RADIO ASTRONOMY IN MEXICO: AN HISTORICAL PERSPECTIVE

Citation for the original published paper (version of record):
González-López lira, R., Rodriguez, L., Dzib, S. et al (2025). RADIO ASTRONOMY IN MEXICO: AN HISTORICAL PERSPECTIVE. Journal of Astronomical History and Heritage, 28(4): 943-993. http://dx.doi.org/10.3724/SP.J.1440-2807.2026.01.07

Journal of Astronomical History and Heritage, 29(1), 109–124 (2026).

THE DEVELOPMENT OF EXPERIMENTAL X-RAY AND GAMMA-RAY ASTRONOMY IN ITALY USING STRATOSPHERIC BALLOONS

Enrico Costa
IAPS, INAF, Roma, Italy.
E-mail: enrico.costa@inaf.it

Filippo Frontera
Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, Ferrara, Italy.
E-mail: frontera@fe.infn.it

Enrico Massaro (*)
IAPS, INAF, Roma, Italy, and formerly Sapienza Università di Roma, Roma, Italy.
E-mail: enrifv.massaro@gmail.com

and

Bruno Sacco*
(retired) IFC, INAF, Palermo, Italy.
E-mail: bsacco47@gmail.com
*Author for correspondence.

Abstract: In 1975 activity started to launch stratospheric balloons for scientific research from a base at Milo, near Trapani, in West Sicily. The first three flights were across the Atlantic Ocean and reached the United States, but this program was stopped by the USA Administration. The base at Milo was than devoted to flights across the Western Mediterranean Sea that terminated in Spain. This was a very interesting prospect for the Italian teams researching high-energy astrophysics to design and carry out new experiments for hard X-ray and gamma-ray observations. The Milo base was active up to 2003, and was officially closed in 2012.

Here we report the main facts leading up to the establishment of this base, and we summarize the main high-energy astrophysics experiments launched by balloons in those years, and their heritage. This activity was fundamental for the growth of this research community, which later designed and built the first—and very successful—Italian X-ray satellite, BeppoSAX.

Keywords: history and philosophy of astronomy; Italy; Milo; X-ray astronomy; gamma-ray astronomy; stratospheric balloons.

1 INTRODUCTION

The development of experimental High Energy Astrophysics in Italy after 1960 was mainly due to scientists from the community of Elementary Particle Physics interested in cosmic ray research. Indeed, in the traditional astronomical institutions their main activity was based on optical observations obtained with astronomical observatories, while in the universities astronomy courses were generally hosted by mathematical departments.

In 1959 Edoardo Amaldi (1908–1989) proposed to Pierre Auger (1899–1993), who accepted, the coordination of European space research. They prepared a document titled *Space Research in Europe* that was distributed and shared by several influential European physicists. In 1962, the bases for two European organizations were established: ELDO (European Launcher Development Organization) and ESRO (European Space Research Organization). Their goal was to establish a European Space Science Community. Later, in May 1975, these organizations were amalgamated when the European Space Agency (ESA) was founded.

In line with scientific policy at a European level, important decisions were taken at an Italian level. Thus, the National Research Council (Consiglio Nazionale delle Ricerche, or CNR) established the Comitato Ricerche Spaziali (Space Research Committee, CRS), with nine distinguished members, including Edoardo Amaldi and Luigi Broglio (1911–2001), both from the University of Rome, Guglielmo Righini (1908–1978) from the University of Florence, Giampietro Puppi (1917–2006) from the University of Bologna, with the later addition of Giuseppe Occhialini (1907–1993) from the University of Milan. Other leading personalities were Livio Gratton (1910–1991), the first Professor of Astrophysics at the University of Roma (now La Sapienza), and Professor Marcello Ceccarelli (1927–1984) from Bologna Uni-

versity who pioneered radio astronomy in Italy. It is important to mention the fundamental role played by Bruno Rossi (1905–1993), a pioneer of cosmic-ray research in Italy and later a Professor at MIT, who hosted or sent to other institutions many young Italian scientists, thereby involving them in the development of some of the most relevant experimental projects.

Bologna was the first group to begin activity in space research in Italy when Puppi proposed that Domenico Brini (1923–2008) establish and lead in the Physics Institute of Bologna University a space research laboratory named Bologna Ricerche Spaziali (Bologna Space Researches, or BORISPA). This included physicists and technicians from the University and from CNR, and research began in 1961 when a

Figure 1: Livio Scarsi in around 1970 (courtesy: IAPS-INAF).

balloon experiment with a small Geiger-Muller (GM) counter of 6 cm^2 was launched from Medicina, a small town near Bologna, to study intensity changes of the cosmic radiation with altitude. Technological flights also were launched to test an electronic chain for processing and digitizing analogic signals, a PCM (Pulse Code Modulation) telemetry and an AM (Amplitude Modulation) transmitter at 108 MHz. After the discovery of Sco X-1, the first cosmic X-ray source (Giacconi et al., 1962), BORISPA moved to hard X-ray astronomy at energies of >20 keV because soft X-ray astronomy was too expensive as it required rockets or satellites.

In 1963, CNR established the Italian Group of Cosmic Physics (Gruppo Italiano di Fisica Cosmica, GIFCO), with the goal of promoting Italian Cosmic Physics, which initially included four local sections. One was in Milan, directed by Giuseppe Occhialini; one in Turin, directed by Carlo Castagnoli (1924–2004); one in Bologna, directed by Domenico Brini; and the fourtl one in Roma, directed by Guido Pizzella (1933–2024). All were set up to investigate space plasmas and intensity variations of cosmic rays. There also was an independent program started under the supervision of Livio Gratton to develop X-ray experiments launched above the atmosphere on board rockets.

The BORISPA group developed Italy's first hard X-ray directional telescope, which consisted of a NaI(Tl) scintillator with a cross section of 5 cm^2 and a thickness of 0.5 inches providing a passband of 20–200 keV. A lead shield and collimator limited the field of view (FOV) to 0.5 str. To decrease the detector background, it had an anticoincidence plastic shield viewed from the same photomultiplier coupled to the scintillator. This was the first application of the so called *phoswich* configuration, a contraction from 'phosphorous sandwich' that was introduced by Wilkinson (1952). This telescope went on several successful balloon flights, devoted to the discovery of hard X-ray sources. Launches were at first performed from Bologna Airport, and later from Aire sur l'Adour in France, with useful observing time on each flight usually restricted to no more than three hours. Hard X-ray signals from the Cyg X-2 and Ser X-1 sources were recorded (Brini et al. 1965; 1967).

Starting from these 'seeds' (see Setti 2005 and Frontera 2020 for a personal introductory history), in the following decades High Energy Astrophysics in Italy underwent a great development either with experimental projects, culminating in the satellite BeppoSAX for broad band X-ray astronomy, or with theoretical research. In particular, in the two decades 1970–1990, several experiments on board stratospheric balloons were successfully carried out, and some of them were launched from the Milo base, near the town of Trapani in Sicily.

In this paper we describe some of these experiments and their principal scientific outcomes. For a complete worldwide review on satellite and balloon experiments for hard X-ray and soft gamma-ray experiments see Cavallari and Frontera (2017).

2 LIVIO SCARSI IN PALERMO AND THE FIRST BALLOON-BASED RESEARCH FROM SICILY

Livio Scarsi (1927–2006) (Figure 1) arrived at the Institute of Physics at the University of Palermo by the end of 1967 as a Full Professor of

Fisica Superiore. Over the next few months he was able to attract a group of young students interested in cosmic physics, which was a new research field for the University.

Scarsi was born in a small town in the South Piedmont, and he studied at the University of Genova where he obtained the laurea degree in Physics under the supervision of Giuseppe Occhialini. At the end of the 1950s he moved to MIT where Bruno Rossi asked him to investigate extended atmospheric showers. Together with John Linsley, who remained his friend and continued to collaborate with him in Palermo many years later, they developed the first large (8 km^2) ground detector systems at Volcano Ranch in New Mexico, and in 1961 they observed showers initiated by particles with energies of around 10^{22} eV.

Before and during his first period in Palermo, Scarsi worked on a research project as part of an Italian–French collaboration, started in the early 1960s to study the electronic component of primary cosmic radiation. This research was performed with instruments carried to high altitude by small volume stratospheric balloons that were launched from French bases at Gap and Aire-sur-l'Adour. The typical duration of these flights at a ceiling altitude of between 4 and 6 mbar was no longer than 3 hours. To gain more sensitivity in these measurements, either by a reduction of the local cosmic ray background or increasing the E–W asymmetry for estimating the positron-to-electron ratio of the primary radiation, flights at a higher vertical cut-off magnetic rigidity were useful. After examining the possibility of balloon launches from Algeria, the choice was Sicily, and in particular the military airport of Trapani-Birgi. The cut-off rigidity at Birgi was of 8.3 GV, compared to 5.4 GV of Aire-sur-Adour.

In July 1967 four flights from Birgi were performed with balloons of 50,000 m^3 carrying payloads of 200–300 kg (a spark chamber with photographic equipment) and reaching a ceiling at 3–4 mbar for a total duration of 9.3 hours. The launch team were French CNES people, while the recovery of the payload was made by an Italian Navy ship in a region to the Southwest of Sardinia. The results of this experiment on the electronic component of primary cosmic rays were reported in a paper by Agrinier et al. (1970).

In July 1971 a technical balloon flew for >20 hours carrying a collimated (14° FWHM) boron loaded liquid scintillation detector for low-energy gamma-rays (Dean et al., 1973), while in the following years small balloons were used to investigate the summer stratospheric monsoon. The meteorologist Puglisi, a high officer in the Italian Air Force and a collaborator with Scarsi's group, wrote a detailed report that demonstrated the stability of winds able to transport balloons Westwards to reach Spain and out across the Atlantic Ocean. But Birgi was not ideal as the launching site of this research because it was also a civil airport.

