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SoRa first flight

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S. Pirrotta and E. Flamini

Italian Space Agency, viale Liegi 26, 00198, Roma, Italy,
e-mail: `assegnoricerca4.osu@est.asi.it`

Abstract. The SoRa (Sounding Radar) experiment was successfully launched from Longyearbyen (Svalbard, Norway) during the summer 2009 campaign managed by the Italian/Norwegian "Nobile Amundsen / Stratospheric Balloon Centre" (NA/SBC). SoRa is part of the Italian Space Agency (ASI) programs for Long Duration Balloon Flights. Carried by the biggest balloon (800.000 m^3) ever launched in polar regions, SoRa main experiment and its three piggyback payloads (DUSTER, ISA and SIDERALE) performed a nominal flight of almost 4 days over the North Sea and Greenland, until the separation, landing and recovery in Baffin Island (Canada). Despite the final destructive event that compromise the scientific main goal of SoRa, the 2009 ASI balloon campaign can be considered an important milestone, because of the obtained scientific and technical results but also for the lesson learned by the science, engineering and managerial teams looking at the future ASI scientific balloon-born activities.

Key words. Stratospheric balloon, sounding radar, comparative planetology

1. Introduction

The Italian Space Agency can boast a consolidated experience in space science performed through stratospheric balloon flights: the Trapani-Milo base and its specialized team, since the ́70 to the ́90 was the reference point of an intense activity for integration, testing and launch of balloons carrying different scientific instruments. About 70 flights were performed, mainly over Mediterranean sea; the italian launch team was also involved in several campaigns in USA, Brazil, Australia [(P. Ubertini 2008)]. Balloons are a test-bed for new space technologies, for astronomic or Earth observation from a privileged point of view and for performance evaluation of components in a space-representative environment; these goals can be obtained by balloons with a cheap, short and flexible approach. Among the others, the Arctic and Antarctic regions are very promising because of different advantages, primarily connected to the lack of the day/night cycle, that usually imposes a large amount of ballast availability for altitude control during long duration flights but also negatively affects the instruments' performances and operational features. Recently, ASI receipted the increase of interest in scientific community with respect to balloon-born space science and activated a long-term programme to ensure flight opportunities to selected payloads for different scientific and technological purposes. In par-

Send offprint requests to: S.Pirrotta

ticular, for long duration flights at high latitudes in North hemisphere, the Agency created the "Nobile Amundsen / Stratospheric Balloon Centre" (NA/SBC) in partnership with the Norwegian company Andoya Rocket Range (ARR), the University of Roma "La Sapienza" and the ISTAR US company. This launch site, used since 2003, can offer the typical advantages of polar flights, together with logistic good features: easy access for the teams and materials by civil airport and harbours, accommodations availability, regular seasonal winds to Greenland as a suitable site for payloads recovery [(S. Peterzen et al. 2008)]. The selected main payload for the Summer 2009 Launch Campaign was the SoRa (Sounding Radar) experiment, that can be considered as a perfect example of balloon use for comparative planetology devoted to Mars exploration [E. Flamini, S. Pirrotta (2008)]. In fact, it foresees a circumpolar flight at about 35 km altitude over glacial and periglacial regions for a sounding radar similar to SHARAD (SHAllow RADar), the Italian instrument on board of NASA Mars Reconnaissance Orbiter (MRO), in Mars orbit since 2006 and designed for subsurface exploration with high resolution. This radar, together with the other Italian lead radar MARSIS on board Mars Express ESA mission, are providing a huge amount of unique data of Mars first subsurface structure and composition including polar caps layering and total volume [Seu R. et al. (2007)]. The main scientific goals of the SoRa experiment are: the validation of the algorithms and data calibration of the sounding radars for planetary exploration and investigation of ice sheets over bedrock, permafrost areas, seasonally snow covered zones and maybe also sea ice for Earth modelling (the observed regions can be correctly considered as Terrestrial analogue of Martian polar morphologies, with similar geological structures) [G. Colombatti et al. (2007)]. For the development of this programme ASI experienced a very productive cooperation between its scientific unit OSU (Observation of the Universe), engaged with the development of the gondola payload, and the operative personnel of the TST (Ground segment and Operative bases) unit, involved in the preparation and launch and recovery activities within the NA/SBC team.

