

X-ray Technologies for Astrophysics Missions

supported by the Italian Space Agency

Ph.D. **Miliucci Marco** – Agenzia Spaziale Italiana (on behalf of ASI, INAF and INFN collaborators)

High Precision X-ray Measurements

Frascati, 23.06.2023



- **The Italian Space Agency – ASI “mission”**
- **Study of the Universe**
 - **Solar System**
 - **Cosmology**
 - **Fundamental Physics**
 - **Space Weather**
 - **ExoPlantets**
 - **Astrophysics**
- **X-ray Technologies for Astrophysics Mission**



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The Italian Space Agency – ASI «mission»



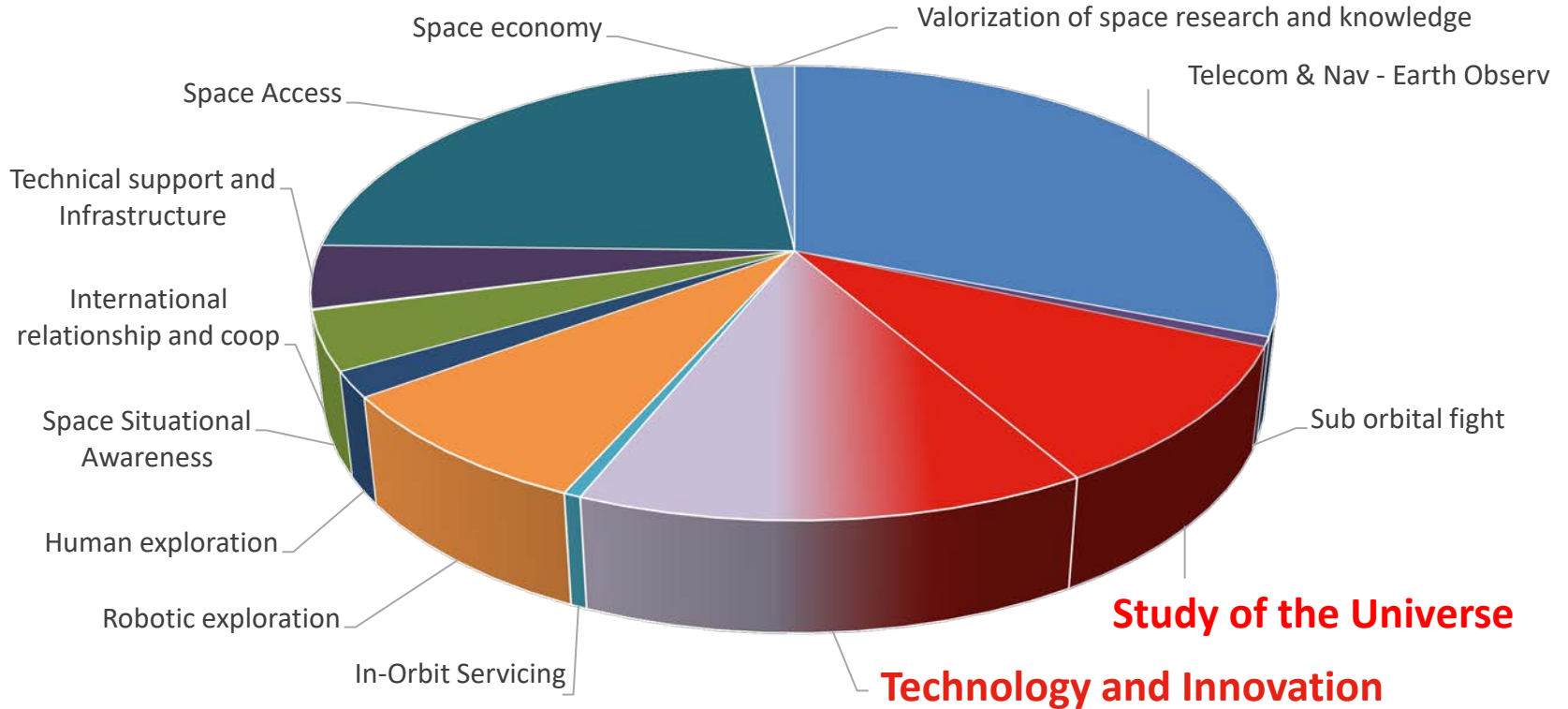
ASI is oriented towards developing a **coherent and synergistic action with the various components of the space community (public research, the industrial world, start-up, small-medium-large enterprises)**, to achieve the **advancement in knowledge, technology and competitiveness**, as well as to strengthen the international dimension of the entire sector, in order to create the right conditions to seize the numerous opportunities offered by European development programs and those at an international level.

The Italian Space Agency – ASI «mission»



ASI funds and leads scientific space programs, since paperwork only to final delivery, **supporting the Italian excellent industrial and scientific laboratory capacities** for the construction of scientific instruments (payloads) for medium-large space missions (typically in **collaboration with ESA and NASA**) and the development of satellites and their ground management. The capacity of the Italian system is demonstrated by a long series of **successful international collaborations** as well as by national initiatives.

