data





Scientific simulations: support to the community and contribution to mission definition

- The scientific activities are strongly linked with the mission definition: Scientific Requirements, Observing Plan (#pointings, cadence, exposure), Instrument performances, ...
- The proposing team has been and is still in charge to prepare and submit the response matrices (arf and rmf) and background for science simulations and their routine update depending on the instruments definition and characterization. We released in 2021 the latest version of the eXTP matrices and background.



SpecTemPolar

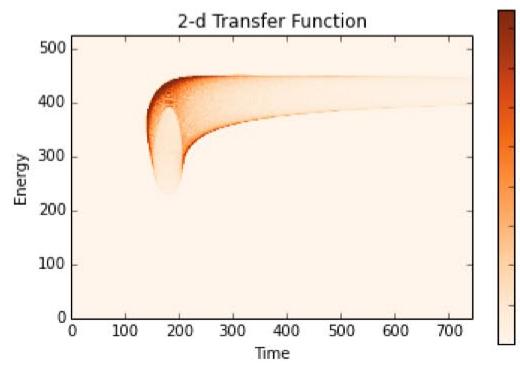
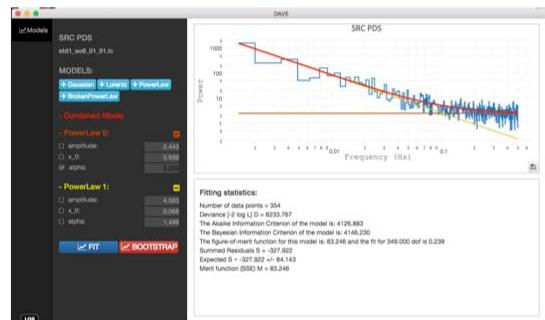
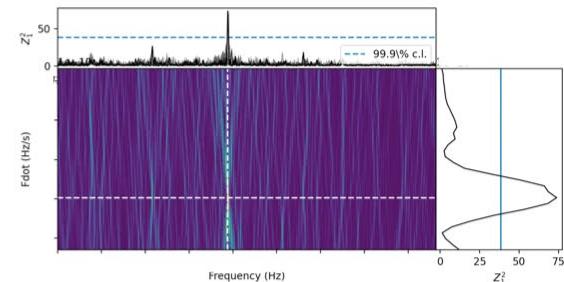