In 1972 the Servizio Attività Spaziali (Space Activity Service, SAS) of the CNR was charged to finding another location. The most suitable site was Milo Airport, which was about 10 km from Trapani, and had been used during World War II (WW2). It was no longer in operation, and its airstrip was bisected by a new highway (see Figure 2). In 1974 the Milo Balloon Base was formally established under the direction of Marco Malavasi, a CNR executive, and soon preparations began for balloon launches the following year.

Figure 2: An aerial view of the Milo base (courtesy: Agenzia Spaziale Italiana).

A summary the balloon flights from Sicily until 1994 was presented by Livio Scarsi (1994) in the opening talk of the workshop held in October 1994 at El Arenosillo (Spain) and his paper was published by INTA (the Instituto Nacional de Técnica Aeroespacial) in a book with a small print run. We will rely on this paper for the information about individual on-balloon experiments, supplemented by our own personal memories of these events.

3 THE BEGINNING OF BALLOON FLIGHTS FROM MILO: THE TRANSATLANTIC CAMPAIGNS

The first activity at the Milo base, from 1975 to 1976, consisted of the launching of three large-volume balloons (600,000 m^3) intended for long-duration flights across the Atlantic Ocean to the United States. All three flights were successful and reached their intended destinations A summary of these flights is given in Table 1.

Table 1: Information about the three Milo transatlantic balloon flights in 1975–1976.

Name	Date	Duration (hr)	Volume (m^3)	Weight (kg)	Experiment
Milo 1	5 August 1975	82	600,000	800	Bristol cosmic ray detector
Milo 2	29 July 1976	75	600,000	800	HXR-76; ITESRE hard X-ray; IROE IR
Milo 3	13 August 1976	107	600,000	1833	

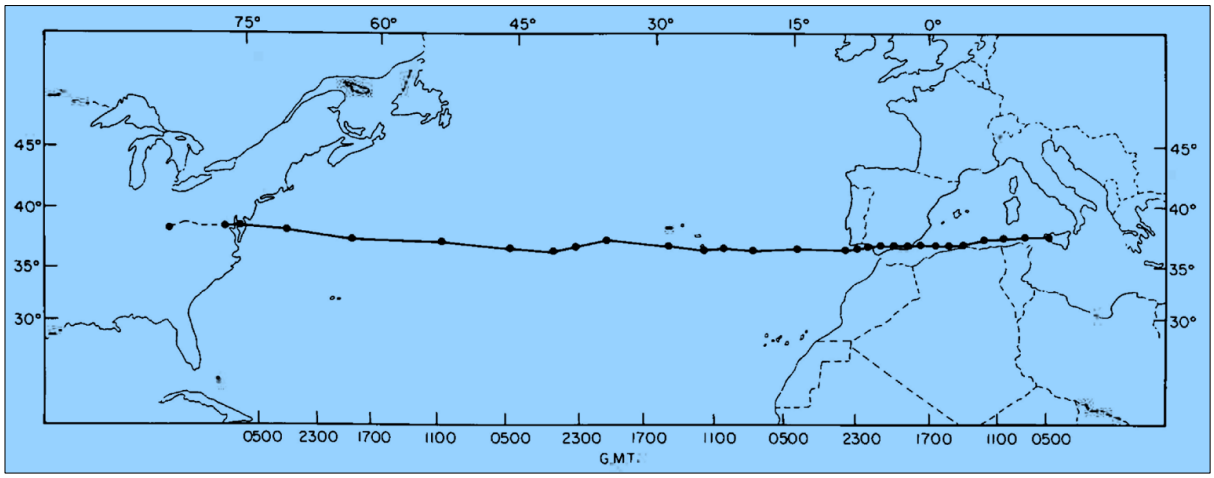


Figure 3: The actual trajectory of the first transatlantic balloon validation flight, Milo 1 (after Delury et al. 1976; courtesy: ESA).

The idea of long-duration balloon flights was early developed by David Ramsden from Southampton University, who helped support the three flights and is acknowledged by Scarsi in his paper. The advantages of long-duration flights, along with descriptions of some of the technical improvements that were required, are given in the papers by Delury et al. (1976) and Ramsden (1979).

During that epoch the Italian Space Agency (Agenzia Spaziale Italiana, or ASI) had yet to be established and the National Space Plan (Piano Spaziale Nazionale, or PSN), operated by CNR, would only start in 1979, so no team with expertise in launching large stratospheric balloons existed in Italy. Therefore, a Memorandum of Understanding was signed among the Nation States that participated of this endeavor, identifying clear responsibilities. In particular, the United States, through the National Science Foundation (NSF), funded the NSBF (National Scientific Balloon Facility) to furnish

1) the balloon,
2) needed helium,
3) launch hardware, and
4) crew.

In addition, the NSF took care of the entire American segment of the mission. The Italians, meanwhile, provided the balloon base facilities and full support to the ground operation crew. An additional important collaboration involved the Italian Air Army (Aeronautica Militare), which offered radar coverage over the initial part of each balloon flight.

3.1 The First Transatlantic Flight: Milo 1

The first transatlantic balloon flight occurred on 5 August 1975 and was considered as a validation test for future projects (Delury et al., 1976). The UK Science Research Council approved the proposal by P.H. Fowler of Bristol University and D. Ramsden of Southampton University, who were in charge of the payload for this flight. This consisted of an experiment with a total collecting area of 8 m^2 from the University of Bristol to investigate the charge spectrum of cosmic rays with atomic numbers $Z > 40$, as well as a small detector provided by Southampton University to study gamma-ray bursts.

A problem that had to be faced was the change in the ceiling altitude from night-time to daytime due to gas heating and expansion of the balloon because of solar irradiance. Because no telecommand was active during the crossing of the ocean, the payload was equipped with ballast that was automatically released at programmed times during the flight.

This validation test was successful and the flight path of Milo 1 is shown in Figure 3. The payload was recovered near the town of Lexington (Kentucky) after about 82 hours of flight, and the latitude excursion of the balloon was constrained within the rather narrow window of from 36°–39° N. The Bristol experiment detected 21 cosmic-ray nuclei with $Z > 65$ (Fowler et al., 1979).

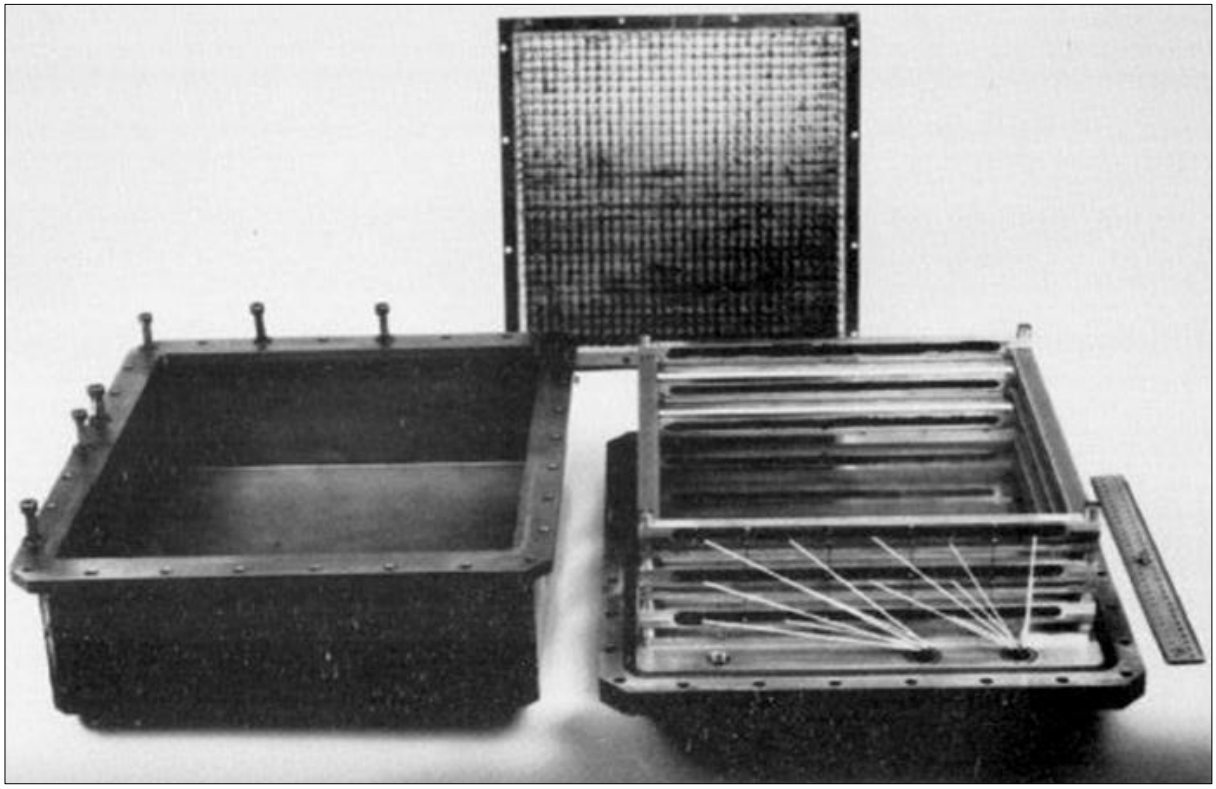


Figure 4: Open view of the high-pressure proportional counter of the HXR-76 experiment showing the inner structure of anodes and ground planes and the collimator. The rule on the right side is 20 cm long (photograph courtesy: Enrico Costa archives).

3.2 Transatlantic Flights in 1976

The transatlantic campaign continued in 1976 with two flights: Milo 2 departed on 29 July and terminated before arriving at the coast of Massachussets with a useful flight duration of about 75 h. Unfortunately, the payload was lost.

Milo 3 started two weeks later on 13 August 13, and after a long flight of about 107 h, the payload was recovered near Gardner in Massachussets.

The Milo 2 payload carried hard X-ray and infrared experiments designed and developed in Italian laboratories. The hard X-ray experiments are described in the following subsections.