2. SoRa experiment design and development

The SoRa program started on December 2007 and it went on with design, simulation and part procurement until final integration and testing at ASI Trapani facility during 2008 Spring. The combined scientific team, composed by IRSPS (International Research School of Planetary Science) geologists, INFOCOM Department of the "Sapienza University" of Rome and TASI (Thales Alenia Space Italia) - CORISTA (Consorzio di Ricerca su Sistemi di Telesensori Avanzati) radar experts defined the functional requirements as: flight over periglacial terrains >24 h, flight altitude (initially settled at 34±2 km, then modified to 38±2 km because of buoyancy stability needs), nadir pointing angle antenna (±10°), radar autonomy. The consequent system requirement for gondola design, under the responsibility of the prime contractor CISAS (Centro Interdipartimentale Studi e Attivit Spaziali "G. Colombo") of the University of Padua, were: power = 200 W (peak 500 W), pressurized buoyant gondola with pressure gradient (in/out gondola) = 30 mbar, active thermal control (only heating), remote control with partial on board autonomy (i.e. logic for on/off radar switching), maximum bit rate = 240 bytes/s (nominal = 170 bytes/s), on board memory = 32 GB. The launch campaign, originally foreseen in June 2008, was postponed to summer 2009 because of delays in organization and adverse meteorological conditions. During the further 12 months, a review of the design was performed; the general architecture was confirmed and some improvements and test activities were evaluated and introduced. During the whole design phase, the main topics were:

- data handling and communications: the size of each radargram file makes the total amount of the acquired data not suitable to be transmitted to ground stations, nor by the IRIASI system (selected as baseline) neither by the L band based IRILASI one.

Hence, the storage was arranged on board, in a pull-out memory module, accessible through a dedicated access door;
- the high priority of the recovery imposes requirements as localization systems (GPS, beacon radio), a watertight gondola whose internal pressure is passively regulated by differential valves;
- parachute separation device: in order to avoid dragging after landing by strong arctic winds, an electromechanical device was asked as additional equipment to cut the parachute chain after the impact on the ground; no off-the-shelf system was suitable, so a breadboard was asked to be developed together with the gondola by the SoRa team.

The operational functionalities were tested in Padua on February 2009, when the radar was controller by gondola CMDU in low pressure (10 mbar) and temperature conditions. The monitoring of components temperature indicated an unpredicted higher temperature on few components; the consequent recovery action was implemented by passive cooling system. The final integration and interface test campaign was successfully completed at the Trapani ASI facility on March 2009.

