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ASI programs in astronomy, astrophysics and fundamental physics

Elisabetta Cavazzuti
Agenzia Spaziale Italiana, Via del Politecnico snc, 00133 Roma

Abstract

ASI funds and leads scientific space-based projects in several science topics, among which astronomy, astrophysics and fundamental physics. Here I will review the main on-going programs and the near-future projects.

1 Introduction

Italian Space Agency funds and leads scientific space programs, since Phase 0/A studies, i.e. from paperwork only, to final delivery of the payloads and disposal of the mission (when is led by ASI). The department appointed to lead the astrophysics, cosmology and solar exploration programs is named Exploration and Observation of the Universe (hereafter EOS). Synergic with EOS is the Space Science Data Center (http://www.ssdc.asi.it/, hereafter SSDC, former ASDC). Data from all scientific missions funded by ASI end up being archived

at and distributed by the SSDC. Recently it has been created a so-called Research group, which is also (but not only) synergic with EOS and SSDC. ASI is part of the European Space Agency and cooperates as well in bilateral or multilateral programs with other space agencies (NASA, JAXA, Roscosmos, CNSA etc). Finally ASI owns and leads an equatorial ground base in Malindi (Kenya), involved in many space programs. Currently it is supporting among other programs AGILE, Swift and NuSTAR and it is foreseen to be involved in many future EOS missions. Last but not least, synergic with the EOS group is the italian scientific community (INAF, INFN, CNR, Universities, etc).

All these entities work together to define the road maps for the space-based scientific missions and experiments.

2 ASI science programs

EOS department involves programs from different scientific areas: cosmology, IR, optical and UV astronomy, high energy astrophysics, cosmic rays experiments, fundamental physics, solar system exploration and exoplanets. In this proceeding all but solar system and exoplanets programs will be considered.

Currently operating scientific missions supported by ASI are Newton-XMM (ESA), INTEGRAL (ESA), Swift (NASA), AGILE (ASI), Fermi (NASA), AMS-02 (DoE), NuSTAR (NASA), GAIA (ESA) and CALET (JAXA). For these missions, ASI funds the scientific teams in charge of on-orbit support and data analysis.

2.1 Programs in the development phase

The near future missions already approved to be launched and in the development phase are:

LARES–2 (ASI) – An experiment approved and led by ASI and planned for a launch in 2019. The main objectives of the LARES–2 experiment are gravitational and fundamental physics, including accurate measurements of General Relativity, in particular a test of frame-dragging aimed at achieving an accuracy of a few parts in a thousand, i.e., aimed at improving by about an order of magnitude the present state-of-the-art and forthcoming tests of this general relativistic phenomenon. LARES–2 will also achieve determinations in space geodesy (Ciufolini et al (2017) **?)**).

EUCLID (ESA) – Euclid is an ESA Medium Class mission in the Cosmic Visions program (see https://www.euclid-ec.org/ for details) foreseen to be launched in 2021. Euclid is primarily a cosmology and fundamental physics mission. Its main scientific objective is to understand the source of the accelerating expansion of the Universe and discover its very nature that physicists refer to as dark energy. Euclid will then address to the following questions: is dark energy merely a cosmological constant, as first discussed by Einstein, or is it a new kind of field that evolves dynamically with the expansion of the universe? Alternatively, is dark energy instead a manifestation of a breakdown of General Relativity and deviations from the law of gravity? What are the nature and properties of dark matter? What are the initial conditions which seed the formation of cosmic structure? What will be the future of the Universe over the next ten billion years?

Contribution from Italy are: for NISP infrared instrument, the Detector Processing Unit (DPU) / Detector Control Unit (DCU) with on-board data processing software, the high-level software for instrument control, the Grism Wheel Assembly (GWA) Unit and the EEWS of warm electronics and instrument; for the VIS visible instrument, the Command and Data Processing Unit (CDPU) and related on-board software. Also within the consortium, Italy is responsible for the Euclid Consortium Science Ground Segment (EC-SGS) of the mission, which will receive and analyze the data produced on board. Italian scientists also hold key roles in several Science Working Groups (SWG) of the consortium and in the various mission and consortium boards.

