TITLE: # AtmoCube Proposal

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ANNEX DOCUMENTS

AN1	Curriculum Vitae of AtmoCube Key Persons
AN2	List of Thesis
AN3	Technical details of the AtmoCube Systems and Sub-systems
AN4	Bibliography
AN5	Letter of Commitments

ACRONYMS LIST

ADT	AtmoCube Development Team
AS	AtmoCube Scientist
COTS	Commercial Off The Shelf
DEEI	Dipartimento di Elettrotecnica, Elettronica e Informatica
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
ESWW	European Space Weather Week
EVB	Evaluation Board
GENSO	Global Educational Network for Satellite Operations
GS	Ground Station
GSS	Ground Station Server
HK	House Keeping
INAF	Istituto Nazionale di AstroFisica
INFN	Istituto Nazionale di Fisica Nucleare
MCC	Mission Control Client
MED	Mechanical Engineering Department
MOC	Mission Operations Centre
MPPT	Maximum Power Point Tracking
OATS	INAF - Osservatorio Astronomico di Trieste
OBDH	On Board Data Handling
PI	Principal Investigator
PM	Product Manager
S/C	Spacecraft
SC	Steering Committee
SDD	Silicon Drift Detector
SEU	Single Event Upset
SW	Space Weather
SWENET	Space Weather European NETwork - ESA
TM	Telemetry
TS	Trieste
TTC	Telemetry, Tracking and Command
WBS	Work Breakdown Structure

TABLE OF CONTENTS

1 THE ATMOCUBE MISSION

This document is the AtmoCube mission proposal. It gives a description of the scientific case, the baseline design and development status of the instrument, both from the technical and economical point of view. All the technical details are given in the annex document [AN-3].

AtmoCube represents an innovative measurement system to study the near Earth space environment above 350 km altitude. It appears as a cubic nano-satellite, 10 cm side, with a total mass less than 1 kg (aluminum structure). This project is being carried on by a cooperation between the Department of Physics, the DEEI (Dept. of Electronics) and the MED (Mech. Eng. Dept) of the University of Trieste. The scientific instrument is a silicon detector capable to monitor the radiation environment. The main goal is to build a map of the radiation's flux impinging on the instrument. The payload also includes a magnetometer and a GPS. The magnetometer provides measurements of the Earth magnetic field which are related to the Space Weather effects. The GPS allows to correlate the measurements performed by AtmoCube with those performed on Earth and from the Space. This will connect AtmoCube measures with the indexes of the Solar activity. In addition, orbital parameters obtained from GPS are used to estimate the atmospheric density. A continuous measurement along the satellite orbit provides a global atmospheric coverage and gives the possibility to analyze the correlation among the three main systems that characterize the Earth: the Sun and Solar activity, the Earth atmosphere and the terrestrial environment. Moreover the proposed detector, developed within the INFN, is supposed to fly on board future space missions dedicated to cosmic rays studies. Its use in AtmoCube can be considered an important test bench for the future utilization of the detector in space.

It has been decided to use the CubeSat international platform, a "quasi-standard" structure that allows to start from well consolidated bases. The power required for the operations is given by solar cells and by a battery. The satellite is equipped with a mechanism of passive stabilization (magnetic torque) in order to expose the antenna towards the Ground Station located in Trieste. Voltage, temperature and light sensors are used to control the instrument and S/C state. AtmoCube is equipped with a processor capable of controlling communications in the radio amateur bands.

According to the VEGA launcher specifications, the orbit will be elliptical, between 350 and 1,200 km and 71^{o} inclination. Eventually, also a circular orbit at 350 km altitude can be considered as favourable but this will cancel out the atmospheric density measurement. The satellite lifetime varies according to the solar activity, with a minimum value of about half a year. Ad-hoc shielding of instrumentation and electronics will be eventually implemented after a detailed environmental study if it will turn out to be necessary to improve the instrumental lifetime (see Par. 3.3.4). Measurements will be performed during the whole life of the satellite for a complete coverage of the Earth atmosphere.

The project has a strong educational interest. The University and the other institutions with their infrastructures (laboratories, mechanical and electronics workshops) and the students that will improve their scientific and technical knowledge and capabilities, are supporting the project. Due to the involvement of the Departments of Physics, Electronics and Mechanical Engineering of the University of Trieste, of INFN (Istituto Nazionale di Fisica Nucleare) and INAF (Istituto Nazionale di AstroFisica), AtmoCube has also a strong scientific content that allows an even more interested involvement of students. In addition, the technical group is supported by a group of small industries (ENTEOS, ELCON, ELIMOS, SCEN, and SICOM).

An agile mission as AtmoCube, both for the reduced development phases and the interchanging instrumentation that can be accommodated on board, can be considered as a precursor of a series of small scientific missions for the analysis of the Earth atmosphere at very low costs. AtmoCube can play a pioneering role in the low-cost probes of the Sun-Atmosphere-Earth system which would help in the "Space Weather" forecast. ESA is elsewhere active in space weather applications and the AtmoCube team would seek to maintain exchange with the SWENET service network in terms of data and/or space weather products.