The Italian Space Agency – «strategic sectors»



Source: <https://www.asi.it/lagenzia/documenti-istituzionali/>



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Source: <https://www.asi.it/2022/10/ixpe-rivela-i-piu-energetici-segreti-di-una-celebre-supernova/>

Italy is among the leading countries, under the coordination of the Italian Space Agency.

The scientific community (INAF, INFN, research centers, Universities, etc) and Italian industry gained an internationally recognized leadership for the construction of scientific instruments (payloads) for medium-large space missions and for the development of satellites and their ground management. The capacity of the Italian system is demonstrated by a long series of successful international collaborations as well as by national initiatives.



Credits: X-ray: Chandra: NASA/CXC/SAO, IXPE:NASA/MSFC/J. Vink et al.; Optical: NASA/STScI

Source: <https://www.asi.it/2022/10/ixpe-rivela-i-piu-energetici-segreti-di-una-celebre-supernova/>

- **Implementation of ESA Science Programme** in which the Italian scientific and industrial community are involved through the management and coordination of activities by ASI for the creation of scientific instruments and the analysis of data from satellites in orbit.
- **Programs in collaboration with NASA**, Italy is considered the priority partner.
- Participation in scientific missions of JAXA (Japan), ROSCOSMOS (Russia) and CNSA (China).



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The **Study of the Universe** sees the constant involvement of ASI in scientific missions in the sectors of **Space Astrophysics, the Study of the Solar System, the search for Exoplanets, Cosmology, Space Weather and Fundamental Physics.**

Synergic with **Study of the Universe** is the Space Science Data Center (<http://www.ssdsc.asi.it/>). Data from all scientific missions funded by ASI end up **being archived at and distributed by the SSDC**

Study of the Universe – Solar System

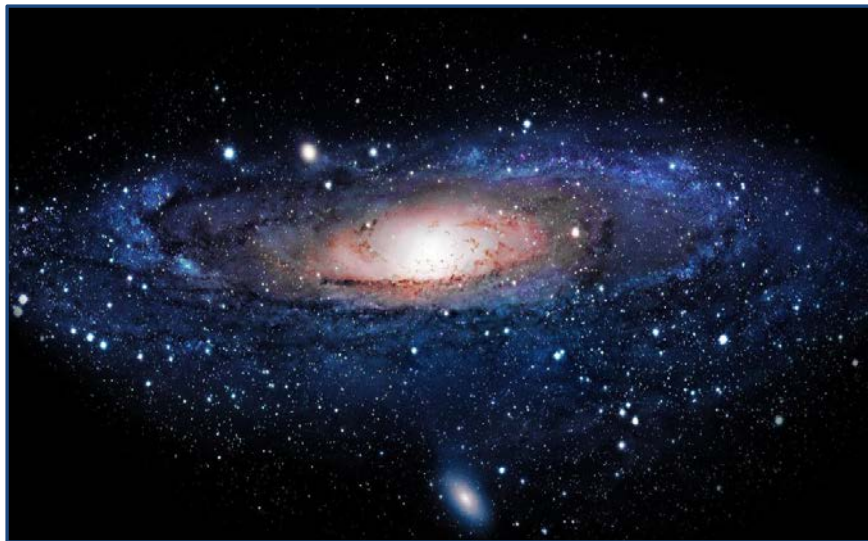


Source: <https://www.asi.it/esplorazione/>

- Origin and evolution of Solar System;
- Interactions of the Sun and the planets;
- Search for life on other planets;

Italy and the ASI play a key role in the largest international missions contributing with scientific instruments, as **ExoMars**, **BepiColombo** (2 satellites of ESA for the first European mission destined for the in-depth study of Mercury), **Solar Orbiter** (a mission for the study of the Sun which has on board the Italian METIS coronagraph) and **JUICE** (dedicated to the study of the icy moons of Jupiter - Ganymede, Callisto, Europa)

Study of the Universe – Cosmology



Source:<https://www.asi.it/esplorazione/>

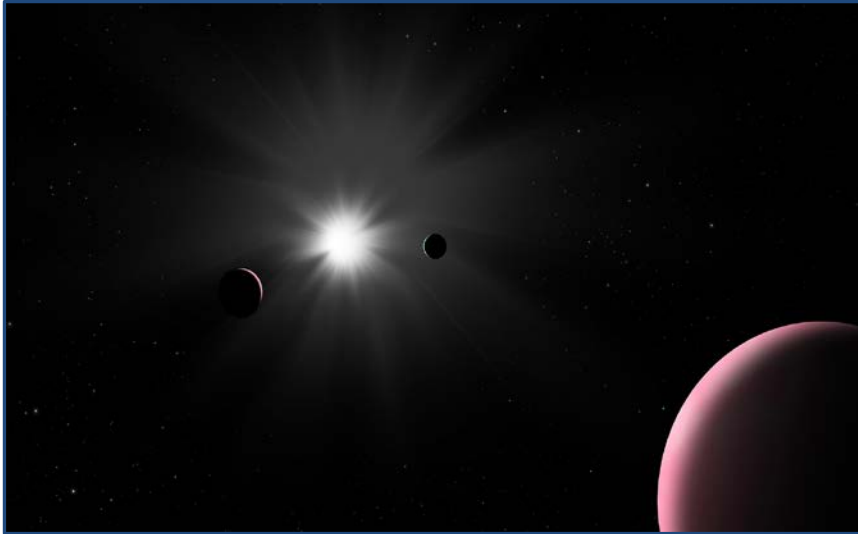
- Study of the origin and evolution of the Universe
- Formation of the first structures (diffuse background radiation, in the microwave band, and large-scale structures which evolve on cosmological times, in the infrared and millimeter ranges).

