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Scientific balloons: historical remarks

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Abstract. The paper is an overview of the Human attempt to fly, from the myth of Daedalus and his son Icarus to the first "aerostatic" experiment by Joseph-Michel and Jaques-Etienne Montgolfier. Then, via a jump of about 200 years, we arrive to the era of the modern stratospheric ballooning that, from the beginning of the last century, have provided a unique flight opportunity for aerospace experiments. In particular, the Italian scientific community has employed stratospheric balloons since the '50s for cosmic rays and high energy astrophysical experiments with initial launches performed from Cagliari Helmas Airport (Sardinia). More recently an almost ideal location was found in the area of Trapani-Milo (Sicily, Italy), were an old abandoned airport was refurbished to be used as a new launch site that became operative at the beginning of the '70s. Finally, we suggest a short reminiscence of the first transatlantic experiment carried out on August 1975 in collaboration between SAS-CNR (Italy) and NSBF-NASA (USA). The reason why the Long Duration Balloon has been recently re-oriented in a different direction is analysed and future perspectives discussed. Finally, the spirit of the balloon launch performed by the Groups lead by Edoardo Amaldi, Livio Scarsi and other Italian pioneers, with payloads looking like "refrigerators" weighting a few tens of kg is intact and the wide participation to the present Workshop is the clear demonstration.

Key words. Stratospheric Long Duration Balloon Experiments

1. Introduction

1.1. The mythology

The desire to fly and dominate the sky has always been a human ambition: the hope to be close to gods and divinities and to dominate the gravity was the stimulus for new, weird ideas. The first and most famous myth related to human flight capability is the one of Daedalus and his son Icarus.

The legend tells that King Minosse of Crete asked Daedalus to built a labyrinth to keep imprisoned the dangerous Minotaur, son of a divine Taurus and the nymph Pasifae, he received as a gift from Poseidon. Daedalus, the ideator and builder of the labyrinth, was then jailed in the knotty labyrinth with his son. They tried to escape from the only possible way out: the sky. They succeeded by building wings made out of plumes and wax but the arrogance and inexperience of the young Icarus brought him so close to the Sun that the wax melted and he free-fall into the sea and lost his life. More realistic attempts to fly small objects lighter than air were exploited by ancient Chinese astronomer and the idea to build "airship" lighter than air is clearly quite old. In the 1700 this idea become a real challenge for scientists with a common

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Fig. 1. Left: Icarus and Daedalus, Charles Paul Landon, 1799 (Muse des Beaux-Arts et de la Dentelle, Alençon). Right: The Minotaur, George Frederic Watts, 1885, (Tate Gallery, London)

starting point: to have an extremely efficient ”lighter-than-air bubble”, possibly carrying a proper ship underneath.

1.2. The invention of aerostats

Apparently, the first to design such a system was the Jesuit from Brescia, father Francesco Terzi Lana. In his book ”Prodromo dell'Arte Maestra”, among several appreciated theories in the field of biology, medicine, astronomy, chemistry, maths, geology, paint etc, he exposed a theory how to build flying machines. He properly started from the Archimedes principle that a body submersed in a fluid receives an up-thrust equal to the weight of the volume of the moved fluid. The basic concept, exposed in 1670, was that generating vacuum in a metallic sphere made out of several laminar copper pieces it would be possible to create a lift, due to the up-thrust induced by the external air, capable to carry into the sky a ship. Of course, he was smart enough to understand the difficulty to have a sphere so rigid to support the external air pressure and exposed his invention as a sort of weird scientific hypothesis or technical exercise. Apparently, he never built a demonstration model of his invention.

A few decades later, year 1709, the bizarre 'father' Bartolomeo Lorenzo de Gusmao was known to have deployed in space a quite big air ship, capable to carry about 10 people! The legend says the machine was able ”to fly” by means the combined use of a sail and wings. His capability to convince people, with negligible practical evidence, was so outstanding that the Portugal king released to him a full patent for the construction of the airship he invented: in a full monopoly situation. Of course, without having shown a single evidence of the capability of the device to float in the air. Incidentally, it was reported he demonstrated in the presence of the king Jean V the flight of a warm sphere (un globo, a sphere). There are also reports saying he was able to lift himself with the use of a 'globo' using a burning material he ignited personally. Nevertheless, none of the above is proven to be true. Mr. Tiberius Cavallo, born in Naples in 1749, member of the London Royal Society, after having studied the tractate titled ”Arte della Navigazione Aerea” (The Art of Aerial Navigation), published in 1755 by the Italian monk Giuseppe