2 THE ATMOCUBE SCIENTIFIC CASE

The Earth's magnetosphere and atmosphere respond to external perturbations originated by the Sun as well as by astrophysical sources located outside the solar system. The geomagnetic topology the chemical and thermal balance of the atmosphere can change at different time scales due to naturally-occurring and/or human-induced changes to the energy balance within each region of such physical systems and sub-systems of the atmosphere. With society becoming increasingly dependent on satellite technology and communications, it is vital to understand the physical dynamics that characterize them. Hence a comprehensive study of the atmosphere as an integrated system can help the space community to predict the effects on communications, satellite tracking, spacecraft lifetimes and on spacecraft re-entering Earth's atmosphere.

2.1 Solar Weather

The primary driver of space weather is the solar weather, characterized by the presence of active regions, acting as magnetic energy reservoirs, and their intrinsic instability which leads to energy release e.g. in flares, resulting in energetic particle acceleration, broad-band electromagnetic emission and, sometimes, in plasmoid formation (Coronal Mass Ejections, CME). Both the particle and the photon components of solar flares are geoeffective, i.e., they both interact with the magnetosphere and atmosphere. Consequently, the detection of flare-originated photons, especially in the X, EUV and UV bands, and the detection of energetic particles in the Earth's radiation environment are fundamental diagnostics for space weather applications in providing proxies of the magnetospheric and atmospheric responses to solar weather perturbations. Typically, solar flares detection from space is routinary carried out in the Soft X-Ray band (SXR: 0.1-0.8 nm) and the standard flare classification is based on the SXR peak flux density.

2.1.1 Radiation Environment Probing

Earth's atmosphere and magnetosphere allow adequate protection of the humans on the ground, but astronauts in space are subject to potentially lethal doses of radiation. The interaction of high-energy particles with living cells, measured as radiation dose leads to chromosome damage and, potentially, cancer. Large doses can be fatal immediately; solar protons with energies greater than 30 MeV are particularly hazardous. Spacecrafts are severly affected by energetic particles that cause e.g. internal charging and electronics failure, SEU, disorientation and deterioration of surface materials and solar panels. Radiation risk estimations at altitudes around 350÷600 km appears to be one of the basic scientific problem in the planning and design of manned and automatic missions. Sample diffuse and event-related X-ray and proton fluxes are reported in annex 3.1.
The AtmoCube Silicon detector (see Par. 3.3.1) will be able to sample both particles and photons in selected energy sub-bands at a wide range of altitudes ranging from about 350 to 1,200 km. In principle this should allow both flare effects detection and Earth inner radiation environment mapping.

2.1.2 Magnetic Field Probing

There is a growing body of evidence that changes in the geomagnetic field affect biological systems. Studies indicate that physically stressed human biological systems may respond to fluctuations in the geomagnetic field. Interest and concern in this subject have led the Union of Radio Science International (URSI) to create a new commission entitled Electromagnetics in Biology and Medicine. Astronauts on extra-vehicular activities can be more subject to such an effect when crossing the magnetic field lines along e.g. the ISS orbits. The typical models (Olson-Pfitzer, Tsyganenko) used to derive the geomagnetic field at low altitudes assume a quasi-symmetric dipolar field configuration and minor changes in association with Sun-driven perturbations. Hence a detailed dynamical measurement of the geomagnetic field at low altitudes has the goal of identifying its variability in time and space due both to the change in location of the probe and to solar/magnetospheric perturbations.

The variations of the Earth magnetic field have been analysed using different models. By changing the orbital parameters, all the relevant magnetic field effects, due to the geometry of the field, to the Solar activity, day-night, seasonal and annual variations, have been evaluated. Details are reported in annex 3.1. The major differences along the orbit are due to the magnetic field asymmetry with respect to the Earth rotation axis. On the other hand, the variation is of the order of 0.15% for both day/night and seasonal effects while is of the order of 0.5% due to the Sun conditions.

2.1.3 Atmospheric Density Measurement

The atmosphere extends tens of thousands of kilometers out into space. At the height of the lowest satellite orbits the atmosphere is extremely thin and rarefied, but the collision of a satellite with that few air molecules gradually slow down and perturbs the satellite orbital dynamics. Low Earth Orbiting satellites experience orbital decay and have physical lifetimes determined by their interaction with the residual atmosphere. Prediction of such lifetimes or of a re-entry date is of great interest to satellite planners, users, trackers.

Atmospheric drag models commonly in use (MSIS, DTM) suffer from incomplete global coverage, long time constants requiring a great deal of averaging and aliasing from other un-modeled non-conservative forces. The main obstacle is the inability to distinguish enough precisely between spatial and temporal scales on which key processes occur, and to establish the cross-scale relationships among small, meso, and large-scale phenomena. Without understanding these phenomena it will be impossible to improve the existing models adopted for Space Weather prediction.

Atmospheric drag can be modeled as an acceleration a_{drag} acting in the opposite direction of spacecraft motion. It depends on S/C characteristics (drag coefficient, surface area, mass) and altitude (velocity, air density) and causes a change of semi-major axis Δa and of eccentricity Δe. Note that for an elliptical orbit (as for AtmoCube), the change in the semi-major axis is felt at the apogee whereas the perigee altitude is about constant. According to the solar conditions, these perturbations applied to the AtmoCube case are reported in the table below.