Stingray Software

Google
Summer of Code

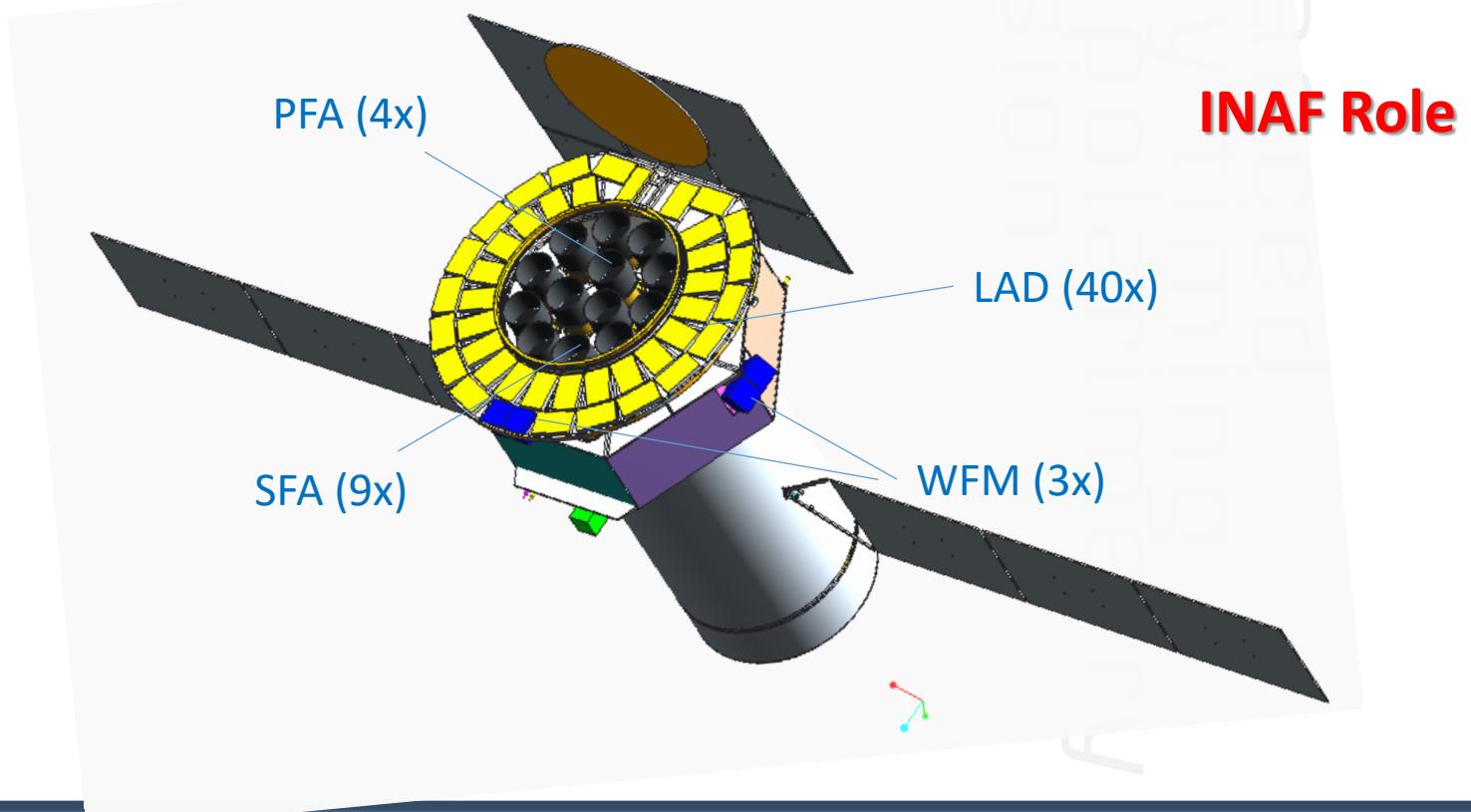
INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

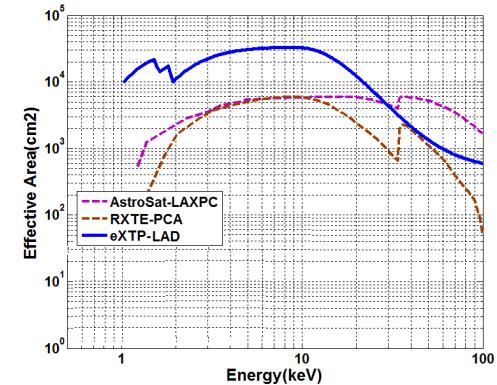
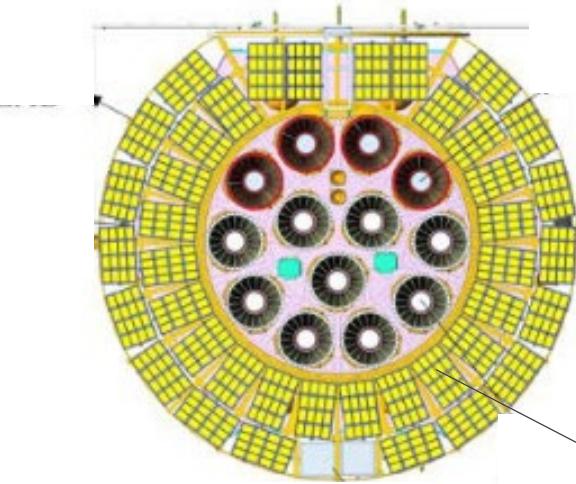
PRIN INAF 2019