IXPE (NASA) – The Imaging X-ray Polarimetry Explorer (IXPE) is a NASA mission to which Italy contributes with the whole focal plane providing X-ray polarimeters (see http://ixpe.msfc.nasa.gov for details). Its launch is foreseen on April 2021. IXPE exploits the polarization state of light from astrophysical sources to provide insight into our understanding of X-ray production in objects such as neutron stars and pulsar wind nebulae, as well as stellar and supermassive black holes. Technical and science objectives include: improving polarization sensitivity by two orders of magnitude over the X-ray polarimeter aboard the Orbiting Solar Observatory OSO-8, providing simultaneous spectral, spatial, and temporal measurements, determining the geometry and the emission mechanism of Active Galactic Nuclei and microquasars, finding the magnetic field configuration in magnetars and determining the magnitude of

the field, finding the mechanism for X ray production in pulsars (both isolated and accreting) and the geometry, determining how particles are accelerated in Pulsar Wind Nebulae.

Italy holds the Co-PIship of the mission and contributes with the whole focal plane, i.e. 3 detector Units and the Detector Service Unit, along with the related software. Italy contributes also to the Ground Segment with the development of part of the instrument software and the involvement of the SSDC as possible mirror archive.

H.E.R.M.E.S. (ASI) – High Energy Rapid Modular Ensemble of Satellites (H.E.R.M.E.S.) is a swarm of LEO nanosatellites equipped with keV-Mev scintillators, with sub μs time resolution. It is a fully italian project led by University of Cagliari (see http://hermes.dsf.unica.it/). The aim is Fast and precise measure of the position of bright, transient HE events & fine temporal structure [GRBs, GW events, FRB HE counterparts, magnetar fares].

Characteristics of the project are: scintillator Crystals: CsI (classic) or LaBr3 or CeBr3 (rise-decay: 0.5 - 20 ns); Photo-detector: Silicon Photo Multiplier (SiPM) or Silicon Drift Detector (SDD); Effective area: 10 $\times$ 10 cm; Energy band: 3 keV - 50 MeV; Energy resolution: 15% at 30 keV; Temporal resolution: $\leq$ 10 nanoseconds

Athena (ESA) – Advanced Telescope for High-ENergy Astrophysics – will be an X-ray telescope designed to address the Cosmic Vision science theme 'The Hot and Energetic Universe'. The theme poses two key astrophysical questions: how does ordinary matter assemble into the large-scale structures we see today? and how do black holes grow and shape the Universe?

To address the first question, it will be necessary to map hot gas structures in the Universe – specifically the gas in clusters and groups of galaxies, and the intergalactic medium – determine their physical properties and track their evolution through cosmic time.

To answer the second question, supermassive black holes (SMBH) must be revealed, even in obscured environments, out into the early Universe, and both the inflows and outflows of matter and energy as the black holes grow must be understood.

Because most of the baryonic component of the Universe is locked up in hot gas at temperatures of millions of degrees, and because of the extreme ener-

getics of the processes close to the event horizon of black holes, understanding the Hot and Energetic Universe requires space-based observations in the X-ray portion of the electromagnetic spectrum.

By combining a large X-ray telescope with state-of-the-art scientific instruments, Athena will be able to make an important contribution to answering these questions.

Contribution from Italy: XIFU CoPI-ship; contribution to XIFU with anticoncidence TES microcalorimeter & background, Instrument Control Unit, Filters, Science Innovation Center; contribution to WFI: contribution synergical with XIFU. The italian team is also involved in the ESA Study Team and co-chairs 9 of the Mission & Science Worging Groups.

Lisa (ESA) – The Laser Interferometer Space Antenna (LISA) will be the first space-based gravitational wave observatory. Selected to be ESA's third large-class mission, with a launch in 2034, it will address the science theme of the Gravitational Universe. LISA will consist of three spacecraft separated by 2.5 million km in a triangular formation, following Earth in its orbit around the Sun.