3.2.1 The HXR-76 Experiment

This experiment was designed and built at the Laboratorio of Astrofisica Spaziale of CNR in Frascati, near Rome, by a team coordinated by Giulio Auriemma (1943–2018). It consisted of a large-area spectroscopic proportional chamber of 800 cm^2, filled with high pressure xenon (4 atm) and sensitive in the nominal energy range 25–190 keV (Figure 4). The hard X-ray proportional counter is described by Costa et al. (1978). For the transatlantic flight, the photon energy band was divided into 15 channels and a square cells collimator limited the field of view to 14° FWHM. The most important result of the experiment was the observation of the Seyfert 1 galaxy NGC 4151, for which a hard X-ray spectrum was obtained, that was described by a power law with a photon index of −0.9 (Auriemma et al., 1978).

3.3 The Bologna Experiment

A hard X-ray experiment of the Bologna group of the TESRE Laboratory of CNR was also flown on the same transatlantic flight from Milo. This research team already had considerable experience in balloon hard X-ray experiments. The experiment, made up of detectors already flown in other successful balloon flights in 1972 (e.g., Fuligni and Frontera 1973), 1973 (Frontera and Fuligni, 1975) and 1974 (e.g., Fuligni et al. 1976), consisted of two independent collimated hard X-ray telescopes, 4 m apart, both pointing to the zenith. Each detector consisted of a large NaI(Tl) crystal 1.27 cm thick and 20 cm in diameter for a total effective area of 525 cm^2 and the field of view was 14° (FWHM). The nominal energy range was 20 to 300 keV. Due to telemetry limitations, the scientific data transmitted were the counts in 0.83 s in two energy channels (20–150 keV and 150–300 keV) and the 60 channel energy spectra integrated over

106 s. Housekeeping data (temperatures, voltages, etc.) also were transmitted.

This experiment provided several relevant results about local phenomena like the measurement of a geomagnetic latitude effect on the background hard X-ray counts (Frontera et al., 1981a), and the detection of two pseudo gamma-ray bursts of long duration, from about 4 s to about 80 s, due to phosphorescence in the detector produced by high-energy cosmic rays (Frontera et al., 1981b). Astrophysical results were the observation of the Galactic source X Persei (Frontera et al., 1979a); of a couple of extragalactic sources, NGC 4151 and MCG 8-11-11 (Frontera et al., 1979b); plus the detection of a transient event (Fuligni et al., 1979).

In particular, the X-ray binary X Per was observed twice, on 30 and 31 July, when transiting in the field of view of the detectors, and its hard X-ray flux varied by more than a factor of 2. The regions containing the two Seyfert galaxies NGC 4151 and MCG 8-11-11, were also observed two times, while data from the third pointing were not useful for telemetry noise. While the hard X-ray emission of the former galaxy was already known, this emission was detected for the first time from MCG 8-11-11, and this was later confirmed by several subsequent observations (see Grandi et al. 1998 and reference therein).

4 THE ODISSEA CAMPAIGNS

After 1976 no more transatlantic flights were allowed because of security concerns by the USA Administration. Thus, an alternative strategy was implemented: to offer the scientific community flights from Sicily to Spain, that crossed the Western Mediterranean Sea in about 1 day.

A collaboration agreement was established between CONIE (Comisión Nacional de Investigación del Espacio, Spain), CNES (Centre National d'Etudes Spatiales, France) and CNR (Italy) to organize these flights. For their part, the Italians provided access to the Milo base, with the necessary facilities, like the machinery and instrumentation for the integration, launch and tracking during the first part of a flight. Spain offered balloon tracking and telemetry coverage through two stations, one located at an airfield near Palma on Mallorca island and the other at El Arenosillo near Huelva on the Atlantic coast. The team at the latter site also was responsible for deciding when to activate the separation of the balloon and how to manage the recovery of the payload and its parachute. For its part, CNES provided the bulk of the launch staff, directed by M. Armand Soubrier, and most of the onboard instrumentation. A large team lead by CNR-PSN but with a substantial participation by staff from CNR Institutes in Frascati, Palermo and Bologna managed all of the ground facilities and supported the experiment teams with the integration, flight control and data analysis. Italians had an important role at both the launch and the recovery, and formed a large part of the ground assistance team, also at Palma station.

This campaign was named ODISSEA, likely proposed by Soubrier and inspired by the Homeric poem that narrated Ulysses' travels across the Mediterranean Sea. The balloons were launched in the summer season when a regular monsoon took them Westward at a rather constant latitude (of around 38° N).

The first two flights, named TECHNO and PAM, of the ODISSEA campaigns, occurred on 6 and 11 August 1977 with balloons of 330,000 m^3. The former balloon was mainly a technical test and after about 22.5 hours it was recovered near Aracena (see Figure 5), while the PAM flight reached the Cadiz region in about 21 hours (Malavasi et al., 1978). This successful experience continued practically every year for 25 years, up to 2002. It gave the astrophysical research community a very useful opportunity to conduct observations above the atmosphere and to test new instrumentation. A nearly complete listing of these flights can be found in the StratoCat (Stratospheric Ballooning Encyclopedia) at the following website: https://stratocat.com.ar/bases/64e.htm

For High Energy experiments, the transition from the transatlantic to the transmediterranean flights was a significant loss of observing time. However, combined with the availability of reliable and fast telecommand systems, this transition allowed the evolution of observations from those based on meridian transit, that limited the targets to a few sources with declinations of around 38°, to pointed observations. In addition, it allowed for a serious budget of telemetry, that was 96 bps in the 1976 flights, and for a rigorous timing of the events, using an atomic clock.

The use of stratospheric balloons was not limited to the high energy astrophysics community but also involved several other scientific experiments: astrophysicists used infrared and microwave observations to study anisotropies in the cosmic background radiation); atmospheric scientists used balloons to research the physics of the stratosphere; and for others they offered a way of testing new technologies.

The Odissea campaign flights continued for 15 years, including when the PSN-CNR evolv-

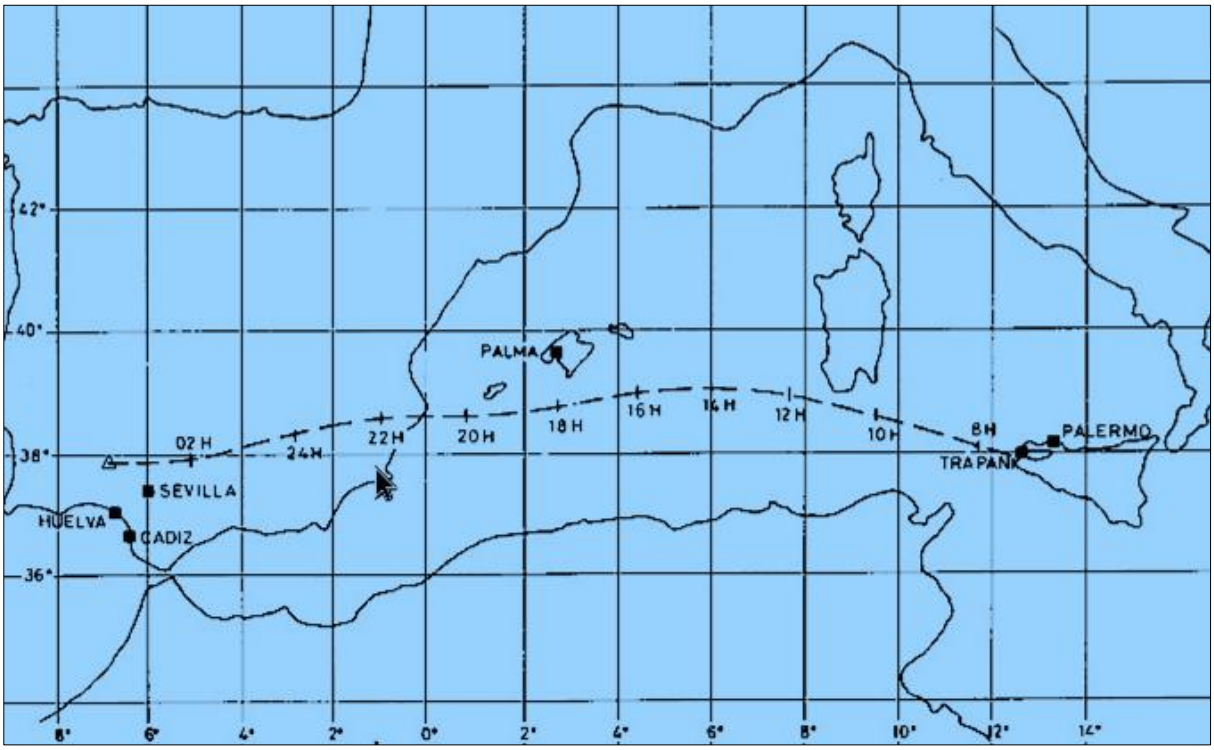


Figure 5: The actual trajectory of the first transmediterranean technical balloon flight (after Malavasi et al.,1976; courtesy: ESA).

ed into ASI and CONIE to INTA, but with substantially the same teams. In 1993 the CNES withdrew from the collaboration. ASI, supported by CNR institutes, thanks to the achieved competence, was able to continue the campaign by substituting in a few months the personnel and the equipment retired from the French partnership. Transmediterranean campaigns were then carried out with the new Italian/Spanish configuration, under the direction of Orazio Cosentino, until 2001.

4.1 Not Only Milo

Apart from Milo other bases were available where scientific balloons were launched, and at some of these the associated services were available on a commercial basis. Many Italian research groups also performed experiments from these other bases.

In some cases this was out of scientific necessity, as with the Cosmic Microwave Background study at Arctic or Antarctic latitudes. A campaign to observe astronomical objects in the Southern Sky with the same experiments usually flown in the Mediterranean area, was organized by the same ASI/CNES/INTA collaboration in Brazil in 1983 and in Australia in 1990. Some experiments involving different collaborative networks or because of the preference of members of a research team, were based at other balloon-launching bases by commercial or scientific agreement.