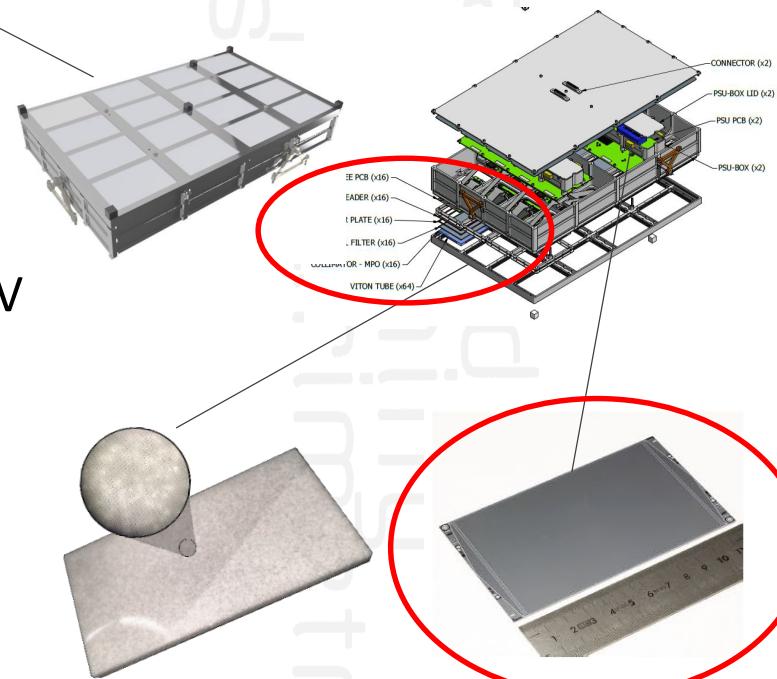


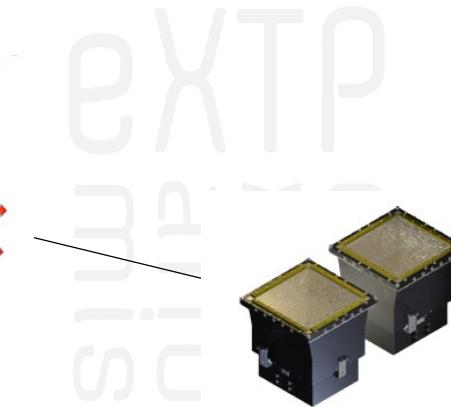
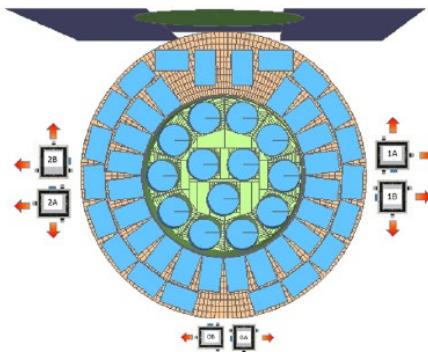
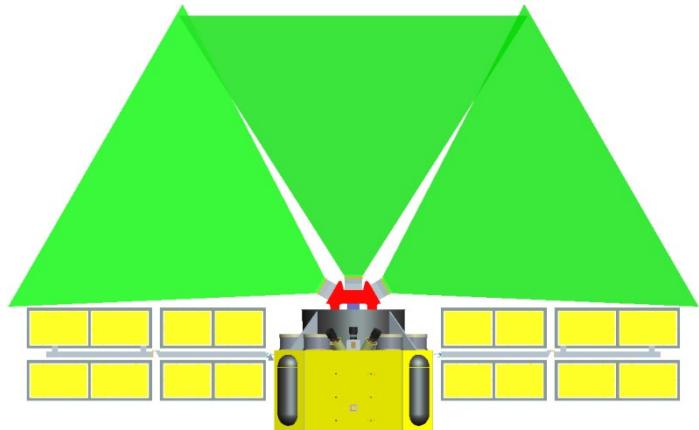
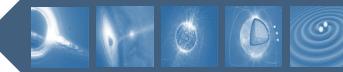
Payload	Configuration	Optics	Detector
SFA	9 Telescopes	Nickel replica	SDD
LAD	40 Modules	MCP Collimator	SDD
PFA	4 Telescopes	Nickel replica	GPD
WFM	6 Cameras	1.5 Coded Mask	SDD