Variable	Solar minimum	Solar average	Solar maximum
a_{drag} (m.s-2)	-2.9×10^{-6}	-8.8×10^{-6}	-2.1×10^{-5}
Δa (m /revolution)	-4.9	-14.5	-34.6
Δe (/revolution)	-6.1×10^{-7}	-1.8×10^{-6}	-4.3×10^{-6}

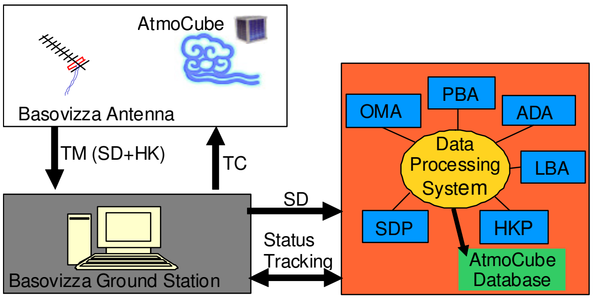
Air density can be recovered by comparing satellite predicted position, obtained from specific propagation software, with satellite measured position given by the on-board GPS. The main difficulties in applying this method are on one side the other orbital perturbations acting on the satellite that should be disentangled, on the other one the knowledge of the drag coefficient, that however, due to the simple cubic form of AtmoCube, can be evaluated. Air density could be estimated directly measuring the drag acceleration term with an accelerometer, but commercial accelerometers can only reach an accuracy of the order of 10^{-3} m/s^2 that is not enough for such purposes.

2.2 Data Analysis Architecture

The ground station (see Par. 5.2) is located at the Astronomical Observatory in Basovizza (Trieste) (45°38' N 13°52' E), where equipment is available. Data packets containing scientific and housekeeping information are downloaded from satellite. In Basovizza GS, HK data are decoded and eventually displayed in real time for a quick check of satellite functionality. All data are sent to the processing facility to analyze and store them. Scientific data are then unpacked, decoded, physical values are produced and stored in the database in text format on a dedicated web site, in order to make data available also from different location. All software for data decoding, real time display (control) and analysis will be developed in IDL, C++ and Matlab languages. A scheme of the data architecture is given in Figure 2.2-1.

The INFN-TS has great computational capabilities, see [AN-1]. A first agreement with INFN-TS has been already given informally (see INFN letter of commitment).

Both University and High-school students can play an important role in the data analysis of Space Weather data thus giving them and to the whole community a new concept of the Space Environment (see also Par. 10).



HKP housekeeping processing
SDP scientific data processing
PBA power budget analysis
ADA attitude determination analysis
LBA link budget analysis
OMA orbit model analysis

Figure 2.2-1 Data analysis architecture

3 ATMOCUBE DESCRIPTION

3.1 AtmoCube System

The block diagram of the AtmoCube system is given in Figure 3.1-1.

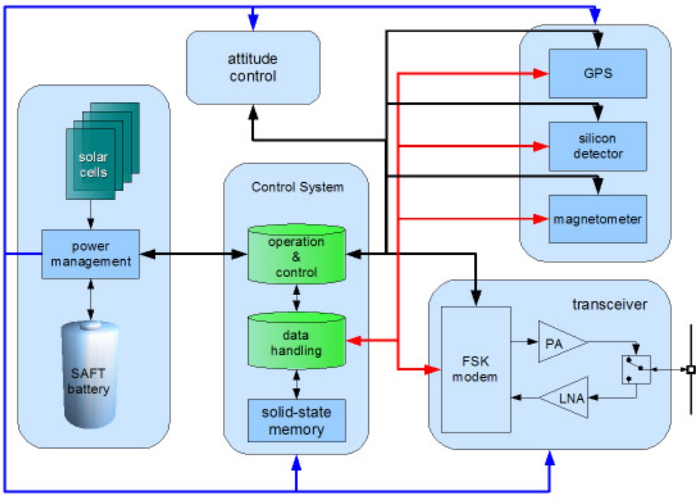


Figure 3.1-1 Block diagram of the AtmoCube system

3.2 AtmoCube Structure

The AtmoCube structure is compliant with the Cubesat requirements. AtmoCube will undergo several numerical simulations and experimental tests. For what concerns numerical simulations, that are already in the pipeline, the main efforts are focused on several objectives, mainly the minimisation of the total mass, of deformation and stresses at the prescribed loading conditions and the maximisation of the first natural frequency (that represents the basic calculation for each structure built to flight in space). The design variables, due to the dimensions constraints, are mostly linked to the satellite sides machining to save weight, accommodate the solar cells and the GPS antenna. Some other variables are linked to the positioning of the satellite's electronics, battery pack and magnets for the system orientation. One of the final designs is presented in Figure 3.2-1 where also the coordinate reference system is shown.
As it can be seen, the inner structure contains five boards dedicated to (from the bottom): 1. RF board, 2. power supply, 3. battery and magnetometer, 4. OBDH, 5. silicon detector and GPS board. The TTC antenna will be located outside on the bottom part and the GPS antenna on the top. The top panel is thinned in order to leave space for the GPS antenna and in correspondence of the silicon detector to avoid blocking the impinging radiation. A very first structure mock-up has already been produced by the INFN mechanical workshop as shown in Figure 3.2-1.
The system has been designed to be compatible with P-POD requirements but the design can be still modified to be adapted to a similar deployment system.