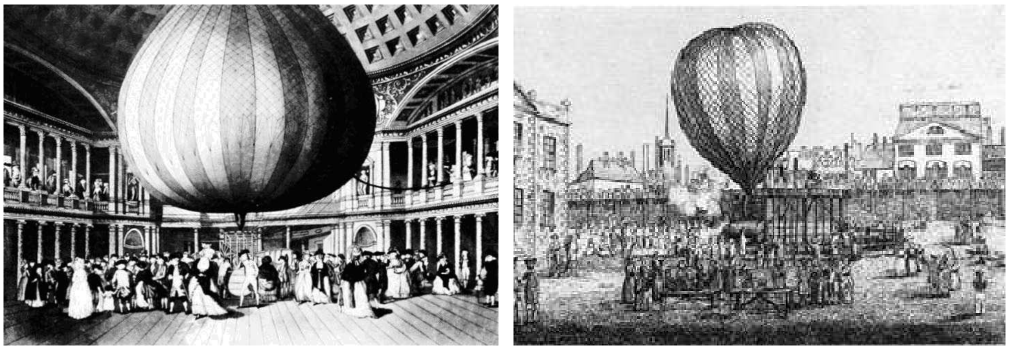

Fig. 2. Left: Vincenzo Lunardi's balloon exhibited at the Pantheon in Oxford Street, London circa 1783, Right: the Lunardi aerostat during filling procedures, 15 September 1784

Gallieno, devoted part of his research, mainly focused to the new discovery of the electricity, to demonstrate that a 'globe', filled with hydrogen would be able to fly. It is reported that in 1782 he was able to run in the laboratory an experiment to demonstrate that a small globe made out of the ox small-intestine was lifted in the air while filled with hydrogen. The publication of his study of the electricity and the high scientific reputation he had at international level made this report plausible. If this was the case, then his experiment was the first to show that a globe was able to float, anticipating of one year the famous hot-air Montgolfier brothers experiment.

The actual beginning of the human flight adventure is finally associated with the name of the two French brothers Joseph-Michel and Jaques-Etienne Montgolfier. In fact, in 1782 they flew the first silk, hot air filled, cube: it was considered at the beginning just a genial idea from two rich industrialist. Their demonstration was so astonishing for the audience and so successful that they decided to build a 30 meter almost spherical aerostat. They succeeded to have a take-off the 4th of June 1783 in the Annonay market square in front of the city political authorities. It reached an altitude estimated to be of the order of 2000 meters and flew for about 15 minutes over a path exceeding one km! It was the beginning of the scientific ballooning era.

They were so successful in the demonstration that were invited to repeat the experiment in front of the Royal Family the 19th September of the same year from the Chateaux de Versaille. The volume was now 1600 cubic meter and had a basked attached underneath the aerostat. The air ship carried one sheep, one duck and one chicken, reminiscent of the flight of the small dog Laika on the USSR sputnik.

Finally, after a number of experiments, the first human flight: the 21st of November the Doctor Pilatre de Rozier and the 'Nobil Homme' Francois Laurent d'Arlandes flew with a similar vehicle from the garden of the Castle de la Muette to Butte-aux-Cailles. The "Montgolfier", this was the common name used since then, was now 21 meter high and 14 meter wide. The hot air was continuously replaced into the globe by on-board burning carbon coke, the first propelled spacecraft.

The last pioneer worth to mention in this short paper is Vincenzo Lunardi, born in Lucca (Italy, 1759). In fact, he was the first person to successfully attempt an ascent in Britain, taking off in Moorfields (London). He was ambassador of the kingdom of Naples in England and the 15 September 1784, in the presence of Prince of Wales conducted his experiment. The Lunardi aerostat was 12 meters in diameter, with a volume of about 600 cubic meter, and was filled with hydrogen, more efficient than the hot air used by the brothers Montgolfier in their demonstration, though more difficult to produce and to handle: if compared with modern stratospheric balloons the pre-flight operations were very demanding. In fact, the fill-