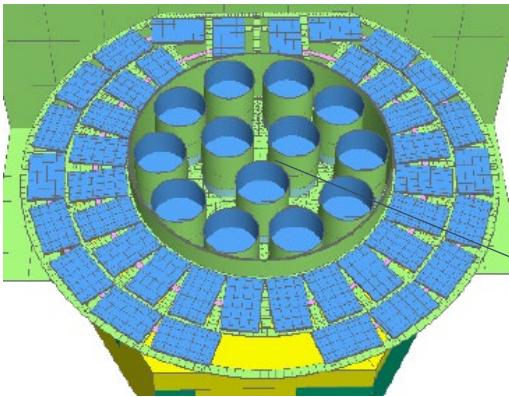
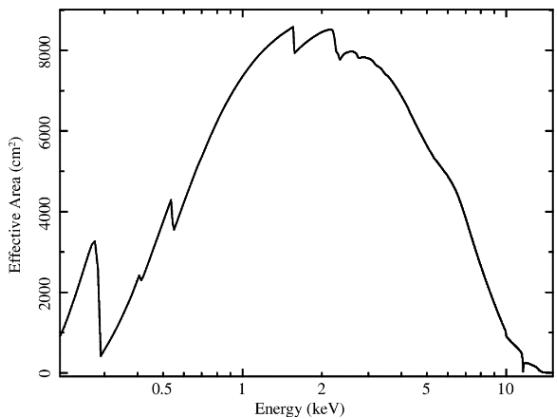
- ❖ Total effective area: 3.4 m^2 @8 keV
- ❖ Energy band: 2-30 keV
- ❖ Energy resolution: <240 eV FWHM @6 keV
- ❖ Based on the LOFT/LAD design
- ❖ 40 Modules on support structure
- ❖ 1° Collimated, large-area SDD detector.
Single photon, <10μs





- ❖ Field of View: 4 steradian (at 20% response)
- ❖ Imaging, <5 arcmin angular resolution, 1 arcmin PSLA
- ❖ Energy band: 2-50 keV
- ❖ Energy resolution: 300 eV FWHM @6 keV
- ❖ Effective area: 80 cm² @6 keV (1 unit, on axis)
- ❖ 3 units (6 cameras)
- ❖ Same detectors as LAD (SDD). Single photon, <10μs