The Italian scientific community has a recognized leadership, achieved through the activities of creating innovative instruments both on satellites (**PLANCK** and **EUCLID**) and on stratospheric balloons (**Boomerang** and **OLIMPO**).

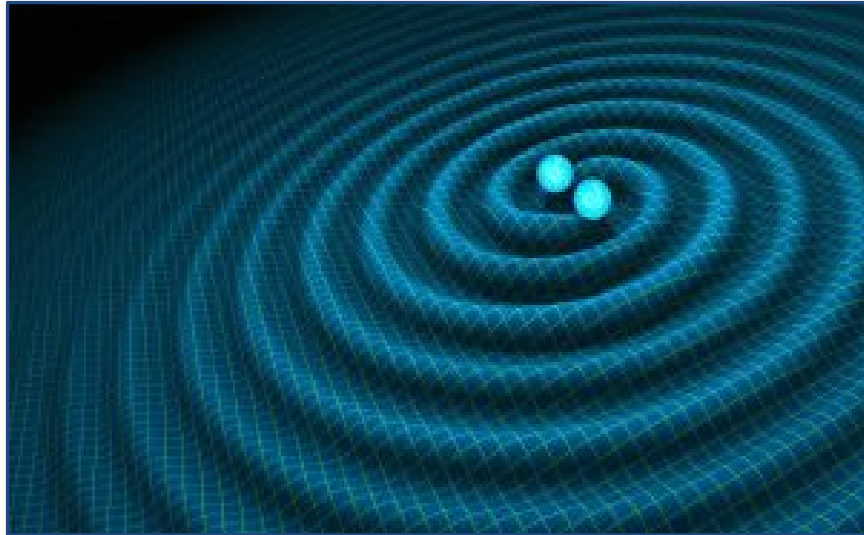
Study of the Universe – Exoplanets

The development of new observation techniques, will lead to a revolution in knowledge of the processes of formation and evolution of planetary systems and to a more extensive understanding of the "habitable zone" in a planetary system.

The Italian scientific community is playing a leading role, officially participating in the three ESA scientific missions (**CHEOPS**, **PLATO** and **ARIEL**) supporting activities for tests and integration on the satellite of scientific instruments as well as data analysis.



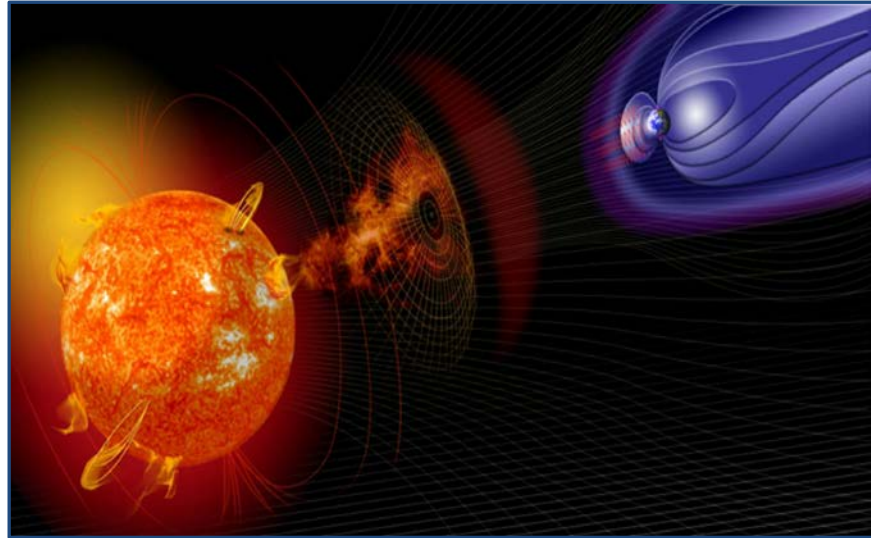
Source: <https://www.asi.it/2021/06/cheops-studia-due-esopianeti-e-ne-scopre-un-terzo-davvero-sui-generis/>



Source: <https://www.asi.it/esplorazione/>

The implementation of ESA's LISA space mission will expand the possibility of studying electromagnetic and gravitational emissions by **allowing the detection of low-frequency gravitational waves** (not observable with terrestrial detectors), emitted by gigantic sources, which release enormous quantities of energy and are therefore visible up to the extreme limit of the Universe. **Italy is at the forefront in the field of Fundamental Physics from space, both from a scientific and technological point of view (LARES)**