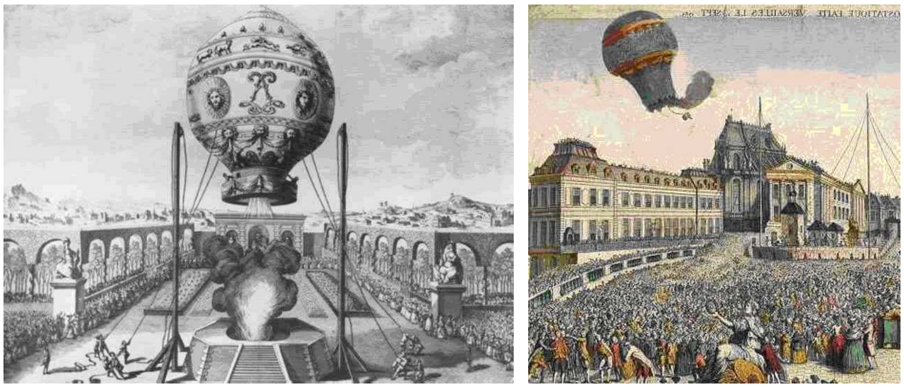

Fig. 3. The Montgolfier brothers hot air balloon in Paris: heating operations and flight

ing of the sphere, made out of oiled silk tissue, lasted the whole night before the launch. Responsible of the hydrogen filling operation was the chemist George Fordyce, that was also the designer and builder of the machinery to produce the hydrogen. Lunardi took off successfully late in the morning bringing with him one dog, one cat and one pigeon. They all landed safely after a more than two hours flight in a locality called Ware. He estimated the maximum altitude reached was exceeding 4 miles, though never demonstrated. The whole operation was a real success to worth, at the landing site, a breastplate with the following assessment:"Let posterity know, and knowing, be astonished, that on the fifteenth day of September, 1784, Vincent Lunardi of Lucca, in Tuscany, the first aerial traveller in Britain, mounting from the Artillery Ground in London, traversing the regions of the air for two hours and fifteen minutes, in this spot revisited the earth. On this rude monument for ages be recorded, that wondrous enterprise, successfully achieved by the powers of chemistry and the fortitude of man, that improvement in science, which the great Author of all knowledge, patronising by His providence the inventions of mankind, hath graciously permitted to their benefit and His own eternal glory".

1.3. The space and human flight era

Another fundamental step propaedeutic to scientific ballooning, boosted at the beginning by cosmic rays and high energy astrophysical studies, was, surprisingly, the human flight on board satellites and the associated rocket experiments and run to space done in full competition between USA and USSR. In fact, the 12 April 1961 the space era started with the flight of the first cosmonaut Yuri Gagarin, lasted 88 minutes, on board the Vostok I: a metallic sphere with a weight of about 4,7 ton. He will run a full orbit (apogee 302 km and perigee 175 km) at the speed exceeding 27.000 km/h. Two weeks later the satellite Explorer 11 is launched with a high energy detector on board: it will record the first 22 gamma-ray photons of extraterrestrial origin. Formally, Gamma-ray is born before X-ray astronomy. Seven days later Alan Shepard is the first USA astronaut to fly for a total of 15 minutes sub-orbital. In fact, the 5 May 1961, on board the Freedom 7, he was launched with a rocket type Redstone in a sub-orbital trajectory that reached the altitude of 116 miles.

The same days the President Kennedy says in front of the congress that he will commit himself "to achieve the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth". The rush to the Moon is started and in the next two years X and Gamma-Ray space astronomy will born and consolidate as a sort of spin-off or side effect. The 19th June 1962 at 6:59 UT an Aerobee 150 is launched from the Navy base of White Sands, New Mexico, with proportional counters on board, sensitive to X-rays. Bruno