The contribution from Italy will be the Gravitational Reference Sensor (GRS) on board LISA PF which needs to be optimized for LISA.

LSPE (ASI) – The LSPE is a project aimed at measuring the polarization of the Cosmic Microwave Background (CMB) at large angular scales, and in particular to constrain the curl component of CMB polarization (B-modes) produced by tensor perturbations generated during cosmic inflation, in the very early universe. A second target is to produce wide maps of foreground polarization generated in our Galaxy by synchrotron emission and interstellar dust emission. These will be important to map Galactic magnetic fields and to study the properties of ionized gas and of diffuse interstellar dust in our Galaxy. The mission is optimized for large angular scales, with coarse angular resolution (around 1.5 degrees FWHM), and wide sky coverage (25% of the sky). The project is splitted in two experiments: STRIP (STRatospheric Italian Polarimeter, Bersanelli et al.(2012) **?**) – an array of coherent polarimeters using cryogenic HEMT amplifiers – will survey the sky at 43 and 90 GHz. SWIPE (Short Wavelength Instrument for the Polarization Explorer, de Bernardis et al.(2012) **?**) – an array of bolometric polarimeters, using large

throughput multi-mode bolometers and rotating Half Wave Plates (HWP) – will survey the same sky region in three bands at 95, 145 and 245 GHz. The wide frequency coverage will allow optimal control of the polarized foregrounds, with comparable angular resolution at all frequencies. SWIPE will be put on a stratospheric balloon and will fly in a circumpolar long duration mission during the polar night. Using the Earth as a giant solar shield, the instrument will spin in azimuth, observing a large fraction of the northern sky. The payload will host two instruments. STRIP will be ground based and synergic with SWIPE observations.

2.2 Programs in Phase A with pending approval

There are projects still in the approval phase for which ASI funds the study activity and these are:

eXTP (CNSA, CAS) – The enhanced X-ray Timing and Polarimetry mission (eXTP) (Zhang et al.(2016) **?**)) is a Chinese-led science mission designed to study the state of matter under extreme conditions of density, gravity and magnetism. Primary goals are the determination of the equation of state of matter at supra-nuclear density, the measurement of QED effects in highly magnetized star, and the study of accretion in the strong-field regime of gravity. Primary targets include isolated and binary neutron stars, strong magnetic field systems like magnetars, and stellar-mass and supermassive black holes.

The mission carries a unique and unprecedented suite of state-of-the-art scientific instruments enabling for the first time ever the simultaneous spectral-timing-polarimetry studies of cosmic sources in the energy range from 0.5-30 keV (and beyond). Key elements of the payload are: the Spectroscopic Focusing Array (SFA); the Large Area Detector (LAD); the Polarimetry Focusing Array (PFA); the Wide Field Monitor (WFM).

The eXTP international consortium includes major institutions of the Chinese Academy of Sciences and Universities in China, as well as major institutions in several European countries and other International partners. Two of the four instruments will be under responsibility of China and two under responsibility of Europe.

The perspective Italian contributions to the eXTP mission include: Coordination of the European Consortium; Contribution to the science case and

mission definition; PI-ship of the LAD instrument; Large-area Silicon Drift Detectors for the LAD; AIVT of the LAD 1; Physical calibrations of the LAD; Large-area Silicon Drift Detectors for the WFM; Front-End Electronics board and AIV for the WFM; Physical calibrations of the WFM Detection Plane (i.e., at the detectors level); SFA and PFA optical design; PFA GPD and Back-End Electronics; Malindi ground station; Support to scientific software and archive.

THESEUS (ESA) – is a mission concept proposed in response to the ESA call for medium-size mission (M5) within the Cosmic Vision Programme and selected by ESA on 2018 May 7 to enter an assessment phase study (see https://www.isdc.unige.ch/theseus/ for details). The mission is designed to vastly increase the discovery space of the high energy transient phenomena over the entirety of cosmic history. Its primary scientific goals will address the Early Universe ESA Cosmic Vision themes "How did the Universe originate and what is made of?" (4.1, 4.2 and 4.3) and will also impact on "The gravitational wave Universe" (3.2) and "The hot and energetic Universe" themes. This is achieved via a unique payload providing an unprecedented combination of: 1) wide and deep sky monitoring in a broad energy band (0.3keV – 20 MeV); 2) focusing capabilities in the soft X-ray band providing large grasp and high angular resolution; and 3) on board near-IR capabilities for immediate transient identification and redshift determination.