Study of the Universe – Space Weather



Source: <https://www.asi.it/2023/01/more-asi-large-scale-solar-wind-structures-in-the-heliosphere-and-their-space-weather-impact/>

Connections with the operation of satellites in orbit and for the impacts on living conditions on our planet. This study, of fundamental importance in modern space research, aims to improve understanding of the complex Sun-Earth relationships and identify the parameters that best characterize the circumterrestrial Space Weather. In this regard, ASI will participate in the **NUSES** mission for the study of the lithosphere-ionosphere-magnetosphere system, carried out by GSSI together with TAS-I, contributing to the launch and scientific operations.

Study of the Universe – Astrophysics



Credits: NASA/CXC/SAO/IXPE

Source: <https://www.asi.it/2022/02/arrivata-la-prima-spettacolare-immagine-dal-telescopio-spaziale-ixpe-della-nasa/>

High energy astrophysics in the **X and Gamma bands** sees an internationally recognized leadership of the Italian scientific community.

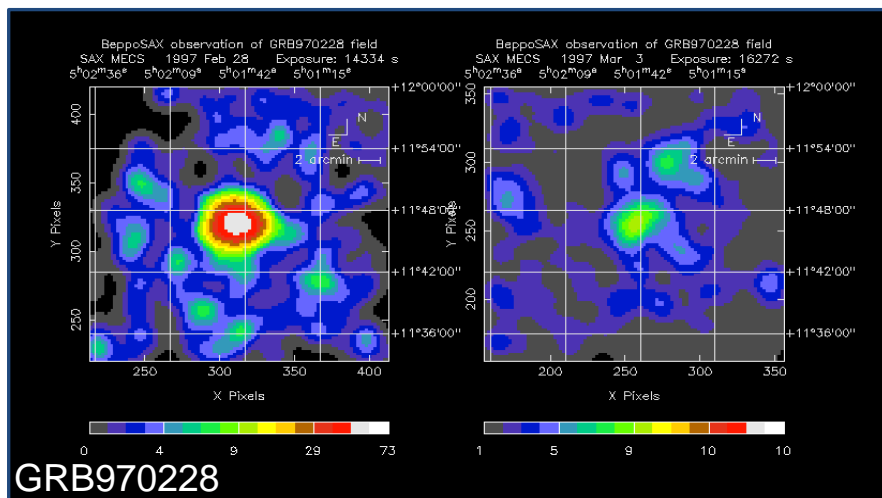
The excellence of the activities related to this sector is amply demonstrated by the scientific results obtained first with **BeppoSAX** and currently with **AGILE**, as well as by the Italian participation, with a primary role, in the NASA **Fermi** and **IXPE** missions. Alongside high-energy astrophysics, the sector of astroparticles (the study of cosmic rays from space) brings excellent results.



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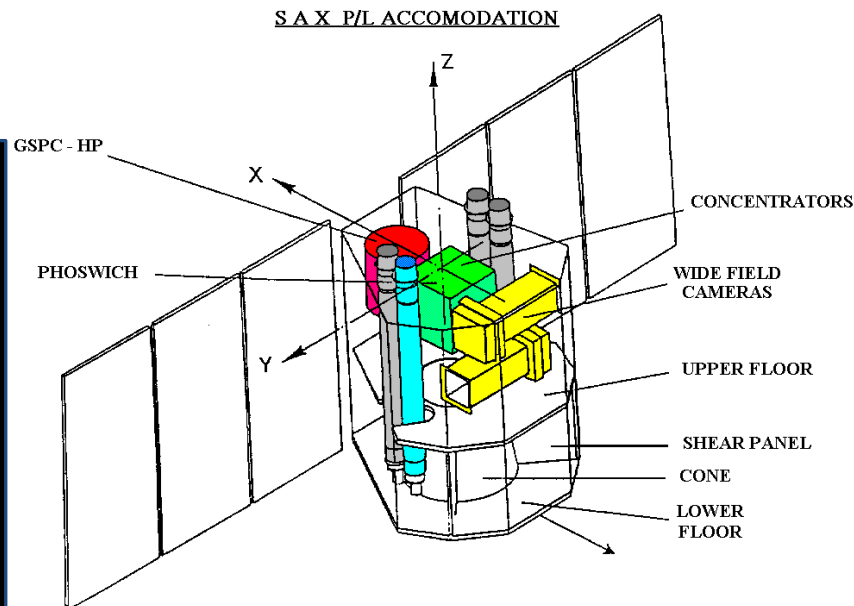
BeppoSAX – «A Breakthrough» in the Universe observation

The discovery of the X-ray counterpart of GRB, solving the long-standing enigma of their origin.