3. Svalbard launch campaign (summer 2009)

The preparation for the 2009 summer Launch Campaign from NA/SBC site in Longyearbyen was an intensive activity performed during spring 2009: the consumable materials (helium, ballast) were procured, the machines adapted and the shipment was arranged. On late April The NA/SBC steering committee completely defined the managerial aspects and prepared an Operation Plan. The Flight Application Forms were accepted for SoRa and three piggyback payloads: DUSTER (Dust from the Upper Stratosphere Tracking Experiment and Return) developed by Parthenope University of Naples for dust collection; SIDERALE (Sistema Integrato Di Elaborazione e Rivelazione per ALte Energie) developed by INAF-IASF in Milan for cosmologic observation and evaluation of radiation effects on electronics; ISA (Italian Spring Accelerometer) of the INAF-IFSI as breadboard of the high sensitivity accelerometer included in the BepiColombo. Moreover, the SIDERALE system included the advanced SIT telemetry developed by the LEN company. The technical interface aspects were discussed and defined among the teams with the ASI supervision. The Launch Campaign started on 27th May 2009, with the scientific and launch teams joining at the facility within Longyearbyen airport area. The main phases and event of the campaign are summarized in the Table 1; final integration activities include mechanical (gondola radar, power, sensors, CDMU subsystems assembly, piggyback interfaces definition and implementation, ballast release system setting, telemetry antennas installation) and electrical ones (connectors definition, power system functional testing, radar-CDMU and CDMU-IRIASI telemetry interfaces verification, onboard and ground software testing and long functional simulation). The SoRa system was then integrated with piggyback PLs and with the breadboard of Parachute Release system; anyway, this nice-to-have device was not considered fully-qualified, so was included in disarmed configuration in order to test the capability of the electronic sub-system to properly survive and operate in the environmental condition of the flight. On 7th June the SoRa gondola was formally accepted by ASI and made available to NA/SBC launch team for integrated test with complete flight chain, suspended at the launch crane head (Figure 1); finally, since 12th June the system was ready for the flight. Unfortunately the adverse weather conditions jointly with the restrictive operative constrains (narrow launch runway close to airplanes ones, matching with airlines timetables) and impose a 19 days-long waiting, before the launch, performed on 1st July (Figure 2). The flight, whose phases are summarized in Table 2 and Figure 3, took place in nominal conditions: the altitude, controlled by ballast dump and gas leakage, was maintained within functional limits; the trajectory followed the numerically predicted one, especially during the early phase. After about one day, the latitude

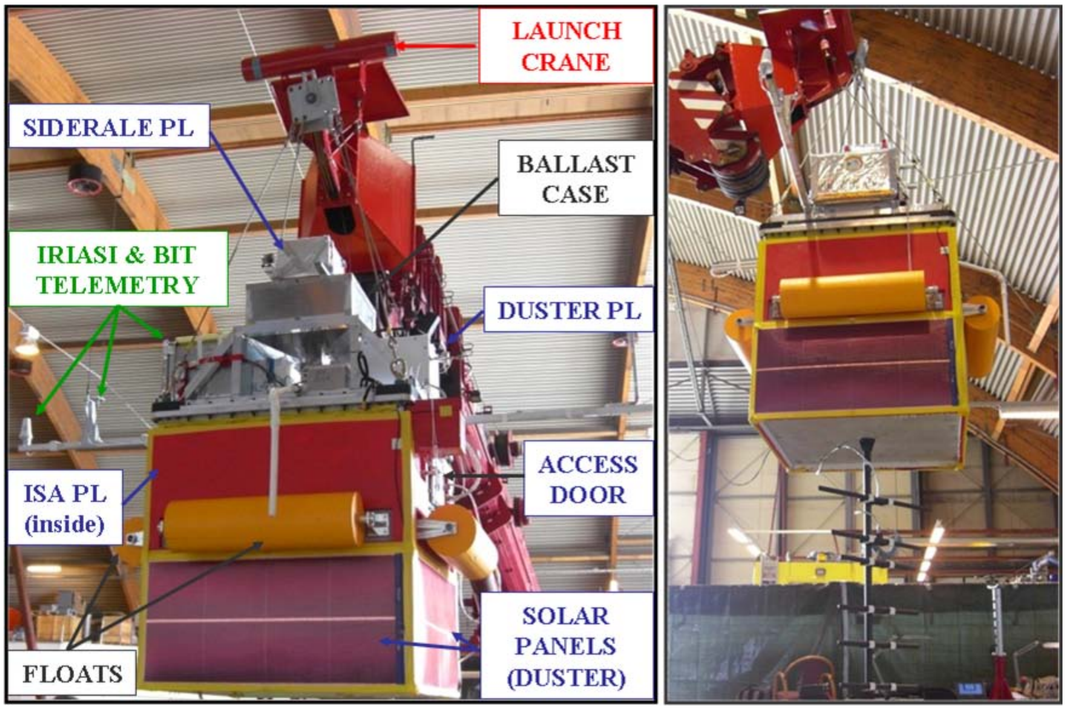

Fig. 1. The SoRa gondola in final configuration, ready for flight chain integration