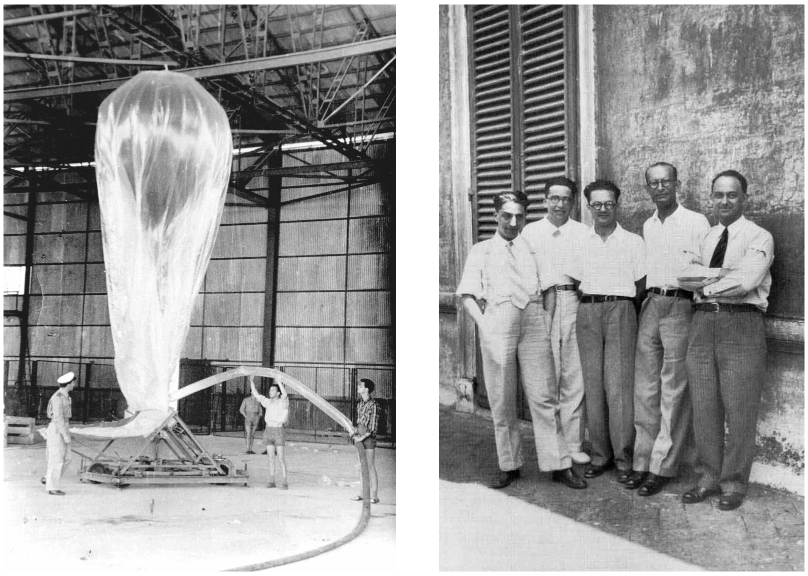

Fig. 4. Left: one of the first experiment carried out with stratospheric balloon in Italy is shown. The Balloon, with a volume of about 9,000 cubic meters, was launced from the Cagliari Elmas Airport (Sardinia, Italy). The experiment was designed and exploited under the lead of Prof. Edoardo Amaldi. Right: The group of the "Ragazzi di Via Panisperna": starting from the left: Oscar D'Agostino, Emilio Segre, Edoardo Amaldi, Franco Rasetti ed Enrico Fermi. The scientific objective was to study the production of "starge" particles in the atmosphere, by means the use of emulsions. The flight was successfully exploited in 1953.

Rossi and Riccardo Giacconi are the masterminds, the master being passed away when the latter one was awarded with the Nobel prize, almost 40 years later (2002), for they discovery of the X-ray sky.

Two years later, the 21st July 1964 Gamma-ray emission is discovered from the Crab Nebula and Pulsar with a scintillation detector based experiment on board a stratospheric balloon launched from the NASA Balloon Facility in Palestine, Texas. Scientific Stratospheric Balloons are finally established to be an efficient and reliable aerospace carrier.

2. The Trapani-Milo transatlantic balloon facility

With a jump of about 200 years we arrive now to the era of the modern stratospheric ballooning, that provide a unique flight opportunity for aerospace experiments from the beginning of the last century. Among the operative facilities worldwide, the Trapani-Milo launch site was operative since the beginning of the '70s.

The military airport, located in the area of Trapani-Milo, abandoned after the end of the world war II, was revived as a possible facility to perform scientific experiment at the beginning of the '70. One of the main scientist active to set up such a facility was Prof. Livio Scarsi, a mastermind in cosmic rays astrophysics, originating from Milan Laboratorio di Fisica Cosmica e Tecnologie Relative, headed by Beppo Occhialini. In the late 70s Prof. Scarsi moved in Palermo to lead a small Group active in high energy astrophysics with a particular interest in balloon experiments.

The stratospheric balloon facility was located in the area of "Punta Milo", close to the north-west coast of Sicily and was used to perform time to time scientific experiments. In fact, it was an ideal launch site in view of the vicinity of the old runway to the Mediterranean sea shore, with constant high altitude winds blowing in the summer period towards the

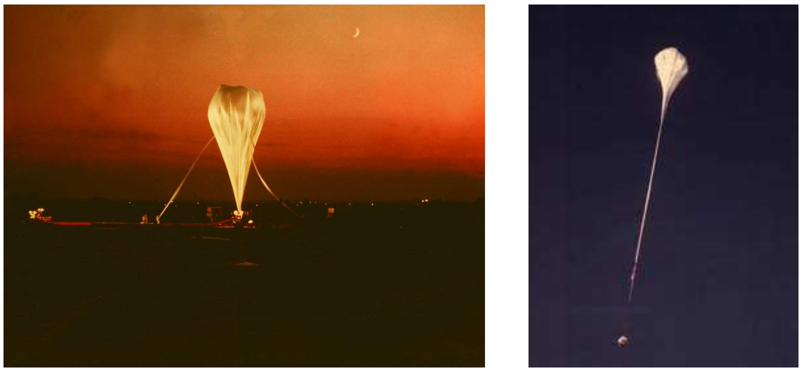

Fig. 5. Left: the first Italian transatlantic payload, launched August 5, 1976, at 5.05 UT. Right: the last balloon experiment in high energy astrophysics exploited by the Space Astrophysics Institute (IASF), launched from the Balloon Facility of Alice Spring (Australia), 17 May 1989, in the framework of the Supernova 87a NASA-ASI balloon campaign.