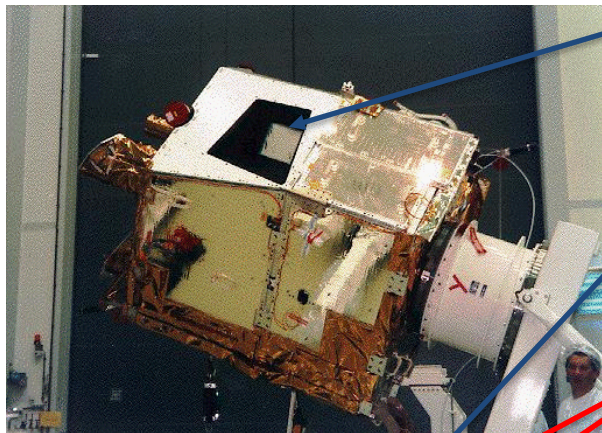
ASI – CNR – SRON – SSD(ESA)

IASF-Mi=IFCTR; OAS=TESRE; IASF-Pa=IFCAI; IAPS=IAS



- GRB Trigger (GRBM)
- GRB Localization (WFC)
- Afterglow discovery (NFI)

BeppoSAX – «A Breakthrough» in the Universe observation



Wide Field Cameras (WFI):

- Coded Mask
- Imaging proportional counters

Low Energy Concentrator Spectrometer (NFI):

- Conical Wolter I type grazing incidence X-ray optics
- Gas Scintillation Proportional Counter

Medium Energy Concentrator Spectrometer (NFI):

- Conical Wolter I type grazing incidence X-ray optics
- Gas Scintillation Proportional Counter

Phoswich Detection System (NFI):

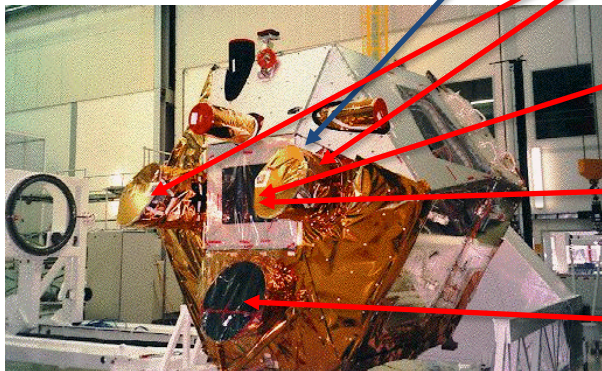
- Na(Tl)/CsI(Na) scintillator crystals

Gamma Ray Burst Monitor (WFC):

- CsI(Na) large-area scintillator crystal

High Pressure Gas Scintillation Proportional Counter (NFI):

- Gas Scintillation Proportional Counter



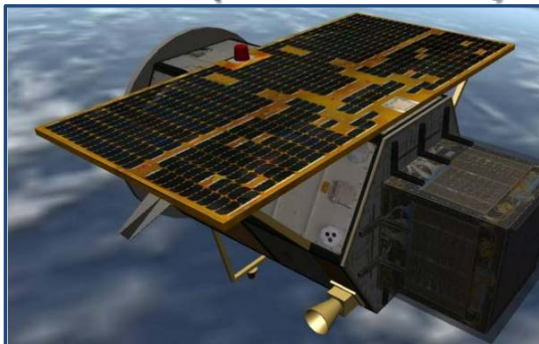
BeppoSAX – «A Breakthrough» in the Universe observation



The BeppoSAX technological breakthrough was the wide spectral coverage (the range of energy levels of the observable emissions), from 0.1 to over 200 KeV. **It was the first mission capable of studying X-ray sources over such a wide energy range, but also to pinpoint the position of the gamma burst in just a few hours.** In this way SAX was able to contribute to the study of a large variety of cosmic phenomena such as compact galactic sources, active galactic nuclei, galaxy clusters, supernovae remnants, normal galaxies, stars, gamma ray bursts.

BeppoSAX – The «heritage»

AGILE (since 2007)



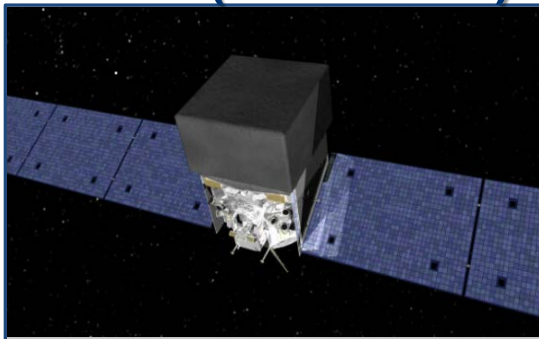
Simultaneous detection of Hard-X and γ rays with excellent resolution and fast data analysis tools (provided by **ASI-SSDC**).