AtmoCube will be tested according to the requirement of the Vega launcher in order to asses that the item perform satisfactorily in the intended environment with sufficient design margins. The satellite will be tested as described by the document "Vega Programme – Qualification and Acceptance Test of

Equipment" with sweep sine, random and transportation vibration tests along the three axis within the Mechanical Engineering Department facilities or in affiliate labs according to the test requirements.

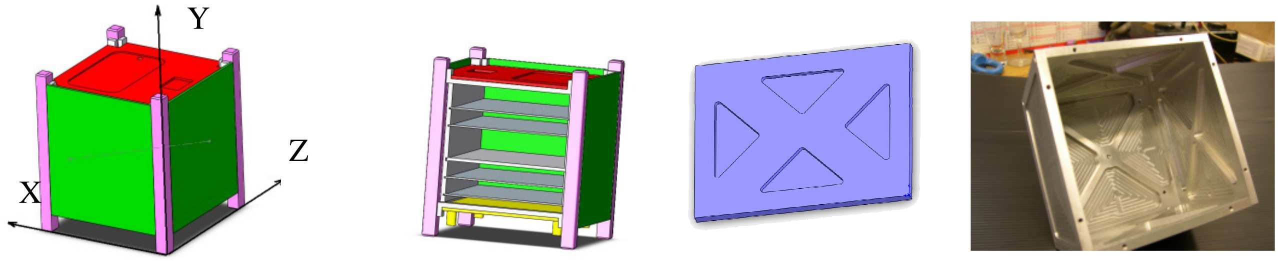


Figure 3.2-1 The technical design of AtmoCube from different views and the mock up

From the thermal point of view, preliminary simulations have shown, for the expected elliptical orbit, an average temperature of 250 K with a day/night variation of +/- 20 K, which are acceptable for the on-board electronics and the high-quality battery. Further testing is foreseen for the evaluation of the thermal behaviour of the satellite along the orbit (see annex 3.2).

3.2.1 Mass And Geometrical Properties

Mass estimation of the AtmoCube structure (battery and boards included) is 596.6 g. The total mass, instrumentation and cables included, is below the maximum limit of 1 kg.

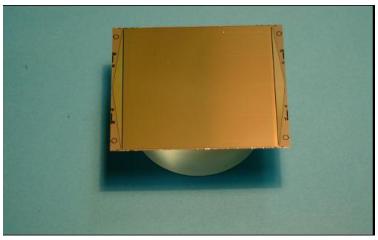
Variable	X	Y	Z
centre of mass (mm)	49.83	57.34	49.73
centre of geometry (mm)	50.00	61.50	50.00
Principal inertia axes	(1.00, -0.02, -0.00)	(-0.00, -0.01, -1.00)	(0.02, 1.00, -0.01)
Principal moment ($g{\cdot}mm^2$) $\times 10^6$	1.2132	1.3196	1.4659
Moment of inertia ($g{\cdot}mm^2$) $\times 10^6$	1.2132 -0.0039 -0.0003	-0.0039 1.4659 0.0007	-0.0003 0.0007 1.3196

3.3 AtmoCube Instrumentation

The AtmoCube instrumentation consists of a silicon detector, a magnetometer and a GPS, described below. Housekeeping sensors and photodiodes are COTS devices and are not detailed here.

3.3.1 Silicon Detector

The detector used is a Silicon Drift Detector (SDD), realized on high-resistivity n-doped silicon substrate, having a surface of ~2 cm^2 and a thickness of 300 μm. The SDD is particularly suited for low-noise spectroscopy, given its working principle based on the "transverse depletion" concept, i.e. the possibility to deplete a large silicon wafer (e.g. n type) via a small n+ electrode (the anode) that is positively biased with respect to a set of p+ diodes (field electrodes or cathodes) placed on both surfaces of the wafer. The small dimensions of the collecting electrode ensure low capacitance and hence low noise and good energy resolution. The measurement energy range extends up to 70 keV. The expected rate of events due to charged particles is of the order of 4 Hz at poles. See annex 3.3 for a detailed description of the SDD and the read out electronics. A picture of the SDD and its schematic working principle is given in Figure 3.3-1.



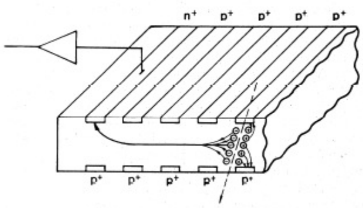


Figure 3.3-1 An SDD developed for the ALICE at LHC (left) and a schema of the charge transport in a SDD (right)

The SDD sensor and the read-out electronics are both mounted onto an ad hoc designed printed circuit board, fitting the available space inside the satellite. The estimated power consumption of the complete read-out electronics is of the order of 0.4 W. Tests are going on the detector and the read-out

electronics which are under development at INFN laboratories and should be ready for EVB integration by July 2008.
Note that this will be the first time a Silicon Drift Detector will be used in the space and thus it could be considered a very important possibility to test its behaviour on board a space mission.