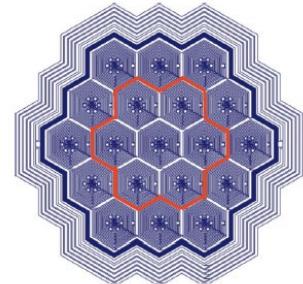


COVER

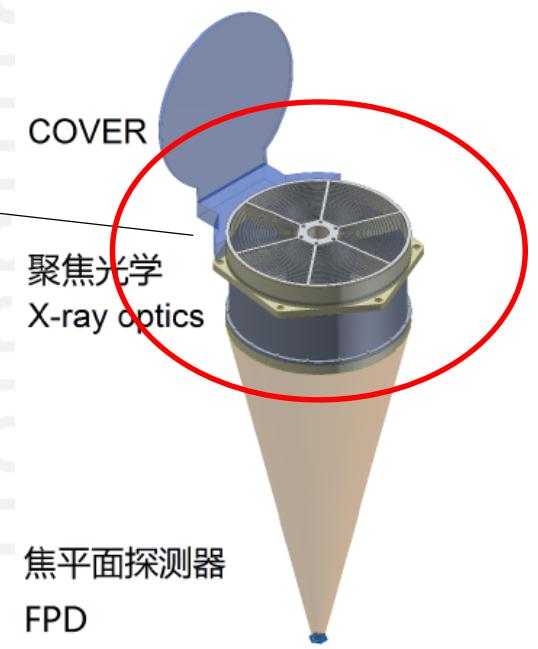
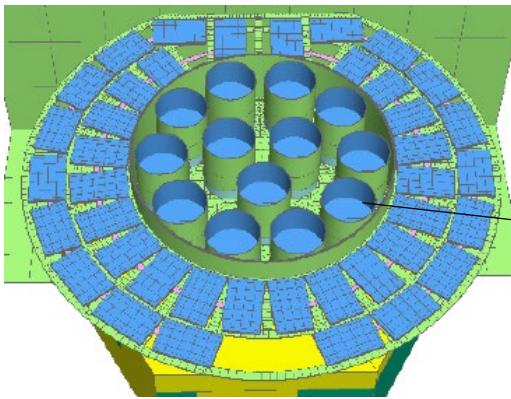
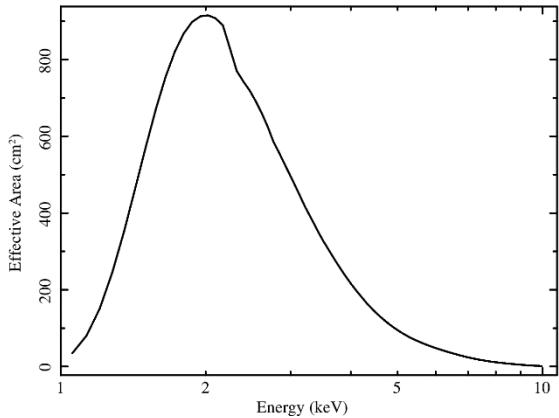
聚焦光学
X-ray optics

焦平面探测器

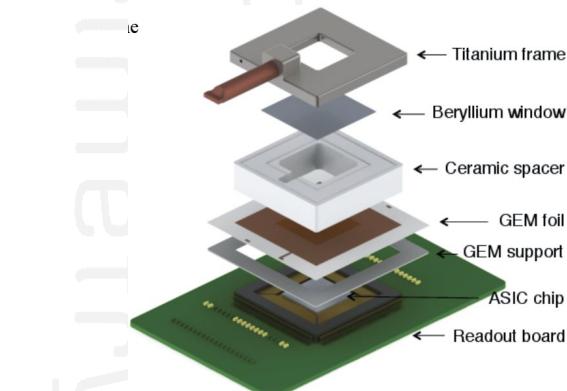
FPD



- ❖ Large collecting area achieved by multiple optics with short focal length. Baseline: 9 optics with 5.25m FL
- ❖ Total effective area: >0.7 m² @1 keV, 0.5 m² @6 keV
- ❖ Non-imaging, PSF requirement 1 arcmin HPD, 12' FoV
- ❖ Multi-pixel SDD detector (to enable background subtraction). Single photon, <100μs
- ❖ Energy band: 0.5-10 keV
- ❖ Energy resolution: <180 eV FWHM @6 keV