Sicilian channel, and easterly ground winds. Of particular value was the full time availability of the old airport infrastructures including a flat area to deploy and launch large volume balloons and old barracks to be used to store and integrate the payloads, the flight supporting hardware and to be used to host scientific teams for pre-launch payload calibrations, tests, pre-flight operations and in flight quick-look activity and experiment control.

Prof. Scandone, Director of the so called "Servizio Attivita' Spaziali" of the National Research Council, during 1972 agreed to reconvert the old Airoport, damaged by the allied bombardments, in the national site for balloon launches. A formal MOU was signed with NSBF-NASA (USA) for launch and recovery, with University of Southampton and Bristol (UK) and Appleton Labs (U.K.) for the payloads and data receiving systems, in order to provide a new launch facility across the Atlantic ocean (Malavasi, 1975). The goal was to achieve long duration flights, strongly requested by astrophysical experiment, mainly in the field of high energy and IR astronomy, cosmological studies and initial biological biomedicine experiment in space (Cecchini, Malavasi and Ubertini, 1978, Cecchini and Malavasi, 1978). A substantial number of experiments were initially proposed for payloads mainly dedicated to scientific research in the field of Cosmology, Infrared and Radio Astronomy, High Energy physics and Biological samples.

Since the beginning balloon experiments had been an invaluable test bench for new space technology, new cutting edge detector in flight test and in general to test the performance of new devices in an 'almost full' space environment at a very low cost and turn-around time frame.

At that time the main world wide available balloon launch site was the NSBF facility in Palestine, Texas, USA. The average flight duration was, in the period 1967-1976, of the order of 10-15 hours, with a few exception lasting 40-60 H (4 flights) up to 120 H (one in 1974). The main driver for transatlantic flight was the substantially longer and stable expected duration estimated to be 5-6 days during summer and winter season, with very stable high altitude winds and a reliability factor better than 85%. The latter was an important feature to have a predictable separation and recovery region on the US territory. An appealing feature was the capability of the modern 'open' balloons to carry payloads up to 2-3 tons at altitude above 38-42 km, with residual atmospheric pressure of 6 to 2 mBar, accessible to X-Ray investigations for cosmic sources. Another important feature was the lower cost/kg/hour, from 50 to 100 times less if compared, at that time, with the Space Shuttle.

Table 1. High Energy Astrophysics Balloon Experiments with the IASF participation in the time frame 1975-1991

Name	Energy Range	Main aim	Range	Launch	Note
HXR-76	Hard-X-Ray	AGN, Cosmic BGD	Trapani-Milo Italy/USA	1976	Transatlantic
HXR-79	Hard-X-Ray	Crab Nebula	Trapani-Milo, Italy	1979	TransMed.
TXT	Hard-X-Ray	Gamma ray bursts	Trapani-Milo, Italy	1978	TransMed.
HXR-80	Hard-X-Ray	Galactic Binaries	Trapani-Milo, Italy	1980	TransMed.
HXR 80-I	Hard-X-Ray	Her X-1	Hyderabad, India	1980	Turn around
TXT	Hard-X-Ray	Gamma ray bursts	Trapani-Milo, Italy	1981	TransMed.
HXR-81	Hard-X-Ray	Galactic Binaries	Trapani-Milo, Italy	1981	TransMed.
Minizebra	Soft Gamma Ray	Test Flight	Trapani-Milo, Italy	1981	TransMed.
FIGARO	Soft Gamma-Ray	Pulsar	Trapani-Milo,Italy	1982	TransMed.
Phoswich	Hard X-Ray	Binaries	Trapani-Milo,Italy	1982	TransMed.
FIGARO	Soft Gamma-Ray	Pulsar	Sao Manuel, Brasil	1983	Turn around, Free Fall
POKER83B	Hard X-Ray	Galactic Centre	Sao Manuel, Brasil	1983	Turn around, Ball. Fault
X-PALLAS 83	Hard X-Gamma	Cygnus X-1	Palestine Texas (USA)	1983	Turn around, Ball. Fault
POKER 84	Hard X-Ray	All Sky Survey	Trapani-Milo, Italy	1984	TransMed., Fault
GAMTEL	Soft Gamma-Ray	All Sky	Palestine Texas (USA)	1984	Turn around, Ball. Fault
X-PALLAS 84	Hard X-Gamma	Binaries	Palestine Texas (USA)	1984	Turn around, Ball. Fault
POKER 85	Hard X-Ray	All Sky Survey	Trapani-Milo, Italy	1985	TransMed.
X-PALLAS 85	Hard X-Gamma	Binaries	Palestine Texas (USA)	1985	Turn around, Ball. Fault
X-PALLAS 86	Hard X-Gamma	Cygnus X-1	Trapani-Milo, Italy	1986	TransMed., Ball. Fault
HIBAL 86	Hard X-Ray	Galactic Centre	Alice Spring, Australia	1986	Turn around, Free Fall
FIGARO	Soft Gamma-Ray	Pulsar	Trapani-Milo,Italy	1986	TransMed.
X-PALLAS 87	Hard X-Gamma	Extragalactic sources	Trapani-Milo, Italy	1987	TransMed.
Sugar	X-Gamma Ray	SN87a	Pocos de Caldos, Brasil	1987	Turn around
SN87a - I	HE X-Ray	Supernova 1987a	Alice Spring, Australia	1987	Turn around
SN87a -II	HE X-Ray	Supernova 1987a	Alice Spring, Australia	1988	Turn around
POKER 89	Hard X-Ray	Galactic Plane	Alice Spring, Australia	1989	Turn around
Lapex	Hard X-Ray	SN87a	Alice Spring, Australia	1989	Turn around
FIGARO	Soft Gamma-Ray	Pulsar	Trapani-Milo,Italy	1990	TransMed.
Blimp	Technological	INTEGRAL CsI test	Fort Sumner, New Mex. USA	1991	Turn around