3.3.2 Magnetometer

The instrument chosen to measure the local magnetic field is the Honeywell HMC2003 magnetometer. This is a COTS device and it has been already tested, see details in annex 3.4. The sensor has a sensitivity of the order of $4 \cdot 10^{-10}$ T along the three axes; this would allow to measure Earth magnetic field with the required accuracy, provided the S/C internal magnetic dipole of the satellite is known.
The use of permanent magnets (see Par. 6.1) for the passive attitude control with a good temperature stability and with a maximum temperature variations of the order of 20 ^{o}C, guarantees the scientific requirements given by the magnetic field measurements are met.
The magnetomer is ready for EVB integration.

3.3.3 Global Positioning System (GPS)

The GPS will be used to both associate each scientific measure with the spatial position, and to estimate the orbit drag by precise orbital measurements. A typical, terrestrial use GPS is already available and is used for testing and measurements. We plan to use a GPS with public domain firmware (see the GPL-GPS project at http://gps.psas.pdx.edu) with ad-hoc implementation of software codes to make it space compliant.
Alternatively, if sufficient funding will be available, the satellite could be equipped with the COTS SSTL SGR-05U. This product is compatible with the technical (dimensions, bias, data rate) and scientific requirements providing a 3-d position accuracy of the order of 10 m (worst case 20 m). The typical consumption is of the order of 0.7 W. Many contacts has been already taken with the productor. Since ordered, the GPS should be available in a few months.

3.3.4 Radiation damage

It is very important to study the robustness of the payload and the other electronic systems on the satellite with respect to radiation damage. Radiation investing the satellite is due to both the energetic particles coming from the Sun and cosmic rays; also the contribute of the particles in the Van Allen radiation belts has to be taken into account.
After the final orbit definition, the first step will be the simulation of “dose vs depth” curves for both Total Ionization Dose (TID) and Non-Ionizing Energy Loss (NIEL) models. The minimum shielding thickness (worst case) will be estimated for each component of the satellite: the corresponding dose will be compared with the maximum radiation dose acceptable for each component. Fluxes will be simulated to verify if the scientific instruments and their electronic components can survive the count-rate levels in the radiation belts. If the dose found will be too large for the components, a more detailed shielding analysis will be performed. This second step consists in the evaluation, for each component, of the required shielding thickness as a function of the solid angle using a ray-tracing program. The tools that can be used for the simulations are SPENVIS, for the radiation dose and flux, SSAT, FASTRAD and Geant4 for the ray-tracing analysis. Eventually, it will be necessary to protect some devices using e.g. a “spot shielding”, i.e. by shielding locally the more sensitive components.

4 MISSION ANALYSIS

According to the specification of the VEGA launcher, we studied the case of an elliptical orbit with inclination 71^{o}, perigee at 350 km and apogee at 1,200 km. Neutral drag causes orbital decay which is estimated to be from a few kilometers to about 20 km per month in the worst case (maximum solar activity). Note that for our scientific purposes also a circular orbit at 350 km altitude can be considered but some computation would be required. The main characteristics of the orbit are reported in the table below. Perturbations to the orbital parameters have been considered and the results are reported in the paragraph below together with the study of the S/C visibility from the Basovizza ground station.

4.1 Orbit Perturbation

The main perturbation effects acting on AtmoCube orbit are given by atmospheric drag (§2.1.3), Earth mass distribution, third body interactions (Moon, Sun) and the S/C gravity gradient. Perturbations depend on satellite altitude and on inclination. The main effect of the Earth mass distribution (J_2) is a variation of the RAAN (Ω) and the argument of the perigee, ω. The presence of Sun and Moon cause a minor variation on Ω and ω. The rates of change of Ω and ω are reported in Table 4.1-1.

Perturbation (deg/day)	$\Delta\Omega$	$\Delta\omega$
Earth mass distribution J_2	-2.85	-1.73
Moon	-8.08×10^{-5}	-4.90×10^{-5}
Sun	-3.68×10^{-5}	-2.23×10^{-5}
Total	-2.85	-1.73

Table 4.1-1 Rate of change of Ω and ω

The atmospheric drag, the radiation pressure and the gravity gradient cause possible torquing effects on the AtmoCube S/C. By taking 0.8 mm as the maximum distance between the centre of mass and the geometrical centre where the perturbing force is applied (twice the maximum value estimated in 3.2.1), these torques can be estimated, see Table 4.1-2. Aerodynamical torque is the dominant effect.