Fig. 2. SoRa '09 launch

gradually decreased more than expected because of winds direction. During the flight, different functional and environmental parameters of the SoRa payload were monitored by:

Table 1. Launch Campaign Summary

Date	Time	Event
29 May 2009		Beginning of payloads integration activities
7 June 2009		Formal delivery of the gondola to ASI
10 June 2009		Payload check-out success full completed
11 June 2009		Gondola hang test on launch spool machine
12 June 2009		Final integration of launch chain
12 - 31 June 2009		Waiting time for favourable meteorological conditions
01 July 2009	00:30	Balloon launch from Longyearbyen
04 July 2009	10:30	Descending phase until landing in Baffin Island
04 July 2009	12:40	Last signal received from SoRa CDMU
07 July 2009	00:20	Last signal received from piggyback payload DUSTER
09 July 2009		First team personnel reaching landing site
20 July 2009		Beginning of recovery activities

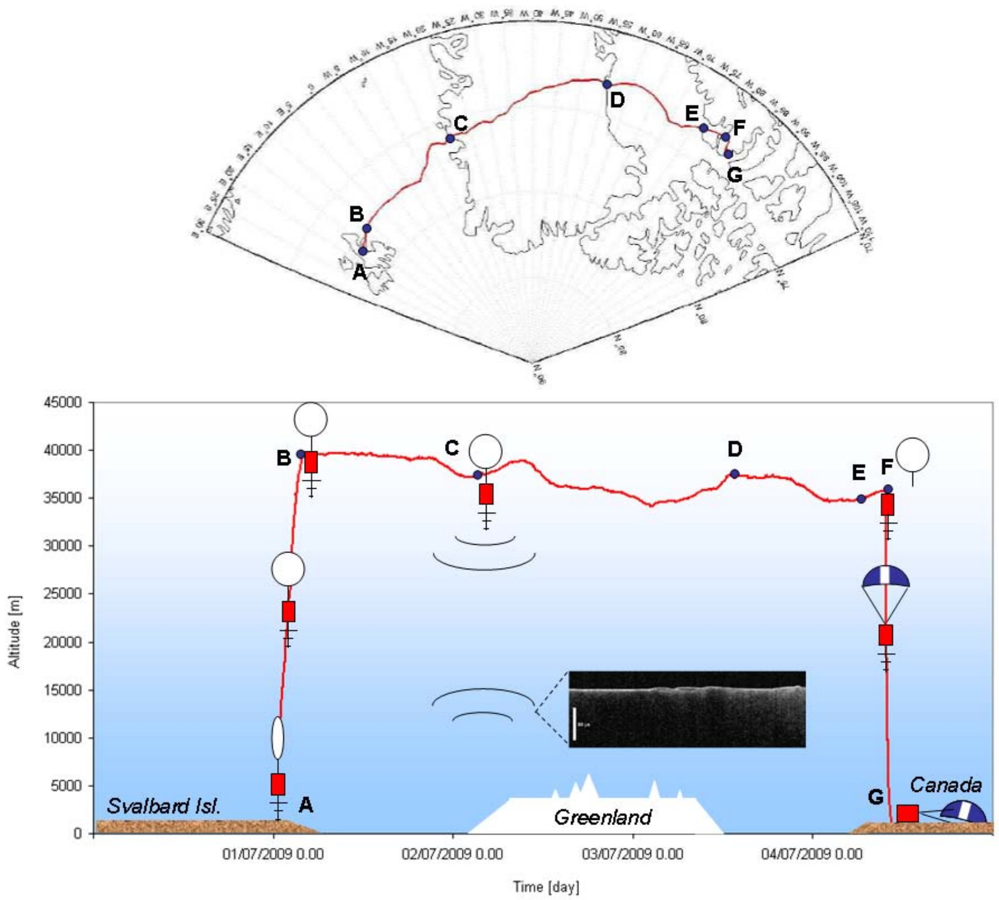

Fig. 3. Ground trajectory and altitude of SoRa 2009 flight (IRIASI data)