5 X-RAY AND GAMMA-RAY EXPERIMENTS

5.1 The Bologna XG Experiment

In 1982 the X-ray group of the ITESRE Institute in Bologna launched from Milo a hard X-ray experiment named X Grande (XG, Large X) which had the largest area among the already flown Bologna experiments. This experiment had been already successfully flown twice, in 1980 and in 1981, from Palestine (Texas), with significant results in 1980 on the X-ray pulsar A0535+26 in outburst (Frontera et al., 1985a; Dal Fiume et al., 1988) and in 1981 on other Galactic (Crab Nebula, Cyg X-1, Cyg X-2, Her X-1) and extragalactic X-ray sources (NGC 5548, MKN 464, Perseus Cluster, Matt et al., 1990; Piro et al., 1991).

The first version of the XG experiment employed for the 1980 and 1981 launches had a detection system based on an array of 4 × 4 independent NaI(Tl) scintillators, two of which with a thickness of 12.7 mm and the other two of 3 mm, and total surface area of 1455 cm^2. The energy band was 20–200 keV, and the FOV was 9° (FWHM). The experiment included in-flight calibration, a high time resolution (1 ms) transmission of the count data in three energy channels and the transmission of count spectra in 64 channels integrated over 2 s. The gondola was azimuth stabilized within 20 arcmin, and sources could be tracked in both azimuth and elevation.

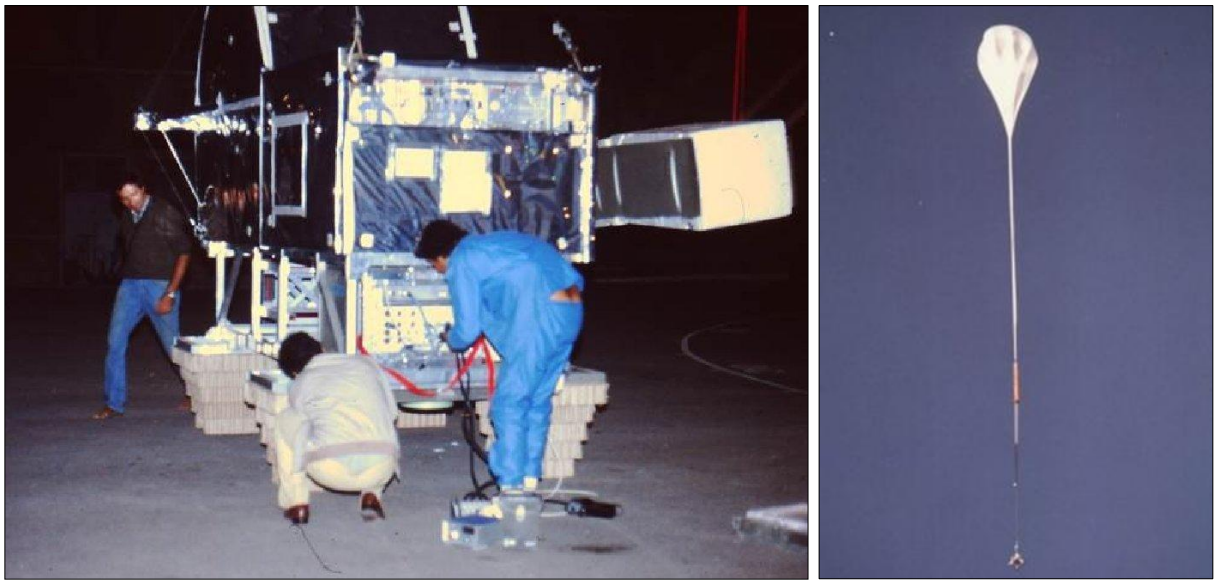


Figure 6 (Left): Preparation of the gondola with the XG Bologna experiment at the Milo base. Right: the balloon with the experiment soon after the launch (photographs: F. Frontera).

The 1982 experiment, with participation of the X-ray group at the CNR-IAS Institute in Rome, was also motivated by the goal of establishing the best configuration for the Phoswich Detector System (PDS), a hard X-ray experiment (15–300 keV) proposed for the future SAX mission, which had just been approved by the National Space Plan. To achieve this goal, 4 standard detection units of the XG experiment were replaced by 4 NaI(Tl)/CsI(Na) phoswich units, with two different thicknesses (3 and 10 mm) of the NaI(Tl) scintillator that had the role of main detector, and three different thicknesses (30, 40, 50 mm) of the CsI(Na) that had the role of active bottom shield. For these units, special electronics with a shape analyzer of the signals, was developed. The launch was performed on 10 August 1982, with a nominal functioning of the experiment. The test results of these phoswich units (Frontera et al., 1985b) were crucial for establishing the best configuration of the PDS telescope for SAX (Frontera et al., 1997). Two pictures of the 1982 balloon experiment from Trapani Milo are shown in Figure 6.

5.2 The Continuation of HXR and the POKER Experiment

After the transatlantic flight the Frascati IAS-CNR group, Pietro Ubertini coordinated hard X-ray observations with detectors that evolved from the original HXR-76. There were three flights from Milo: on 10 August 1978 (HXR-78/Celimene I), 26 August 1979 (HXR-79/Celimene II) and on 10 August 1980 (HXR-80/Circe). Another flight was from Hyderabad (India) on 19 April 1980 (HXR-80-I) in collaboration with the Tata Institute of Fundamental Research Balloon Facility.

The final evolution was the POKER Experiment, which consisted of an array of four (in some flight reduced to three) high-pressure xenon multiwire proportional counters (MWPCs) with a sensitive area of 2700 cm^2 each. These detectors were filled at a pressure of 3.6 kPa with a mixture of Xenon-CO2 (one module) and xenon-isobutane (two modules) to provide an efficiency greater than 20% for photons in the energy range between 13 and 110 keV. The spectral resolution was 13% at 60 keV. The fields of view of the three MWPCs were co-aligned and limited by means of hexagonal copper collimators with an aperture of 5°.0 FWHM. A description is given in Ubertini et al. (1983). The experiment had two successful trans-mediterranean flights, on 21 July 1981 (POKER HXR-81M), and 5 August 1985 (POKER 85), while a launch on 22 July 1984 (POKER 84) failed. Another launch was on 17 May 1989 from Alice Springs (Australia) (POKER89) in the framework of the NASA Supernova 1987A campaign.

Results from the first three flights included a possible detection of spectral feature around 73 keV from the Crab Nebula (Manchanda et al., 1982), reported earlier by Jacobson et al., (1978) and Ling et al. (1979), but not observed in subsequent experiments (Ling and Wheaton, 2003). Furthermore, in the HXR80 flight an enhancement of hard X-ray emission from the region of the unidentified Uhuru source 4U 0515+38 was reported (Ubertini et al, 1982).

The flight of July 1981 had a duration of about 17 hours, and although two of the four

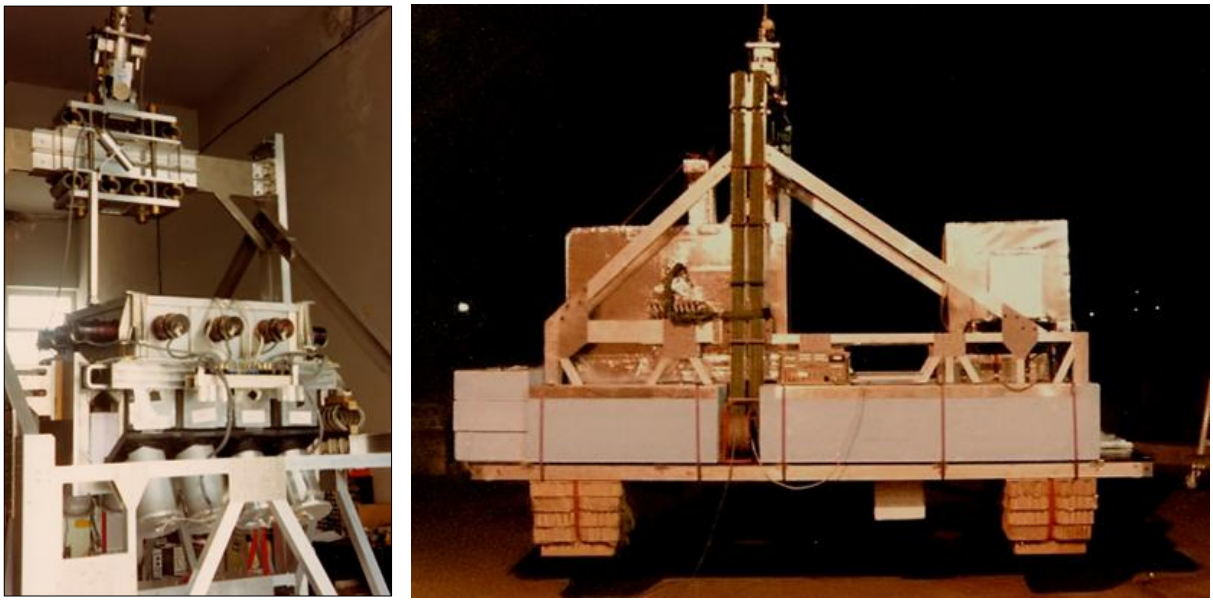


Figure 7, Left: A photograph of the F.I.GA.R.O. II experiment without the screen covers showing the lateral anticoincidence wall and the four bottom plastic scintillators for the atmospheric background. The tagged 22Na source for the gain control is inside the inclined cylinder on the top of the vertical bar on the left side of the scintillator wall. Right: The F.I.GA.R.O. II balloon payload at the Milo launch base before the third flight in July 1990. The experiment with anticoincidences is in the large box on the left while the electronic system box is on the right side (photographs: E. Massaro).

detectors were not working data were obtained for some sources. Ubertini et al. (1984) reported the detection in the energy range 20–100 keV of the Seyfert galaxies MCG 8-11-11, NGC 4151, and of the blazar Mrk 421. Polcaro et al. (1984) found again an X-ray excess from the region of 4U 0515+38/1H0521+373, possibly an X-ray transient (Polcaro et al., 2006). Bazzano et al. (1984) reported the detection of hard X-rays from the three clusters of galaxies: Coma, A2142 and 3C 129.