The mission explored our galaxy, acquiring the complete map of the sky observed in gamma radiation and revealing various galactic sources subject to very rapid changes (fast X-ray emission) from many neutron stars and black holes (**Bruno Rossi Prize in 2012**)



Source: <https://www.asi.it/esplorazione/alte-energie/agile/>

FERMI (since 2008)

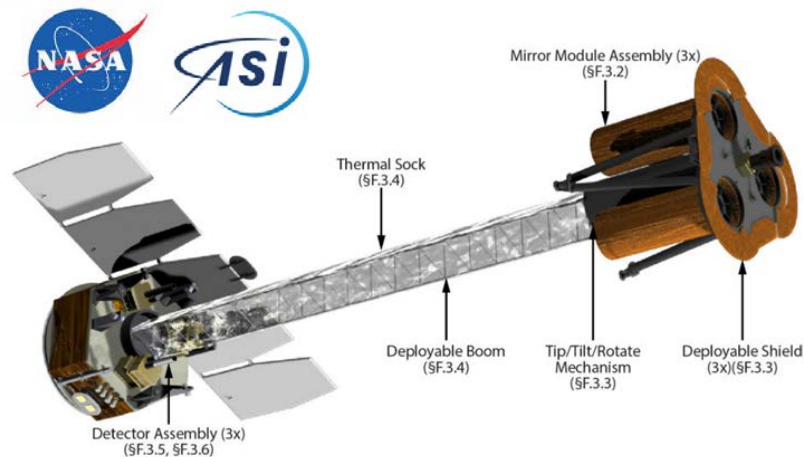


Understanding of particle acceleration mechanism in Active galactic nucleus, Pulsars and Supernovae, sky mapping in gamma radiation component...The important Italian contribution, managed by ASI, is related to the realization of the LAT tracker (INFN), the data analysis (INAF and INFN) and the storage - distribution of mission data (**ASI-SSDC**) (**4 Bruno Rossi Prizes**).



Source: <https://www.asi.it/esplorazione/alte-energie/fermi/>

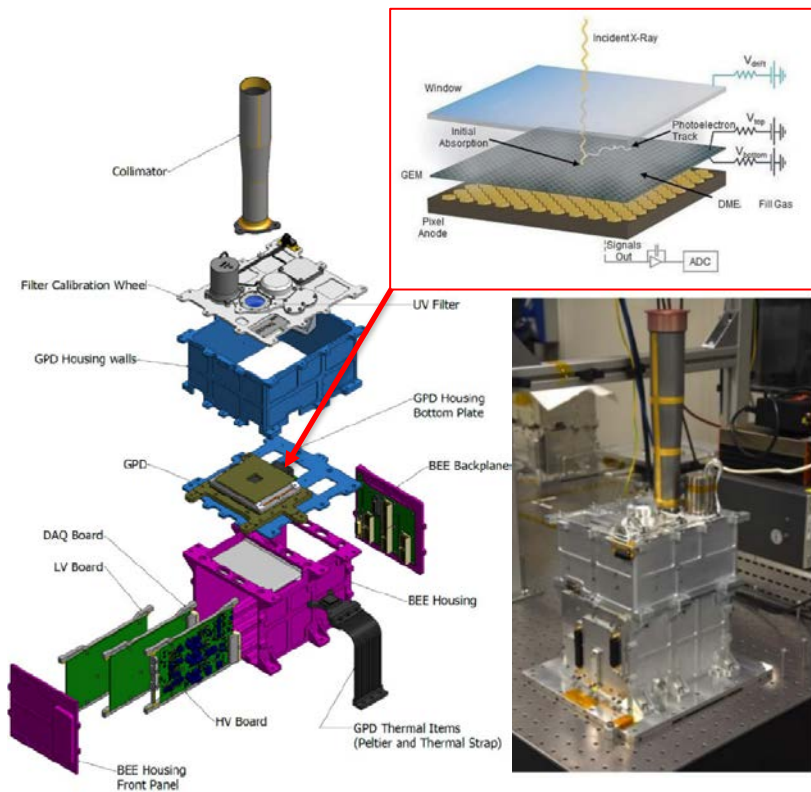
IXPE – Imaging X-ray Polarimetry Explorer



IXPE observatory, a **joint NASA/ASI mission** launched in December 2021, for the first time will carry out polarization measurements from celestial sources that emit X-rays.

Italy provided the strategic instrumentation for carrying out the mission, consisting of three X polarization detectors (Detector Units - DUs), a unit for service functions to the three detectors (Detectors Service Unit - DSU); the support to the operational phase of the mission; the analysis of scientific data; the operations from the Malindi Base of ASI.

IXPE – Imaging X-ray Polarimetry Explorer



3 Detector Units (DUs) (Italian contribution including the Detector Service Unit) at the focus of 3 Mirror Module Assemblies (MMAs) (by USA)

GPD developed by INFN-INAF – Range 2-8 keV

- Δ Energy: 100 eV @ 5.9 keV - energy resolved polarimetry in few bins;
- Δ Space: 90 μm @ 5.9 keV - l.t. optics blurring
- Δ Time: few μs – phase resolved polarimetry (pulsars)
- Modulation Factor agreement with scientific requirements
- Flat response to unpolarized radiation