Table 2. SoRa '09 Flight Timetable summary (related to Figure 3)

Date	Duration	Event
01 July 2009 00:30 (A)		Balloon launch from Longyearbyen
01 July 2009 00:30 (A) - 01 July 2009 04:30 (B)	4 hours	Ascending phase
01 July 2009 04:30 (B) - 02 July 2009 01:00 (C)	20,5 hours	Flight time over North Sea (Radar in-flight health check and calibration)
02 July 2009 01:00 (C) - 03 July 2009 12:00 (D)	35 hours	Flight time over Greenland (Radar operations)
03 July 2009 12:00 (D) - 04 July 2009 04:30 (E)	16,5 hours	Flight time over Labrador Sea - Baffin Bay
04 July 2009 04:30 (E) - 04 July 2009 09:45 (F)	5,25 hours	Flight time over Baffin Island (Canada) until separation (F)
04 July 2009 09:45 (F) - 04 July 2009 10:30 (G)	0,45 hours	Descending phase until landing in Baffin Island (G)

six thermocouples (glued on camera box, battery plate, radar radiator, diode, CDMU plate, pc104 DC/DC converter respectively), batteries voltage level indicators, IMU for gondola dynamics, magnetometer, GPS, external videocamera. The adopted IRIASI telemetry system efficiently worked for the control of balloon flight, while showed reduced performances for the transmission of environmental scientific data as requested by the experiment. Upon completion of the operative phase over Greenland and taking into account the observed trajectory (mainly the latitude lower than predicted), it was decided to let the balloon fly until Baffin Island for the recovery, because of the proximity of more suitable logistic infrastructures. Hence, the gondola was separated form the balloon and it descended by parachute at the predicted velocity, measured as about 5 m/s in the final stage. The gondola landed at 10:30 of 4th July 2009 on a rocky terrain in Baffin island; the telemetry signals of IMU showed a high lateral inclination, while the temperatures and the battery pack voltage were at normal values. The SoRa system was switched off two hours after landing; on the contrary, DUSTER was autonomously managed and continued functioning about two days more. Nevertheless, the recovery activities practically started on 20th July, with a long delay especially caused by the modification of the landing site and the consequent need for new organization. When on site, the recovery team found the SoRa payload burnt in fire; it was probably originated in the lithium battery pack, damaged after the landing when the gondola, still attached to the parachute, was dragged on the terrain. In fact, the presence of gondola's debris in a wide area (about 260 meters long) indicated that the parachute, driven by extraordinarily strong winds, strongly pulled the gondola on the craggy landing site. The only instruments not burnt by the fire were the external ones (DUSTER and SIDERALE), that were recovered and sent back to Italy for the subsequent data analyses, now in progress.

4. Conclusions

The SoRa first flight from Longyearbyen (Svalbard, Norway) in early July 2009, notwithstanding the disruptive events after landing that caused the lost of several payloads and data, can be consider as a successful experience for the Italian Space Agency and its new balloon programme. Anyway, the collected data and the post-flight analyses suggested several technical improvements as: the increase of safety levels of the whole gondola especially for batteries isolation and data memories protection; the adoption of a qualified parachute separation device; the improvement of performances of the telemetry dedicated to scientific data; the optimization of thermal control by the adoption of heating and cooling active systems. Different lessons were also learned about the campaign organization and running by the operative team, so that the future launch balloon activities will be further optimized. Moreover, the usual approach for scientific balloon management was for the first time replaced with a more systematic one, derived from satellite development programs. The whole experience of the launch campaign 2009 represents the first significant step for an Arctic regular balloon activity that ASI intends to guarantee to the national space scientific community and open to international partners.

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