Italy has the PI-ship (Lorenzo Amati, University of Ferrara) and would provide the X-Gamma rays Imaging Spectrometer (XGIS): 3 coded-mask X-gamma ray cameras using bars of Silicon diodes coupled with CsI crystal scintillators observing in 2 keV – 10 MeV band, a FOV of $\sim$2 sr, overlapping the SXI, with $\sim$ 5' source location accuracy.

LiteBird (JAXA) – is a satellite led by JAXA (see http://litebird.jp/eng/ and http://www.litebird-europe.eu/ for details) that will search for primordial gravitational waves emitted during the cosmic inflation era (around $10^{-}38$ sec after the beginning of the Universe). Its goal is to test representative inflationary models (single–field slow-role models with large field variation) by performing an all-sky CMB polarization survey.

Primordial gravitational waves are expected to be imprinted in the CMB polarization map as special patterns, called the "B-mode". If we succeed to detect them, it will provide entirely new and profound knowledge on how our

Universe began.

From the viewpoint of high-energy physics or elementary particle physics, the observation of the CMB B-mode is very important because it will allow us to search for physics in ultra high-energy scales, which are not accessible with man-made accelerators. Measurements of CMB polarization will open a new era of testing theoretical predictions of quantum gravity, including those by the superstring theory.

LiteBIRD was recently nominated one of the 7 large-scale projects in the MEXT 2017 roadmap. Support from NASA has funded detector and cryogenic readout system development in the USA for Phase A, and is now supporting risk-mitigation R&D.

With the LiteBIRD baseline design still under discussion, Europe has an opportunity to provide significant impact on the final payload by delivering the High-Frequency Telescope (HFT) unit.

2.3 R&D and Data Analysis activities

ASI is funding also two main stream activities on cosmology and high energy astrophysics. Under these activities, research and development are funded. ASI issues calls for R&D relying on international peer reviews to select submitted proposals, and participates to MIUR calls (Progetti Premiali) . Thanks to past R&D calls the polarimeter has been funded leading to the selection of IXPE mission by NASA. This indicates, if still necessary to be understood, that R&D is mandatory for healthy scientific communities.

In the last call the following projects have been funded:

- 3D-CZT Module (3DCaTM) for spectroscopic imaging, timing and polarimetry in hard X-/soft γ rays satellite mission (E. Caroli, INAF)
- FluChe - Fluorescence and Cherenkov light detection with SiPM for space applications (O. Catalano, INAF)
- Increase of the Technological Readiness Level for the realization of hard X-/soft Gamma-ray Laue optics (E. Virgili, Uni Ferrara)
- STAR-X: the next generation of X-ray imaging surveys (R. Gilli, INAF)
- POX (Pangu [sub-GeV γ ray telescope] Optimization and eXperimental verification) (D. D?Urso, Uni Sassari)

Data analysis as well is funded for both on orbit missions with ASI contribution and proposals approved by Time Allocation Committees of other missions (Chandra, HST etc). In the last call 20 proposals for 18-month long projects have been funded.

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References

1. I. Ciufolini *et al*, A new laser-ranged satellite for General Relativity and space geodesy: I. An introduction to the LARES2 space experiment, The European Physical Journal Plus, 2017, doi = 10.1140/epjp/i2017-11635-1.
2. Bersanelli, M., Mennella, A., Morgante, G., et al. 2012, SPIE, 8446, 84467C
3. de Bernardis, P., Aiola, S., Amico, G., et al. 2012, SPIE, 8452, 84523F
4. Zhang, S. N., Feroci, M., Santangelo, A., et al. 2016, SPIE, 9905, 99051Q