IXPE – Imaging X-ray Polarimetry Explorer



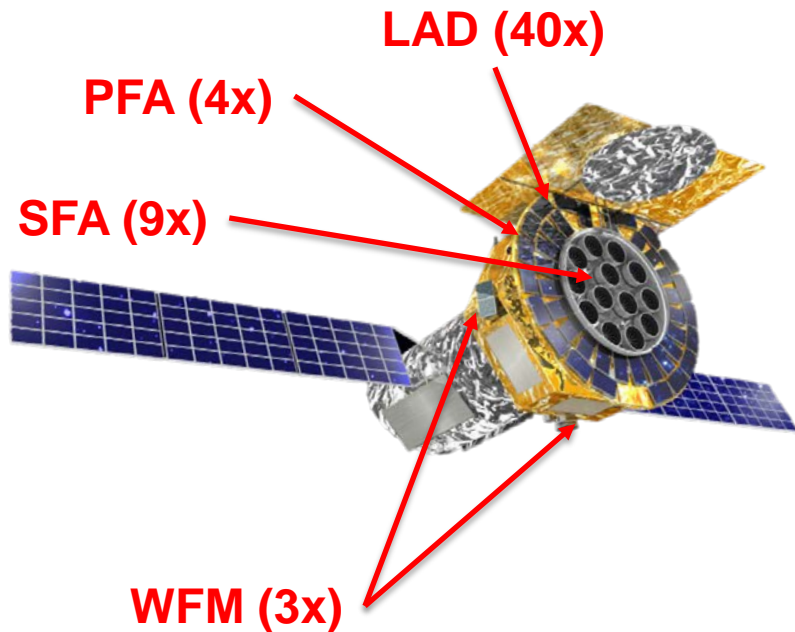
Credits: NASA/CXC/SAO/IXPE

Source: <https://www.asi.it/2022/02/arrivata-la-prima-spettacolare-immagine-dal-telescopio-spaziale-ixpe-della-nasa/>

Outcomes in the first 18 months of IXPE mission:

- Determination of X-ray pulsar geometry (*Nature Astronomy*), October 2022.
- X-Ray Polarization Detection of Cassiopeia A with IXPE (*The Astrophysical Journal*), October 2022.
- Polarized blazar X-rays imply particle acceleration in shocks (*Nature*), November 2022.
- Polarized x-rays from a magnetar (*Science*), November 2022.
- ...

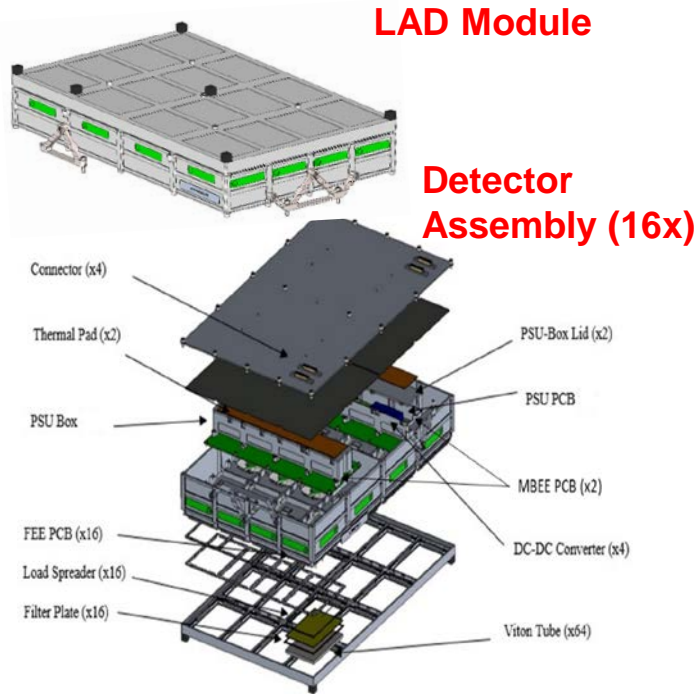
eXTP – Enhanced X-ray Timing and Polarimetry



Flagship mission of the Chinese Academy of Sciences, with a major contribution by a European Consortium, led by Italy. Current launch date is 2029. **Italy expertise and knowhow relates to all 4 instruments of the eXTP scientific payload:**

- Large Area Detector (LAD): PI-ship, large-area SDD detectors, AIVT, calibrations, design of optical filters
- Wide Field Monitor (WFM): large-area SDD detectors (24 units), AIT of Detector Assembly, calibrations
- Polarimetry Focusing Array (PFA): GPD ASIC and design heritage, optics design
- Spectroscopy Focusing Array (SFA): optics design