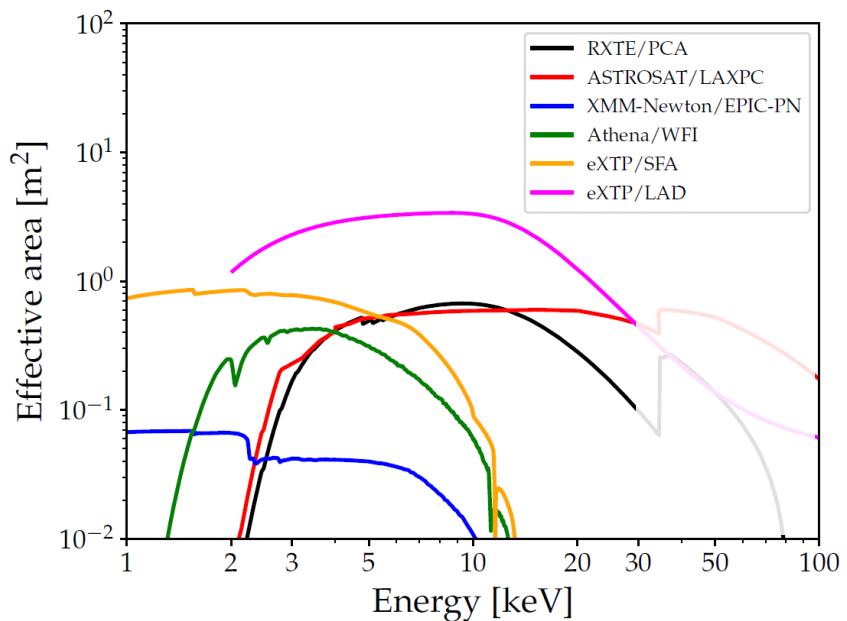


- ❖ Focal plane imaging polarimeter: 4 telescopes with 5.25m FL
- ❖ Imaging, PSF 20 arcsec HPD
- ❖ Total effective area: 900 cm² @2 keV (includes QE)
- ❖ Gas Pixel Detector: single photon, <100μs
- ❖ Energy band: 2-10 keV
- ❖ Energy resolution: 20% FWHM @6 keV

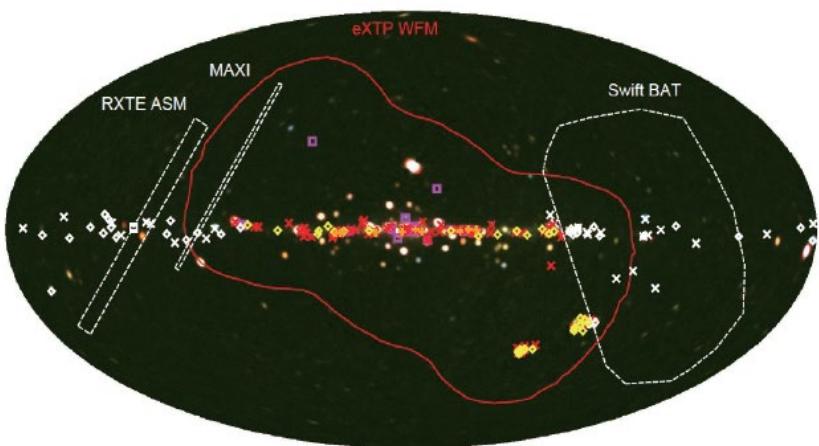




Effective Area of SFA and LAD



Instantaneous FoV of WFM



- ❖ **LAD:** 6x RXTE/PCA, 35x XMM-Newton (*but collimated!*) + hard-X response
- ❖ **SFA:** 8x XMM-Newton (*but multiple optics and larger PSF!*).
Limiting sensitivity $\sim 10^{-14}\text{-}10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$
- ❖ **PFA:** 5x IXPE. Sensitivity: 1% MDP in 50ks for a 100 mCrab source
- ❖ **WFM:** Largest FoV ever, first time with 300 eV resolution. 3 mCrab in 50ks



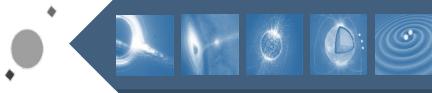
La missione eXTP nasce dal merging tra la missione europea LOFT e la missione cinese XTP.
La missione LOFT era stata proposta a PI-ship INAF.

Su eXTP INAF è:

- Coordinatore consorzio europeo
- PI dello strumento LAD
- Col degli strumenti WFM e SFA
- Co-coordinatore(trice) del team scientifico

Il ruolo INAF include inoltre le seguenti attività:

- Project Office LAD (PM, SM, PA, PS, ingegneria, ...)
- Design e test filtri ottici LAD
- Design e test ottiche SFA e PFA
- Integrazione e test LAD
- Calibrazioni LAD e WFM
- Matrici di risposta LAD
- Simulazioni background LAD
- Simulazioni scientifiche WFM
- Software scientifico (SSDC, SpecTempPolar)
- Studio requisiti scientifici (Studi Alte Energie)



Lo sviluppo di eXTP è finanziato dall'ASI:

- ✓ Accordo ASI-INAF studio di Fase A: completato
- ✓ Accordo ASI-INAF Studio Alte Energie 2017 – Scienza eXTP: completato
- ✓ Accordo ASI-FBK per sviluppo rivelatori: completato