POKER 85 had data on the black-hole candidate Cygnus X-1, the Crab Nebula and its pulsar (Ubertini et al., 1994). POKER 89 was launched from the Australian base of Alice Springs with the goal of detecting hard X-ray emission from the remnant of SN1987A in the Large Magellanic Cloud. This source was not detected but some other interesting targets were observed: Sco X-1 (Ubertini et al., 1992), Cen A (Ubertini et al., 1993), GRS 1758-258 (Bazzano et al., 1993) and the Galactic Center region (Bazzano et al., 1992).

5.3 The F.I.GA.R.O. II Experiment

The name F.I.GA.R.O. is the acronym for French Italian Gamma Ray Observatory, because in this project several research institutes of the two countries were involved: the CESR of the P. Sabatier University in Toulouse, the Section d'Astrophysique of the CEN in Saclay, the Observatory of Paris-Meudon, the Istituto di Fisica Cosmica con Applicazioni all' Informatica (IFCAI, CNR) in Palermo, the Istituto di Astrofisica Spaziale (IAS, CNR) in Frascati near Rome, the Università di Roma La Sapienza, and, after 1988, the Osservatorio Astrofisico di Arcetri in Florence.

The idea of setting up a high-sensitivity balloon-borne experiment for low-energy gamma-ray astronomy was initially discussed by Livio Scarsi and Gilbert Vedrenne during a conference in 1979. The choice was a large area uncollimated detector with a high time resolution and the primary target being the investigation of emission properties from pulsars and other sources with a known time signature or rapid variability. Likely, this experiment was developed because of the possibility of using the Milo base where French and Italian teams were already successfully collaborating.

A first version of the experiment with a total geometric area of 4000 cm^2 had two unsuccessful launch attempts, from Milo in 1982 and from San Manuel (Brazil) in 1983, in which the payload was destroyed after a free fall, because a balloon burst during the ascent.

The collaboration decided to continue the project and in a short time designed and built a new version, F.I.GA.R.O. II, with a slightly lower geometrical area (3600 cm^2) and an array of nine NaI(Tl) tiles with thickness of 5 cm, allowing a useful energy range of 0.15–6.0 MeV. A description and its technical performances can be found in Agnetta et al. (1989). Here we include an archive picture (Figure 7, left panel)

without the external screens.

The main detector was shielded against the atmospheric and cosmic gamma-rays by a system of thick plastic and inorganic scintillators. Another plastic scintillator (0.5 cm thick) was placed just above the detector to work in anti-coincidence for discriminating downwards charged particles. The gain of each module of the main detector was continuously monitored by means of a small BGO detector tagging photons from a low-activity ^{22}Na radioactive source located well above the top scintillator. Accepted events were transmitted to the ground station in asynchronous mode with a bit rate of 300 kHz and then correlated to UT by means of an atomic clock with an accuracy of 10 μs. After the first transmediterranean flight, in order to compensate the serious perturbation in the time series analysis due to telemetry gaps, a streamer video tape recorder with an overall capacity of 2 Gbytes was installed on-board, operating in buffer mode for gap-loss acquisition. Events recorded on-board were then correlated with those transmitted by the identification of equal sequences of photon energies, resulting in a time resolution of 0.1 ms.

F.I.GA.R.O. II had three successfully flights: twice from the Milo base (11 July 1986 and 9 July 1990) and once from Charleville Airport in Queensland, Australia (25 November 1988). A night picture of the payload before the last flight is shown in the right panel of Figure 7.

The source most extensively observed by F.I.GA.R.O. II was the Crab pulsar: it was possible for the first time to measure the shape of its double peaked pulse profile at energies higher than 0.5 MeV and to obtain phase resolved spectra above 0.15 MeV (Agrinier et al., 1990). A comparison of the F.I.GA.R.O. II pulse profile with that of the OSSE experiment on board the Compton-GRO mission, in nearly identical energy bands (0.22–0.35 MeV and 0.22–0.34 MeV, respectively), confirmed the better S/N ratio of the former experiment (Massaro et al., 1994).

The analysis of the data of both transmediterranean flights provided evidence for a spectral feature in the second peak at the energy of 0.44 MeV, which was interpreted as a possible redshifted e^+e^- annihilation line (Massaro et al., 1991). Up to now no robust confirmation or disclaimer of this result has been published.

The delay between the gamma-ray first peak and the same feature in the radio band was also measured, an analysis never attempted before, that was possible because of the very fine timing accuracy reached with the asynchronous transmission mode of the events. Masnou et al. (1994) evaluated a radio-to-gamma-ray pulse delay of 600 ± 145 ms and 375 ± 148 ms for the 1986 and 1990 observations, respectively. This finding was substantially confirmed about ten years later by Rots et al. (2004) who measured a delay of 344 ± 40 ms between the X-ray and the radio first peaks on the base of 8 years of observations with the Rossi-XTE satellite.

In the region of the Galactic anticenter F.I.GA.R.O. II observed the binary pulsar A 0535+26 and measured its spectrum up to 0.4 MeV (Cusumano et al., 1992), reporting the existence of an absorption feature at around 0.16 MeV. This was interpreted as an upper harmonic of the cyclotron line. Such a line was actually detected by Kendziorra et al. (1992; 1994) with the TTM and HEXE experiments on board the MIR Space Station at an energy around 0.05 MeV, thus corresponding to about one-third of the F.I.GA.R.O. II energy. The detection of an absorption feature at 0.11 MeV was later confirmed by data from the OSSE-CGRO experiment (Grove et al., 1995). For some unknown reason, these two papers do not mention the F.I.GA.R.O. II results.

In the Australian flight, PSR 0833-45 (the Vela pulsar) and the Galactic Centre region were observed. A pulsed signal from the former source was not detected. The upper limit indicated a low energy bending of the spectrum in the MeV range with respect to the power law in the COS-B range (Sacco et al., 1990), later confirmed by the detection with OSSE-CGRO (Strickman et al., 1996) and a photon flux compatible with F.I.GA.R.O. II upper limits. Furthermore, an evaluation of the extended emission from the Galactic Centre region of the electron–positron annihilation line at 0.511 MeV was obtained (Niel et al., 1990).

5.4 The MIFRASO Experiment

The MIFRASO, named after MIlano, FRAscati, Southampton, but also called PALLAS or X-PALLAS, was an instrument for hard X-ray astronomy developed by three research teams from the Istituto di Fisica Cosmica (CNR) at Milano, the Istituto di Astrofisica Spaziale (CNR) at Frascati, and the Department of Physics at Southampton University. This collaboration was extended to scientists at ITESRE in Bologna. A detailed description is given by Baker et al. (1984).

The main photon detector system (HED) consisted of an array of eight identical scintillation counters of NaI(Tl) crystals with a thickness of 6 mm and an active shield of an equal number of NaI(Tl) crystals 50 mm thick. Contrary to the phoswich concept the detectors of

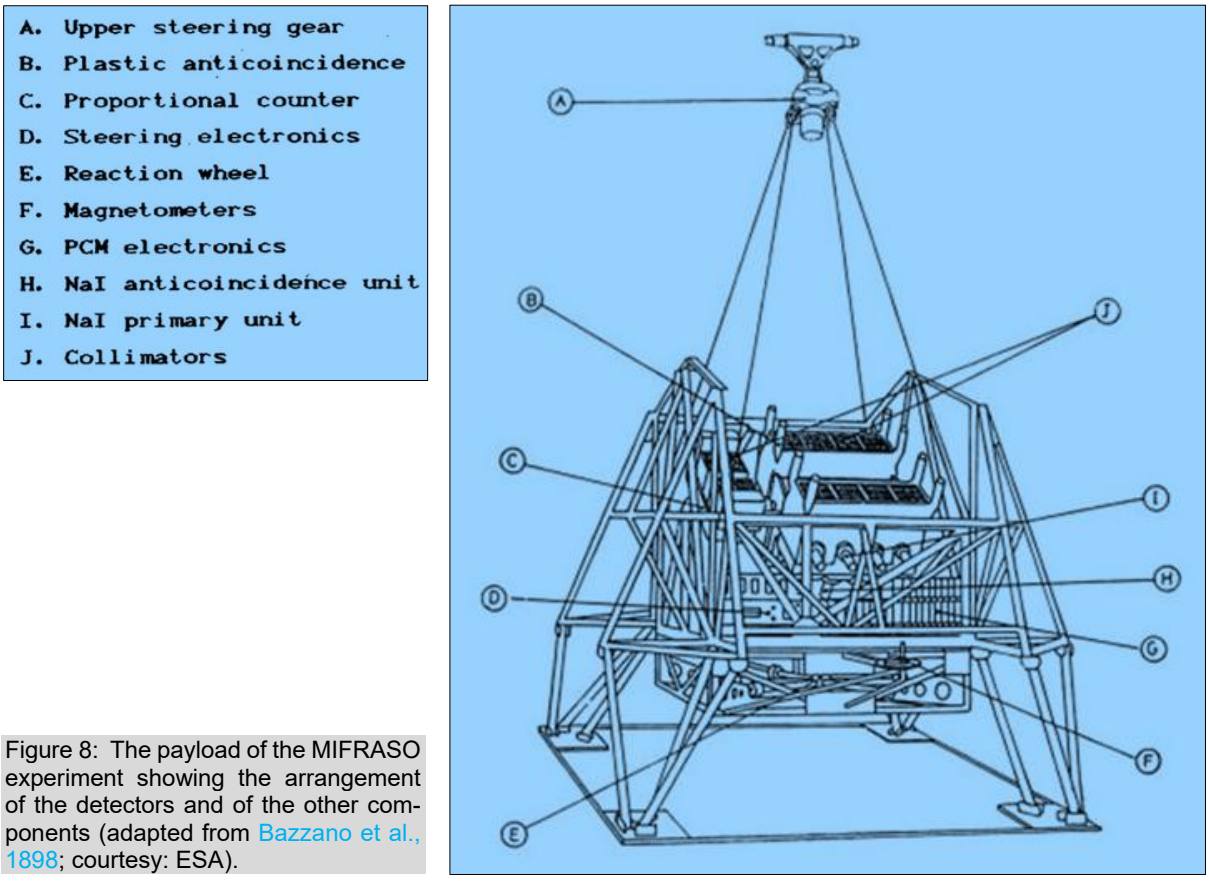


Figure 8: The payload of the MIFRASO experiment showing the arrangement of the detectors and of the other components (adapted from Bazzano et al., 1898; courtesy: ESA).

the signal and those of anti-coincidence had independent read-out photomultipliers. The total sensitive area of this detector was 2700 cm^2. The energy range was from 15 to 300 keV and the typical energy resolution was 25% FWHM at 60 keV. Another detector, consisting of two high-pressure xenon gas proportional counters (LED), similar to those of the HXR-76 experiment, had a total area of 900 cm^2 and was sensitive to photons in the 10–120 keV energy range. It provided a higher spectral resolution, typically 12% FWHM at 60 keV. Figure 8 gives an image of the whole payload mounted in the balloon gondola.