The flight campaign started in 1975 with a precursor flight operated by a Italy-US crew: the Trapani-Milo ground operation crew and the launch team from NSBF-NASA. The payload had a total weight of 1500 kg out of which 750 of ballast and 500 kg of scientific experiments and flight services. The flight started the 5th of August and landed on the US east coast after a flight lasted 81 Hours (8,500 km path) at an altitude of about 40 km and was safely recovered. Two more flights were successfully performed during the 1976 campaign, lasting 70 and 104 hours respectively. All the exploited flights were not allowed, for safety reasons, to go across the US territory with the planned recovery on the east cost of US. Nowadays, it would be impossible at all even to imagine a 2-3 tons payload flying over New York City, as happened in the ’70s.

After the initial few successful transatlantic flights, exploited during 1975 and 1976, became clear the difficulty connected with the complex in flight operations and difficulty for the scientific data transmission to ground and telecommand uplink. The last attempt of a transatlantic flight, with a recovery path planned with termination over Spain, was exploited during the summer 1980. The flight, because of an on-board navigation and telemetry system failure, was terminated over Spain territory and the scientific payload (the HXR-80 Hard X-Ray Large Area Experiment) successfully recovered. In the meanwhile several trans-oceanic launches targeted to long duration were exploited by Italy, US and other countries.

A more easy and reliable operative scheme was found via the Italy-French-Spain agreement due to operate trans-mediterranean flights from Milo to Spain. Among them, from 1978 to 1995 regular flights exceeding the day duration were performed in the framework of the ODISSEA program jointly exploited by Italy, France and Spain. Several campaign with multiple flights (up to 6) were operated, during the summer period, taking advantage of the very stable stratospheric winds. More then 70 successful flights were performed from 1977 to 1992 with an average duration above one day.

In this framework several successful balloon experiment were exploited by the Istituto di Astrofisica Spaziale of Rome

Fig. 6. The payload of the 1976 Italian transatlantic experiment. The total weight was about 1500kg plus flight service module and ballast. The main experiment were from LAS-CNR (Rome), ITESRE-CNR (Bologna), IROE-CNR (Florence), IFCAI-CNR (Palermo) plus a few small piggy-bag. The man on top the crane arm is Dr. Marco Malavasi, at that time the Director of the Trapani-Milo Facility. The pink net, visible in the bottom part of the payload, is the virtual-ground of about 8 m diameter necessary to operate the HF transmitter during the flight (Courtesy of F. Giovannelli).