Perturbation torque ($kg\cdot m^2/s^2$)	Solar conditions	@350 km	@600 km	@1,200 km	elliptical
Aerodinamic torque	min solar	2.22×10^{-8}	1.54×10^{-10}	1.42×10^{-10}	2.35×10^{-8}
	max solar	1.58×10^{-7}	4.47×10^{-9}	4.11×10^{-9}	1.66×10^{-7}
Gravity Gradient		5.23×10^{-9}	4.70×10^{-9}	3.66×10^{-9}	4.36×10^{-9}
Solar Radiation		2.22×10^{-9}	2.22×10^{-9}	2.22×10^{-9}	2.22×10^{-9}
Total (min/max solar)	min solar	2.96×10^{-8}	7.06×10^{-9}	6.02×10^{-9}	3.01×10^{-8}
	max solar	1.65×10^{-7}	1.14×10^{-8}	1.00×10^{-8}	1.74×10^{-7}

Table 4.1-2 Perturbing torques

4.2 Ground Station Visibility

Ground station visibility is given by the time intervals in which AtmoCube can be seen from the Basovizza ground station. An estimation of total visibility time allows to determine the total quantity of data that can be downlinked from satellite. The study is performed on a period of 1 year considering an elliptical orbit for the satellite, a minimum elevation angle for the antenna of 20^{o} and a maximum range between antenna and satellite of 2,500 km. We have obtained a total link duration of 533,514 s distributed in 1,325 passages over Basovizza ground station corresponding to an average value of 402.6 s per link, a maximum of 678.4 s and a minimum duration of 11.5 s. In annex 3.5 the distribution in time length of visibility periods and gap lengths are reported. The total gap time is 3.2×10^{7} s with an average value of 2.4×10^{4} s, a maximum of 8.4×10^{4} s and a minimum of 5.0×10^{3} s.

5 TELECOMMUNICATION SYSTEM

The telecommunication system is composed by the on board system and the ground station. It will be designed to be compliant with IARU requirements; main features are:

- Simplex communication in UHF band;
- Binary Frequency Shift Keying modulation (2-FSK);
- 9600 baud (symbols per second) programmable transmission rate;
- Packet-oriented connection;
- Channel coding capability.

The following simple handshaking protocol is envisioned for the establishment of the connection between the satellite and the antenna. A beacon signal is transmitted from the ground station when the satellite is supposed to fly above Trieste; when the satellite receives it, it starts downloading the data. As a backup, the satellite transmits a beacon signal itself when it knows (thanks to the GPS data) that it is above Trieste; this signal (besides being a proof of the proper operation of the satellite) can be used by the ground station to improve the antenna tracking.

5.1 On Board System

A scheme of the on board telecommunication system is shown in Figure 5.1-1.

The first, low-power, stage is fully integrated in a single-chip complete UHF radio modem and transceiver. Since it was originally designed for low power wireless application (such as in Short Range Devices-SRD), some improvements are needed to have a reliable communication between AtmoCube and the Ground Station. They consist in the addition of the two amplifying stages (one for the transmitted and the other for the received signal-both entirely designed by students) and the use of an external antenna. The solution adopted for the antenna is non-optimal, because the use of a high gain antenna isn't possible due to the mass and dimension constraints.

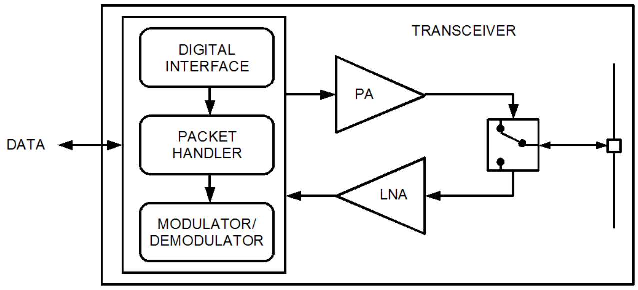


Figure 5.1-1 A scheme of the on-board TC system

The transmission power amplifier amplifies the signal modulated by the low power transceiver. It provides a signal input of 5-10 dBm and the amplifier output power complies with the sensitivity of the base station. As a result, the minimum signal power level for a good transmission is 2 W. Critical issues in the design are power dissipation and power saving, so that a high efficiency amplifier is needed (generally, class C or E). Power saving is also provided by a control circuit, which switches on the amplifier only when in use. We have already developed and simulated a class C amplifier using a software for radio-frequency simulation (AWR).

A quarter wavelength dipole antenna will be mounted on one face of the S/C. The prototype antenna and its measured radiation pattern are shown in the figure below.

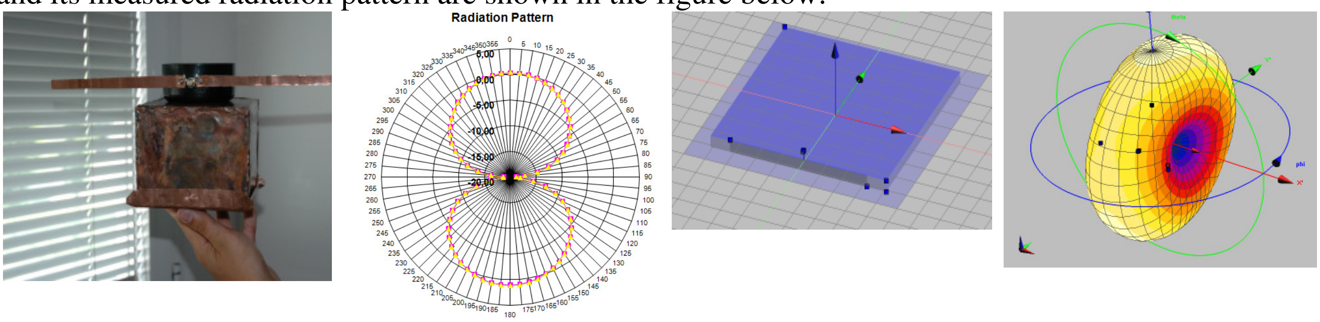


Figure 5.1-2 The prototype and the radiation pattern for the dipole (left) and the microstrip patch antenna (right)