MIFRASO was launched from Milo four times between 1985 to 1989, but only the two fights on 29 July 1986 and 15 July 1987 were successfully and the payload, after about 20 hours at ceiling, was recovered near Sevilla in both cases. Scientific results were obtained from the X-ray binary A 0535+26 (Coe et al., 1990), from the Seyfert 1 galaxies NGC 4151 (Perotti et al. 1990a; 1991) and MCG 8-11-11 (Perotti et al., 1990b), and from the region of Coma cluster of galaxies (Bazzano et al., 1990).

5.5 The TXC Experiment

Finally, we would like to mention an experiment aimed at testing the technique of coded masks for the imaging of rapidly transient events in the hard X ray. This experiment, inspired by a suggestion from Giulio Auriemma, was named Transient X-ray Camera (TXC) and was carried out at the Istituto di Astrofisica Spaziale with the coordination of Marcello Ranieri and in collaboration with a group at INFN-Bari.

The TXC consisted of a position-sensitive multi-wire pressurized proportional chamber filled with Xe, surmounted by a coded mask in the field of view, providing a coarse spatial resolution of 4° × 5° (Cardini et al., 1983). The TXC was tested on a transmediterranean flight on 6 August 1981 and produced an image of a solar flare, whose main peak had a duration of about 5 s, at energies higher than 35 keV, as shown in Figure 9 (Emanuele et al., 1994). This was the very first image of a cosmic event in hard X-rays obtained by means of a coded mask.

Interestingly, in 1984 another experiment aimed at detecting sources, and especially Gamma Ray Bursts, was a wide field NaI(Tl) gamma-camera with a coded mask, that was launched from the Milo base (Ventura et al., 1984) by a team from of the ITESRE in Bologna.

6 OTHER EXPERIMENTS, THE DECLINE OF THE SEASON, AND THE HERITAGE

We have only described the major experiments but a few more deserve a mention. A Large Area

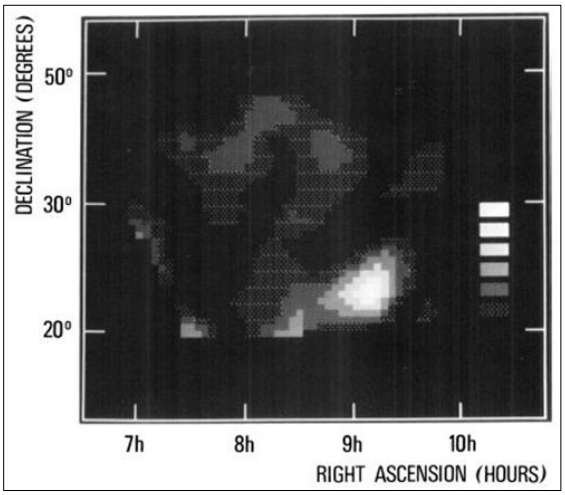


Figure 9: The first image of a solar flare on August 6 1981 at energies higher than 35 keV obtained with the TXC experiment by means of a coded mask (after Emanuele et al., 1984, A&A, 132. 33; reproduced with permission © ESO).

Phoswich Experiment (LAPEX, Frontera et al., 1985b) was designed in the early 1980s for balloon experiments. It was based on a phoswich detector made of 4 × 4 units of NaI(Tl)/CsI(Na) scintillators with a 6 mm thickness of the true detector (NaI(Tl)), and each unit was viewed from a PMT with a total effective area of about 3400 cm^2. A configuration with 4 × 2 phoswich units (Frontera et al., 1990) was flown in 1989 to try and observe the famous supernova SN1987A from Alice Springs (Australia). No hard X-ray emission was detected and the results were not published. Technical tests of LAPEX were exploited in a couple of successful balloon launches on 14 August 1992 from Milo and in 1995 from New Mexico, but, due to the preparation of the Phoswich Detection System (PDS) instrument for Beppo-SAX, the data were not fully analyzed.

Another technical test was that of the low-energy gamma-ray experiment ZEBRA, developed by three CNR Italian institutes (ITESRE, IFC, IAS) in collaboration with Southampton University. A reduced version (MINIZEBRA), consisting of a detection array of nine position sensitive scintillation NaI(Cs) crystals, was launched from Milo on 14 July 1981, and the final test flight was performed in 1989 from Palestine (NM, USA).

The last flight was that of the hard X-ray experiment HEAT (High Energy Astronomical Telescope) (Perotti et al., 1997) on 10 August 1995, but the payload fell into the Atlantic Ocean about 500 km West of the Portuguese coast and was never recovered.

After 1990 the number of experiments for X and gamma-ray astronomy carried by stratospheric balloons declined rapidly. Many scientists working in this research field were deeply involved in the design and construction of the first Italian space mission for broad band X-ray astrophysics BeppoSAX, which was successfully launched in a near equatorial orbit in April 1996. BeppoSAX included two hard X-ray instruments, the HPGSPC and the PDS, that in combination with telescopes sensitive at lower energies allowed a full exploitation of the techniques previously hosted aboard balloons, with comparable sensitivities but observing times incomparably longer. The NASA mission XTE (renamed RossiXTE), hosting a hard X-ray experiment, had been launched on 1995. After 1996, more satellite missions in the high energy band were in the development phase, such as the Soviet Spectrum X-Gamma and the ESA INTEGRAL. Most of the Italian research teams were now involved in these satellite projects, so interest in and financial support for balloon-based experiments decreased and no new projects were started.

After 1995, the main scientific flights were devoted to investigations of anisotropies in the Cosmic Microwave Background, to infrared astronomy and bioastronomy research. The last transmediterranean flight campaign was in the summer 2002, and in 2003 only a local flight was made. After that no other scientific or technical launches were performed. The Milo base was officially closed in October 2012.

7 CONCLUDING REMARKS

This short account of Italian balloon-based research in experimental High-Energy Astrophysics spans a time interval of about 20 years, from 1975 to 1995, which was fundamental for the development of this research field. There is no doubt that the existence of the Milo base was critical to all of the Italian ballooning activity by providing easier launch opportunities and by stimulating the technical competence that was essential for competitive experiment design. The initial efforts of this project were strongly supported by Livio Scarsi, who continued to follow the Milo base activity for many years.

A new generation of young Italian astrophysicists grew up with these activities, and the Milo facility gave them an important opportunity to develop new experiments and techniques. We notice that in the same years, a community of scientists investigating hard X-ray and soft gamma-ray astrophysics in USA experienced a similar evolution from balloons to satellites with GRO and XTE, even if NASA still required balloon flights to test experiments proposed to be flown aboard satellites, such as NuSTAR (Harrison et al., 2006). Balloons definitely offered an

excellent training-ground in experimental astrophysics, and one that paved the way for future successful satellite missions.

8 REFERENCES

Agnetta, G., di Raffaele, R., Mineo, T., Sacco, B., Scarsi, L., plus 14 more authors, 1989. FIGARO II experiment: description and technical performance. *Nuclear Instruments and Methods in Physics Research Section A*, 281(1), 197–206.

Agrinier, B., Koechlin, Y., Parlier, B., Paul, J., Vasseur, J., plus 4 more authors, 1970. Cosmic ray electrons at 8.3 GV rigidity cut-off. Energy spectrum and charge sign ratio. In Somogyi, A. (ed.), *Proceedings of the 11th International Conference on Cosmic Rays. Budapest, August 25-September 4, 1969*. *Acta Physica Academiae Scientiarum Hungaricae*, 29(Suppl. 1), 203–208.

Agrinier, B., Masnou, J.L., Parlier, B., Niel, M., Mandrou, P., plus 10 more authors, 1990. Observation of the Crab pulsar, PSR 0531+21, at 0.2–6.0 MeV with the FIGARO II Experiment *Astrophysical Journal*, 355, 645–650.

Auriemma, G., Angeloni. L., Belli, B.M., Bernardi, A., Cardini, D., plus 4 more authors, 1978. Hard X-ray spectrum of NGC 4151. *Astrophysical Journal Letters*, 221, L7–L11.

Baker, R., Barbaglia, G., Bazzano, A., Boccaccini, L., plus 21 more authors, 1984. A large area telescope for balloon-borne hard X-ray astronomy. *Nuclear Instruments and Methods A*, 228,183–192.

Bazzano, A., Fusco-Femiano, R., La Padula, C., Polcaro, V.F., Ubertini, P., and Manchanda, R.K., 1984. Evidence of hard X-ray emission from three clusters of galaxies. *Astrophysical Journal.* 279, 515–520.

Bazzano, A., Court, A., Dean, A.J., Dipper, M., Lewis, R., plus 5 more authors, 1989. A Hard X-ray observation of the Coma cluster region. In Hunt, J., and Battrick, B. (eds.), *Proceedings of 23rd ESLAB Symposium. Volume 2, held at Bologna, Italy, 13-20 September 1989.* Noordwjik, European Space Agency. Pp. 901–903.

Bazzano, A., Fusco-Femiano, R., Ubertini, P., Perotti, F., Quadrini, E., plus 5 more authors, 1990. Hard X-ray from Coma cluster region. *Astrophysical Journal Letters*, 362, L51–L54.

Bazzano, A., La Padula, C., Ubertini, P., and Sood, R.K., 1992. Variability of the Galactic Center in the hard X-ray range. *Astrophysical Journal Letters*, 385, L17–L20.