- Accordo ASI-INAF studio di Fase B1: in corso
- Accordo ASI-INAF Studio Alte Energie 2019 – Scienza eXTP: in corso
- Accordo ASI-INAF studio di Fase B2: fondi deliberati, in corso di formalizzazione
- Contratto industriale Fase B2: fondi deliberate, in attesa avvio gara



Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 57

Struttura	Nfte	N0	TI	TI	TI	TD	TD	TD	Nex	Extra
			21	22	23	21	22	23		
O.A. ROMA	4	1	0.30	0.30	0.30	0.10	0.00	0.00	1	0.10
DIREZIONE SCIENTIFICA	1	0	0.25	0.25	0.25	0	0	0	0	0.00
O.A. CAGLIARI	2	2	0.50	0.50	0.50	0	0	0	1	0.10
O.A. BRERA	9	6	0.70	0.70	0.70	0.60	1.00	0.30	2	0.20
IAPS ROMA	11	0	2.20	2.20	2.20	1.15	1.65	1.65	1	0.20
OAS BOLOGNA	6	0	0.70	0.70	0.70	0	0	0	0	0.00
O.A. PALERMO	5	0	0.50	0.70	0.70	0	0	0	0	0.00
O.A. PADOVA	0	2	0.00	0.00	0.00	0	0	0	1	0.15
IASF PALERMO	4	0	0.20	0.40	0.30	0	0	0	1	0.10
IRA BOLOGNA	0	1	0.00	0.00	0.00	0	0	0	0	0.00
O.A. CAPODIMONTE	1	0	0.10	0.10	0.10	0	0	0	0	0.00
IASF MILANO	1	0	0.10	0.10	0.10	0	0	0	0	0.00
O.A. ARCESTRI	0	1	0	0	0	0.00	0.00	0.00	0	0.00
Totali	44	13	5.55	5.95	5.85	1.85	2.65	1.95	7	0.85

16. Personale Associato INAF coinvolto

Numero di partecipanti Associati INAF: 16

#	Struttura	TI 2021	TI 2022	TI 2023	TD 2021	TD 2022	TD 2023	Extra
1	DIFC UNIPA	0.10	0.10	0.10	0	0	0	0.00
2	Università di Palermo	0.30	0.30	0.30	0.60	0.00	0.00	0.00
3	Universita' Roma Tre	0.10	0.10	0.10	0	0	0	0.00
4	Università degli Studi di Roma - Tor Vergata	0.10	0.10	0.10	0	0	0	0.00
5	O.A. Cagliari	0	0	0	0.10	0.10	0.10	0.00
6	IAPS ROMA	0.00	0.00	0.00	0	0	0	0.00
7	OAR	0	0	0	0.20	0.20	0.20	0.00
8	IAPS	0	0	0	0.00	0.00	0.00	0.00
9	OAPa	0	0	0	0.10	0.10	0.10	0.00
10	Università Roma 3	0.10	0.10	0.10	0	0	0	0.00
11	Univ. Cagliari	0	0	0	0.10	0.10	0.10	0.00
12	OA Cagliari	0.10	0.10	0.10	0	0	0	0.00
13	INAF	0.00	0.00	0.00	0	0	0	0.00
Totali		0.80	0.80	0.80	1.10	0.50	0.50	0.00



- Le attività di Project Office richiedono l'acquisizione di personale per le attività di ingegneria degli esperimenti, la gestione del progetto (management) e le interfacce con il Prime Contractor del satellite: Ingegnere meccanico, termico, elettronico, product assurance, export control, system engineering, project management.
- Queste figure sono rare o assenti tra il personale a tempo indeterminato dell'INAF. La loro acquisizione a tempo determinato è molto difficoltosa, sia per la difficoltà di reperire figure professionali di questo genere al contempo esperte e disoccupate, sia per la capacità di mantenerle all'interno dell'INAF con contratti precari, a fronte del mercato esterno.