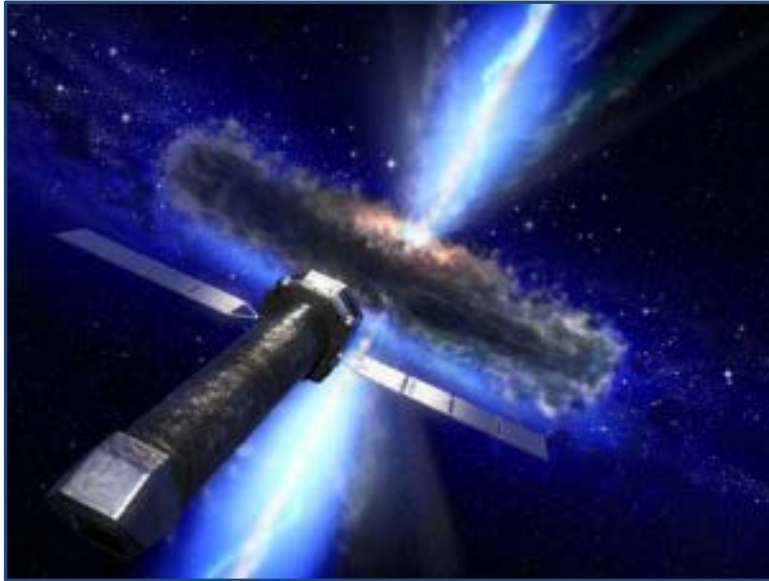
eXTP – Enhanced X-ray Timing and Polarimetry



- **LAD**: 450 μm thick, 76-cm² active area monolithic, 224-anodes, 970 μm pitch
- **WFM**: 450 μm thick, 45-cm² active area monolithic, 384-anodes, 167 μm pitch
- **PFA**: development of a New faster ASIC (XPOL-III) for GPD (single flight deliverable for the mission)

The Large Area Detector is composed of 40 identical Modules, each one containing 16 detector-collimator pairs. **The LAD will expose for the first time ever 3m² effective area** with 250 eV energy resolution and 10 μs time resolution.

ATHENA – Advanced Telescope for High Energy Astrophysics



Source: <https://www.asi.it/esplorazione/alte-energie/athena/>

<https://www.cosmos.esa.int/web/athena>

<https://www.the-athena-x-ray-observatory.eu/en>

<http://x-ifu.irap.omp.eu/>

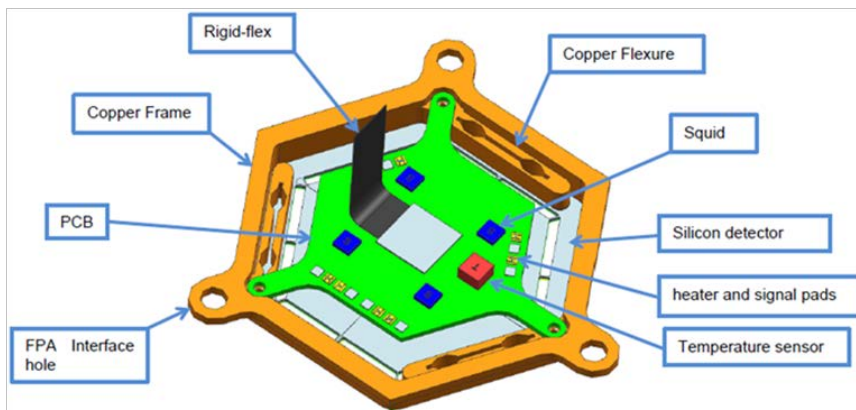
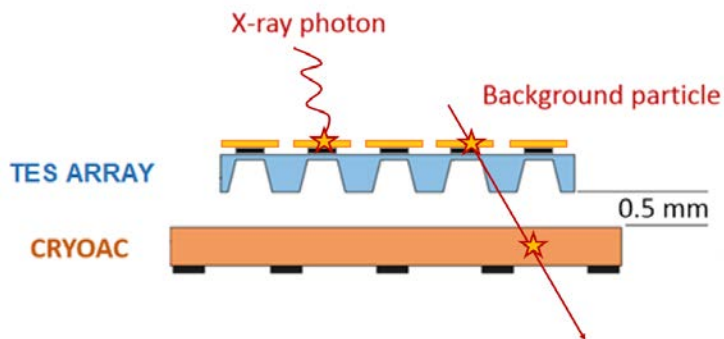
ATHENA is currently an ESA Large X-ray observatory to be launched on the 2nd half of 2030s, operating in conjunction with other large observatories across the electromagnetic spectrum available in the 2030s and in multi-messenger synergies with facilities like (ex. LIGO A+, Advanced Virgo+, LISA). It will house two complementary instruments:

WFI: ~ 170eV@7keV (**good**) and a 40'x40' FoV (**wide**).

X-IFU: ~ 3eV@7keV (**excellent**) and 4' FoV (**narrow**)

Italian participation: INAF, Univ. & INFN Genova, Univ. Pa, Univ. Rm2, Rm3, CNR/IFN Roma

ATHENA – Advanced Telescope for High Energy Astrophysics



Cryogenic AntiCoincidence is a Transition Edge Sensor (50 mK) designed to reduce the flux of primary (and secondary...) particles that deposit energy within the scientific bandwidth of the main detector.

The main detector, is unable to distinguish among scientific photons and particles, hence the necessity of the CryoAC placed at < 1 mm distance from the main detector

The X-IFU design concept is the present main activity in reformulation phase

Special Thanks To the Contributors



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Thanks for your attention

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