Bazzano, A., Cocchi, M., La Padula, C., Sood, R.K.., and Ubertini, P., 1993. Hard X-ray observation of GRS 1758-258. *Astronomy and Astrophysics Supplement Series*, 97, 169–171.

Brini, D., Cattani, D., Ciriegi, U., Fuligni, F., Galli, M., plus 3 more authors, 1965. Results of an X-ray scanning of the sky in the 20-200 keV range. *Annales d'Astrophysique*, 28, 1034–1038.

Brini, D., Ciriegi, U., Fuligni, F., Moretti, E., and Vespignani, G., 1967. Cosmic X-ray sources in the 20-180 KEV energy range. *Astrophysical Journal*, 149, 429–433.

Cardini, D., Badiali, M., Emanuele, A., Farina, G., Gianni, G., plus 5 more authors, 1983. A hard X-ray imaging experiment using a coded mask telescope prototype. *Astronomy and Astrophysics*, 127(1), 169–176.

Cavallari, E., and Frontera, F., 2017. Hard X-ray/soft gamma-ray experiments and missions: overview and prospects. *Space Science Reviews*, 212(1-2), 429–518.

Coe, M.J., Carstairs, I R., Court, A.J., Davies, S.R., Dean, A.J., plus 7 more authors, 1990. High-energy observations of A 0535+26. *Monthly Notices of the Royal Astronomical Society*, 243, 475–479.

Costa, E., Auriemma, G., Boccaccini, L., Emanuele, A., Manchanda, R.K., plus 3 more authors, 1978. High pressure MWPC for hard X-ray astronomy. *Nuclear Instruments and Methods*, 156(1–2), 57–61.

Cusumano, G., Mineo, T., Sacco, B., Scarsi, L., Gerardi, G., plus 12 more authors, 1992. Observation of A0535+26 at energies above 150 keV with the FIGARO II experiment. *Astrophysical Journal Letters*, 398(2), L103–L106.

Dal Fiume, D., Frontera, F., and Morelli, E., 1988. The X-ray pulsar A0535+26 in hard X-rays: average spectrum, pulse phase spectroscopy, and spectral time variability. *Astrophysical Journal*, 331, 313–320.

Dean, A.J., Gerardi, G., De Martinis, C., Monastero, G.F., Russo, A., and Scarsi, L., 1973. Scan of the Cygnus region in the 1–10 MeV gamma-ray energy range. *Astronomy and Astrophysics*, 28, 131–135.

Delury, J.T., Luscombe, G.W., Ramsden, D., and Baker, R.E., 1976. Transatlantic balloon facility. In Burke, W.R. (ed.), *European Programmes on Sounding-Rocket and Balloon Research in the Auroral Zone: Proceedings of a Symposium held at Schloss Elmau, Germany, 3–7 May 1976.* Paris, European Space Agency. Pp. 265–278.

Emanuele, A., Badiali, M., Cardini, D., Ranieri, M., Catanesi, M.G., plus 3 more authors, 1984. Detection and localization of a hard X-ray solar burst with a balloon-borne coded mask telescope. *Astronomy and Astrophysics*, 132, 33–36.

Fowler, P.H., Clapham, V.M., Henshaw, D.L., Thompson, A., and O'Sullivan, D., 1979. Ultra heavy cosmic ray nuclei from the first transatlantic balloon flight. In Miyake, S. (ed.), *Proceedings of the 16th International Cosmic Ray Conference*, Volume 1. Tokyo, University of Tokyo. Pp. 370–372.

Frontera, F., and Fuligni, F., 1975. Evidence for long-period sporadic pulsations in the hard X-ray flux of Cygnus X-1. *Astrophysical Journal Letters*, 198, L105–L108.

Frontera, F., Fuligni, F., Morelli, E., and Ventura, G., 1979a. Observation of hard X-ray flux variability of 3U 0352+30 = X Persei. *Astrophysical Journal*, 229, 291–293.

Frontera, F., Fuligni, F., Morelli, E., and Ventura, G., 1979b. Hard X-ray emission from NGC 4151 and MCG 8-11-11 regions. *Astrophysical Journal*, 234, 477–480.

Frontera, F., Fuligni, F., Morelli, E., and Ventura, G., 1981a. Hard X-ray latitude effect measured during a transatlantic balloon flight. *Advances in Space Research*, 1, 107–110.

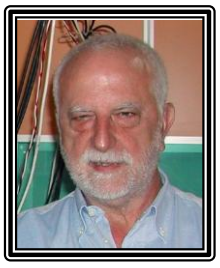
Frontera, F., Fuligni, F., Morelli, E., Pizzichini, G., and Ventura, G., 1981b. Detection of pseudo gamma-ray bursts of long duration. *Astrophysics and Space Science*, 75, 211–217.

Frontera, F., Dal Fiume, D., Morelli, E., and Spada, G., 1985a. The X-ray pulsar A 0535+26: pulse profile and its

time variability in hard X-rays. *Astrophysical Journal*, 298, 585–595.
Frontera, F., Basili, A., Dal Fiume, D., Franceschini, T., Landini, G., plus 5 more authors, 1985b. Lapex: a phoswich balloon experiment for hard X-ray astronomy. In Jones, F.C. (ed.), *Proceedings of the 19th International Cosmic Ray Conference, Volume 3. Greenbelt, MD, NASA Goddard Space Flight Center*. Pp. 355–358.
Frontera, F., Basili, A., dal Fiume, D., Franceschini, T., Landini, G., plus 7 more authors, 1990. The LAPEX experiment for observation of the supernova SN 1987A in hard X-rays. *Nuovo Cimento C, Serie 1*, 13 C, 437–444.
Frontera, F., Costa, E., Dal Fiume, D., Feroci, M., Nicastro, L., plus 3 more authors, 1997. The high energy instrument PDS on-board the BeppoSAX X-ray astronomy satellite. *Astronomy and Astrophysics Supplement Series*, 122, 357–369.
Frontera, F., 2020. L'astrofisica spaziale a Bologna: i primi passi e il suo sviluppo. In Marano, B. (ed.), *Lo sviluppo dell'Astronomia a Bologna del 1960 al 1990*. Bologna, Bononia University Press. Pp. 27–59.
Fuligni, F., and Frontera, F., 1973. Hard X-ray flare-like activity in the Cyg X-1 emission. *Astronomy and Astrophysics*, 28, 373–375.
Fuligni, F., Brini, D., Dusi, W., and Frontera, F., 1976. Flare from the Perseus region in hard X-rays. *Astrophysical Journal Letters*, 208, L111–L113.
Fuligni, F., Dusi, W., Frontera, F., Morelli, E., and Ventura, G., 1979. Hard X-ray transient source observed during the 1976 transatlantic flight. In Baity, W.A., and Peterson, L.E. (eds.), *X-Ray Astronomy*. Oxford, Pergamon Press. Pp. 505–508.
Giacconi, R., Gursky, H., Paolini, FR., and Rossi, B.B., 1962. Evidence for X rays from sources outside the Solar System. *Physical Review Letters*, 9(11), 439–443.
Grandi, P., Haardt, F., Ghisellini, G., Grove, J.E., Maraschi, L., and Urry, C.M., 1998. High-energy break and reflection features in the Seyfert Galaxy MCG +8-11-11. *Astrophysical Journal*, 498(1), 220–225.
Grove, J.E., Strickman, M.S., Johnson, W.N., Kurfess, J.D., Kinzer, R.L., plus 6 more authors, 1995. The soft gamma-ray spectrum of A0535+26: detection of an absorption feature at 110 keV by OSSE. *Astrophysical Journal Letters*, 438, L25–L28.
Harrison, F.A., Christensen, F.E., Craig, W., Hailey, C., Baumgartner, W., plus 8 more authors, 2006. Development of the HEFT and NuSTAR focusing telescopes. *Experimental Astronomy*, 20, 131–137.
Jacobson, A.S., Ling, J.C., Mahoney, W.A., and Willett, J.B., 1978. Observational evidence for extraterrestrial gamma-ray line sources. In Cline, T.L., and Ramaty, R. (eds.), *Gamma-Ray Spectroscopy in Astrophysics.* Greenbelt, MD, NASA Goddard Space Flight Center. Pp. 228–251.
Kendziorra, E., Mony, B., Kretschmar, P., Maisack, M., Staubert, R., plus 8 more authors, 1992. Hard X-ray observations of Vela X-1 and A0535+26 with HEXE: discovery of cyclotron lines. In Shrader, C.R., Gehrels, N., and Dennis, B. (eds.), *The Compton Observatory Science Workshop.* Greenbelt, NASA Goddard Space Flight Center. Pp. 217.
Kendziorra, E., Kretschmar, P., Pan, H.C., Kunz, M., Maisack, M., plus 5 more authors, 1994. Evidence for cyclotron line features in high-energy spectra of A 0535+26 during the March/April 1989 outburst. *Astronomy and Astrophysics*, 291, L31–L34.
Ling, J.C., Mahoney, W.A., Willett, J B., and Jacobson, A.S., 1979. A possible line feature at 73 keV from the Crab Nebula. *Astrophysical Journal*, 231, 896–905.
Ling, J.C., and Wheaton, W.A., 2003. Gamma-ray spectra and variability of the Crab Nebula emission observed by BATSE. *Astrophysical Journal*, 598(1), 334–348.
Malavasi, M., Medina, J., Sequerios, J., and Soubrier, A., 1978. First experimental transmediterranean balloon flight. In aHalvorsen, T., and Battrick, B. (eds.), *European Sounding-Rocket and Balloon Research, with Emphasis on Experiments at High Latitudes. Proceedings of a Symposium held at Ajaccio, France, 24–29 April 1978*. Paris, European Space Agency. Pp. 383–386.
Manchanda, R.K., Bazzano, A., La Padula, C.D., Polcaro, V F., and Ubertini, P., 1982. Line feature around 73 keV from the Crab Nebula. *Astrophysical Journal*, 252(1), 172–178.
Masnou, J.L., Agrinier, B., Barouch, E., Comte, R., Costa, E., plus 14 more authors, 1994. The radio-gamma time delay of the Crab pulsar. *Astronomy and Astrophysics*, 290, 503–509.
Massaro, E., Matt, G., Salvati, M., Costa, E., Mandrou, P., plus 11 more authors, 1991. Detection of a feature at 0.44 MeV in the Crab pulsar spectrum with FIGARO II: a redshifted positron annihilation line? *Astrophysical Journal Letters*, 376, L11–L14.
Massaro, E., and (FIGARO Collaboration), 1994. The relevance of balloon-borne experiments in low-energy gamma-ray astronomy: the scientific results of FIGARO II. In Caballero Requena, F. (ed.), *Proceedings of the 1st Symposium on Stratospheric Balloons, El Arenosillo, October 1994*. Torrejón de Ardoz, INTA. Paper 7.
Massaro, E., Feroci, M., Costa, E., Matt, G., Agrinier, B., plus 12 more authors, 1998. The pulse shape and the spectrum of PSR B0531+21 (Crab pulsar) in the low-energy gamma rays observed with FIGARO II. *Astronomy and Astrophysics*, 338, 184–190.
Matt, G., Costa, E., Dal Fiume, D., Dusi, W., Frontera, F., and Morelli, E., 1990. Observations of Galactic and extragalactic high-energy X-ray sources. *Astrophysical Journal*, 355, 468–476.
Niel, M., von Ballmoos, P., Malet, I., Mandrou, P., Costa, E., plus 10 more authors, 1990. Observation of the 0.511 MeV annihilation line from the inner Galaxy with the FIGARO II experiment. *Astrophysical Journal Letters*, 356, L21–L24.
Perotti, F., Buratti, R., Maggioli, P., Quadrini, E., Bazzano, A., plus 7 more authors, 1990a. Hard X-ray observation of NGC 4151 with the MIFRASO telescope. *Astrophysical Journal*, 356, 467–471.
Perotti, F., Bassani, L., Bazzano, A., Court, A.J., Dean, A.J., plus 6 more authors, 1990b. MCG 8-11-11: a powerful