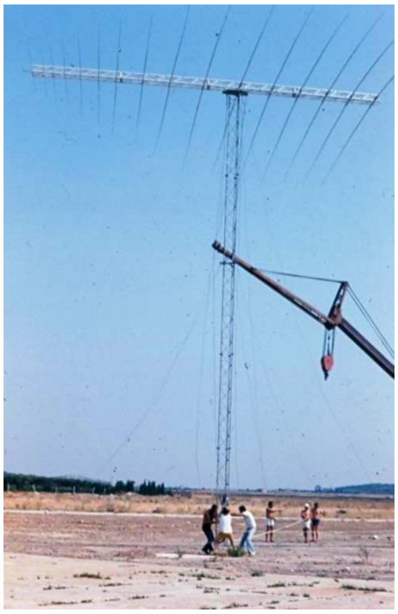

Fig. 7. The HF receiving antenna used for the low bit-rate scientific data transmission (100 bit/s). Courtesy of F. Giovannelli

(CNR), in collaboration with many others Italian Institutes, among them the Istituto di Fisica Cosmica of Milan, the Istituto TESRE of Bologna, the Istituto IFCAI of Palermo, and international Institutions such as Univerisity of Southampton and RAL (UK), TATA Institute (Bombay, India), Tubingen University (Germany), ADFA (Australia), CNES (France), INTA (Spain), etc. A summary table of the experiments carried out by IAS and collaborators is shown in Table I.

At the beginning of 1987, the explosion of the Supernova 87a triggered the interest of the high energy community to the southern hemisphere with NASA and several national agencies strongly supporting observational campaigns from southern sites located in Australia and Brazil. After this successful period the initial boost for balloon experiments was slowly lost, at least in the European community, mainly due to the large amount of outstanding data provided by in flight operation of new a generation of X-Gamma-Ray and IR satellites, releasing to the scientific community a large amount of data.

Last but not least the lower budget devoted to balloon experiment in view of the large national investments released to have large scientific satellites operative in space. Also, the budget to exploit new technologies and R&D was dimming out, at least in Italy.

Now the interest for long duration ballooning is ramping-up again with particular interest to the Artica and Antartica launch opportunity. The absence of the day/night effect, with the need to carry on-board a substantial amount of ballast, has removed one of the main limitation of traditional flights, and is a main plus of the long Polar night and day launch feature.

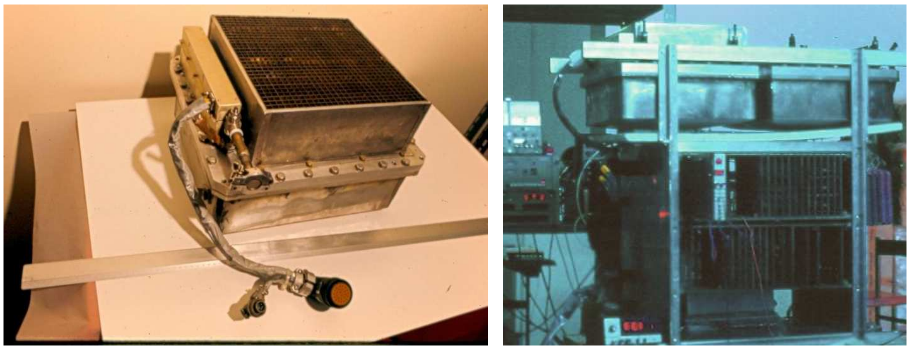

Fig. 8. Left: the HXR-76 high pressure multiwire proportional counter operative in the range 15-150 keV. Right: The HXR-76 LAS experiment, an array of two Hard-X ray MWPC. Courtesy of F. Giovannelli

3. Conclusions

Italy was one of the country to take advantage, since the beginning, of the use of stratospheric balloons for scientific experiments. Scientific ballooning has strongly contributed to the Italian exploitation of science programmes by providing significant scientific discoveries, an ideal training experience for young scientists and technologists and, finally, being a perfect test beds for new space instruments and technologies.

It is a common understanding that on the long run balloon borne instruments will continue to contribute to ASI science objectives, in the field of Infrared, Cosmic Microwave Background studies, High Energy Astrophysics, Earth Observation Science, Biology and Biophysics, Astroparticle, Planetary Science etc.

I wish to end this short overview with the recommendation of the 'ad hoc' NASA Scientific Ballooning Planning Team, chaired by Martin Israel, Washington University in St. Louis (NASA Stratospheric Balloons, Pioneers of Space Exploration and Research, Report Of The Scientific Ballooning Planning Team, October 2005):

"Finally, the Planning Team recognized exciting new possibilities for ballooning 10-30 years from now including flights of heavy instruments at 49 km (less than 0.1% of the atmosphere remaining above this altitude); advanced trajectory control permitting controlled balloon flight paths and large aerostats; and balloons capable of aerial investigating of Venus, Mars, and Titan." (Courtesy of NASA)

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