Further prototypes for the onboard antenna consider the use of a microstrip patch radiator that is realized adopting well established miniaturization methods. The design procedure combines the shorting wall technique with the use of an FR4 dielectric substrate (height 5 mm, ε_r=4.4). The patch is a square copper sheet (edge 82 mm) and the shorting wall has a length of 64 mm to reach the operating frequency of 437 MHz while satisfying the satellite size constraints and the space occupied by the separation springs. The numerical results (SEMCAD simulation) are shown in figure above.

5.2 Ground Station

The ground station is located in Basovizza at INAF-OATS. A scheme of the on board telecommunication system in shown in Figure 5.2-1. The antenna, a 10 elements Yagi-Uda, transmits in double polarization at the frequency of 430 MHz. An adequate controller moves it by means of rotors. We are planning to introduce antenna preamplifiers to improve the global gain both in uplink and downlink. A server computer will be connected to the receiver by microprocessor and TTL. This will be the Ground Station Server (GSS), whose interfaces allow radio controlling, antenna tracking and also allow to predict the position, angles and Doppler shift of the satellite. GSS will contain data incoming from the satellite to which Mission Control Client (MCC) will be able to connect. The recovery of the existing structure began, details are given in annex 3.8.

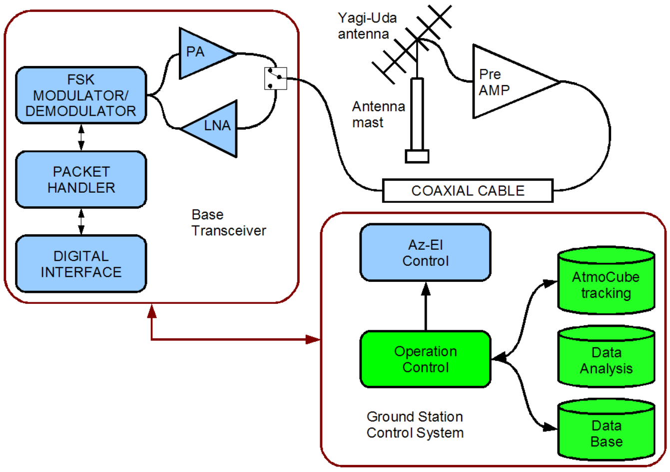


Figure 5.2-1 A scheme of the ground station TC system

The AtmoCube collaboration signed the GENSO letter of intent in 2006 and aims to agree to GENSO standard if its constraints are compatible with those of our project; this could be very beneficial if the data were to be used for space weather nowcasting/forecasting. Analysis is ongoing.

5.3 Link Budget

The performance of a digital communication system is given by its bit error rate (BER). A more useful parameter (from the implementation point of view) is the link margin. The resulting signal to noise ratio (SNR) is compared with the ratio needed to gain the target BER, including an implementation loss; the higher the margin, the lower is the BER. The reference BER set for AtmoCube is 10^{-5}, corresponding to a SNR equal to 13.3.

5.3.1 Downlink

The downlink is the most critical part, as the power to be transmitted is quite limited. In the following table the downlink budget is reported in the worst, best, and average condition. A detailed analysis is reported in annex 3.7. A summary is given in the table below.

Name	Unit	Source	Worst	Best	Average
SNR (1)	dB		18.49	36.17	22.1
Required SNR (2)	dB	System requirement	13.3	13.3	13.3
Implementation loss (3)	dB	estimation	-2	-2	-2
Margin	dB	(1)-(2)+(3)	3.19	20.87	6.8

As it can be seen, the system margin takes in account an additional implementation loss, due to physical realization of the transceiver. A system margin can be considered good if it is at least equal to 3 dB; even in the worst case this condition is guaranteed.

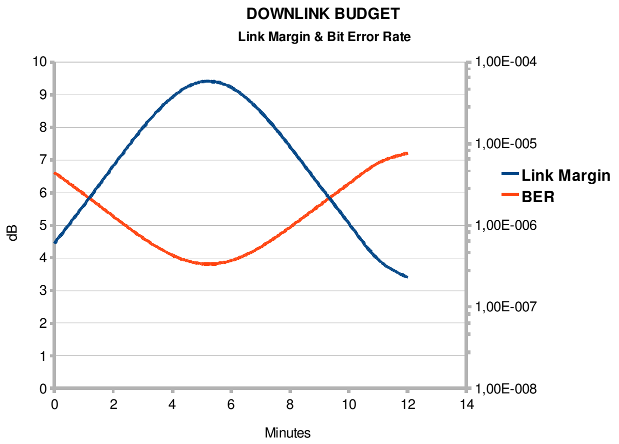
In Figure 5.3-1 (left side), the progress of both link margin (blue) and BER (red) during a sample access is reported. The margin does not fall below 3 dB and the BER does not rise above the 10^{-5} requirement. The peaks correspond to the minimum distance from the ground station to AtmoCube.