source of X- and gamma-rays. *Astronomy and Astrophysics*, 234, 106–108.
Perotti, F., Maggioli, P., Quadrini, E., Bazzano, A., Ubertini, P., plus 6 more authors, 1991. Hard X-ray variability of NGC 4151. *Astrophysical Journal*, 373, 75–79.
Perotti, F., Mattaini, E., Quadrini, M., Santambrogio, E., Bassani, L., and Stephen, J.B., 1997. Hard X-ray spectral feature detected in the region of MCG 8-11-11. *Astrophysical Journal Letters*, 475(2), L89–L92.
Piro, L., Matt, G., Costa, E., Dal Fiume, D., Frontera, F., and Morelli, E., 1991. X-ray observations of the Seyfert 1 galaxy Markarian 464. *Astrophysical Journal*, 380, 357–362.
Polcaro, V.F., Bazzano, A., La Padula, C.D., Ubertini, P., and Manchanda, R.K., 1984. New evidence of hard X-ray emission from 4U 0515+38. *Astronomy and Astrophysics*, 131, 229–231.
Polcaro, V.F., Norci, L., Meurs, E.J.A., Bernabei, S., and Miroshnichenko, A.S., 2006. The Be/X-ray transient HD 34961. In Meurs, E.J.A., and Fabbiano, G. (eds.), *Populations of High Energy Sources in Galaxies: Proceedings of the 230th Symposium of the International Astronomical Union held in Dublin, Ireland 15-19 August 2005*. Cambridge, Cambridge University Press. Pp. 49–50.
Ramsden, D., 1979. Transatlantic ballooning. *New Scientist*, 82, 1072–1074.
Rots, A.H., Jahoda, K., and Lyne, A.G., 2004. Absolute timing of the Crab pulsar with the Rossi X-Ray Timing Explorer. *Astrophysical Journal Letters*, 605, L129–L132.
Sacco, B., Gerardi, G., Mineo, T., Scarsi, L., Agrinier, B., plus 10 more authors, 1990. Observation of the Vela pulsar, PSR 0833-45, at 0.2–6.0 MeV with the FIGARO II Experiment. *Astrophysical Journal Letters*, 349, L21–L24.
Scarsi, L., 1994. History of the transmediterranean stratospheric balloon campaigns, achievements and scientific perspective for the future. In Caballero Requena, F. (ed.), *Proceedings of the 1st Symposium on Stratospheric Balloons, El Arenosillo, October 1994*. Torrejón de Ardoz, INTA. Paper 1.
Setti, G., 2005. 1960 and thereabout: The new astronomy (notes for a history still to be written). In *Cento Anni di Astronomia in Italia: 1860–1960. Atti dei convegni lincei*, 217. Roma, Bardi Editore. Pp. 405–416.
Strickman, M.S., Grove, J.E., Johnson, W.N., Kinzer, R.I., Kroeger, R.A., plus 6 more authors, 1996. OSSE observations of the VELA and Geminga pulsars. *Astrophysical Journal*, 460, 735–743.
Ubertini, P., Bazzano, A., La Padula, C.D., and Polcaro, V.F., 1982. Hard X-ray emission (15–150 keV) from the region of 4U 0515+38. *Astronomy and Astrophysics*, 106, 174–175.
Ubertini, P., Bazzano, A., Boccaccini, L., La Padula, C., Manchanda, R.K., plus 4 more authors, 1983. The POKER experiment: a 10,800 cm2 MWPC array payload for hard X-ray astronomy. *Advances in Space Research*, 3(4), 87–90.
Ubertini, P., Bazzano, A., La Padula, C.D., Polcaro, V.F., and Manchanda, R.K., 1984. Hard X-ray variability of three active galactic nuclei. *Astrophysical Journal*, 284, 54–59.
Ubertini, P., Bazzano, A., Cocchi, M., La Padula, C., and Sood, R.K., 1992. Hard X-ray observation of Scorpius X-1. *Astrophysical Journal*, 386, 710–714.
Ubertini, P., Bazzano, A., Cocchi, M., La Padula, C., and Sood, R., 1993. Hard X-ray observations of Centaurus A. *Astronomy and Astrophysics Supplement Series*, 97, 105–108.
Ubertini, P., Bazzano, A., Cocchi, M., La Padula, C., Polcaro, V.F., plus 2 more authors, 1994. Hard X-ray timing observations of the Crab pulsar and Cygnus X-1. *Astrophysical Journal*, 421, 269–275.
Ventura, G., Horstman, H.M., Brighenti, A., Cavani, C., Camprini, M., plus 4 more authors, 1984. A balloon-borne instrumentation for cosmic gamma-ray burst detection and measurement. *Nuclear Instruments and Methods in Physics Research Section A*, 226(2–3), 524–533.
Wilkinson, D.T., 1952. The phoswich—a multiple phosphor. *Review of Scientific Instruments*, 23(8), 414–417.

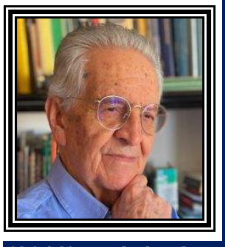
Dr. Enrico Costa was born in Sassari (Italy) in 1944 and has a Laurea in Physics from the University of Roma.



He carried out experimental research in X-ray and Gamma-ray astronomy at CNR and INAF. He contributed the the discovery of X-ray afterglow of GRBs with the Italian satellite for X-ray astronomy Beppo-SAX. He participated in the Agile space mission. Together with R. Bellazzini he designed and built the Gas Pixel Detector for X-ray photoelectric polarimetry, that is used in the satellite IXPE.

For his research activities he has been awarded several scientific prizes: the Bruno Rossi Prize (1998, 2024), Cartesio Prize (2006), Fermi Prize (2010), Shaw Prize (2011) and Feltrinelli Prize (2025).

Professor Filippo Frontera was born in Savelli (Italy) in 1941. He has a Laurea degree in Physics from the University of Bologna. From 1969 to 1985 he was a scientist at ITESRE (CNR) and then Professor of Experimental Physics at the University of Ferrara.



He used phoswich detectors for experiments in X-ray astronomy and was Principal Investigator of the experiments PDS and GRBM on board BeppoSAX. He also developed the first Laue lens prototype to focus high energy X-rays. He is author or coauthor of more than 890 scientific papers.

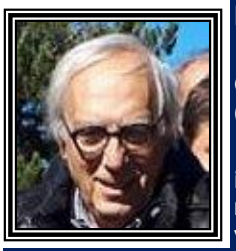
For his research activity he was awarded by several scientific prizes: the Bruno Rossi Prize (1998), Cartesio Prize (2002), Fermi Prize (2010), Marcel Grossman Award (2012) and the International Collaboration Award of the Chinese Academy of Sciences (2024). In 2024 an

asteroid was named 126177 Filippofrontera.

Professor Enrico Massaro was born in Palermo (Italy) in 1948 and has a Laurea in Physics from the University of Palermo in 1971 on cosmic high energy gamma rays. From 1977 until his retirement in 2013 he worked at the University of Roma La Sapienza and from 1980 he was Professor of Cosmic Rays Physics and later of High Energy Astrophysics.

He participated in several research projects in X-ray and Gamma-ray astronomy and in telescopic observational campaigns of BL Lac objects. He was the team leader of the elaboration of the RomaBZCAT project on blazars.

After his retirement he extended his interests to history of astronomy. He is author or coauthor of more than 360 scientific papers.



Dr. Bruno Sacco was born in Palermo (Italy) in 1947 and has a Laurea in Physics from the University of Palermo with Livio Scarsi.

He was a scientist at CNR and worked in the data analysis of the European satellite COS-B for Gamma-ray astronomy. He participated to other experiments with balloons (FIGARO) and satellites (MECS on board Beppo-SAX satellite).

He was Director of the IFCAI-CNR in Palermo and continued to develop instrumentation for X-ray and Gamma-ray astronomy. In that period he played a manager role of the Italian CTA team and worked on the project ASTRI-Horn on Etna volcano, a prototype of small Cerenkov telescopes to support the CTA project. An array of ASTRI telescopes is now in operation at Teide Observatory (Canary, Spain).