5.3.2 Uplink

For the uplink, limitations due to reduced power are relaxed, since the base transceiver can transmit from 10 up to 35 W. In this case, additional losses are more tolerable. The details are reported in annex 3.7; a summary is given in the table below.

Name	Unit	Source	Worst	Best	Average
SNR (1)	dB		32.81	50.49	36.42
required SNR (2)	dB	System requirement	13.3	13.3	13.3
Implementation loss (3)	dB	estimation	-2	-2	-2
Margin	dB	(1)-(2)+(3)	17.51	35.19	21.12

As it can be seen from the last rows of the table, uplink quality is sensibly higher than the downlink, as there is more power available. In Figure 5.3-1 (right side), the progress of link margin and BER (during the same access as for downlink) is reported.



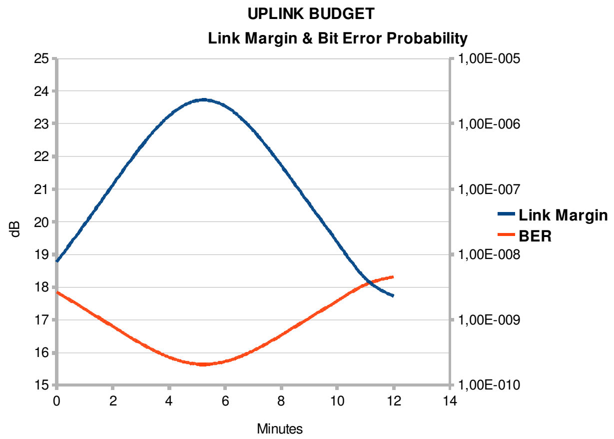


Figure 5.3-1 Dowlink (left) and Uplink (right) budgets

6 ATTITUDE CONTROL AND DETERMINATION SYSTEM

6.1 Attitude Control

Two permanent magnets mounted inside AtmoCube, along the Y-axis and in proximity of the centre of mass, will be used for passive stabilization and control. With the appropriate dipole strength and orientation, the magnets can be used to keep the satellite negative Y axis (nadir) oriented towards the local Earth magnetic field vector. To work as an efficient passive attitude control system, the torque generated by the permanent magnets should be larger than the other perturbing torques acting on AtmoCube and reported in Table 4.1-2.

Magnetic materials have been evaluated according to their cost, magnetic strength, resistance to demagnetization and temperature stability. Alnico (Aluminum, Nickel, Cobalt) has been chosen for its high temperature stability, 0.02% per degree. Considering a temperature variation lower than 20^{o} C (worst case), the stability is compatible with the requirement of the Earth magnetic field measurements (Par. 2.1.2). The final selection consists of two Alnico cylinder-shaped magnets, 0.2 cm diameter by 1.27 cm height each giving a dipole moment of about 3.4×10^{-3} $A\cdot m^2$. The maximum and minimum magnetic torques can be estimated by using the magnetic field values in correspondence of Trieste coordinates as given in the table below at different altitudes.

	max (350 km) min		max (600 km) min		max (1,200 km) min	
Magnetic field ($T\ 10^{-4}$)	0.4019	0.4009	0.3598	0.3588	0.2801	0.2793
Magnetic Torque ($kg{\cdot}m^2/s^2$)	2.748×10^{-7}	2.740×10	2.460×10^{-7}	2.452×10	1.915×10^{-7}	1.909×10

The magnets set the average orientation of the satellite by forcing it towards the correct position but are not able to keep it there (as in any resonant system). The attenuation of the corresponding oscillations has to be obtained via mechanical energy dissipation. The easiest way to obtain this is via the parasitic currents which develop in the metallic (i.e. conductive) frame of the S/C due to the concatenation with Earth magnetic field. Preliminary estimations show that most of the rotational mechanical energy acquired in the separation from launcher is expected to be dissipated within one month.

6.2 Attitude Determination

The attitude will be determined using the information provided by the six photodiodes positioned on the sides of the cube. In addition the currents produced by the solar cells will give information about the solar angle on the corresponding side of the cube. During the eclipse phase, the magnetic field vector measured by the magnetometer will be compared with the Earth magnetic field models to provide information on the satellite attitude.

7 POWER SYSTEM

AtmoCube is powered by an array of solar cells placed on the sides of the cube and connected to a battery, which acts as a reservoir of energy for the eclipse periods. We use Tecstar GaAs 3-junction

solar cells, with a maximum efficiency of 23% and a SAFT Li-Ion cell 3.75 V – 4.8 Ah. Solar cells are under tests, the battery has been ordered and will available in a few weeks.
We have chosen a simple connecting scheme where cells on the same face are connected in series, then they are paralleled with the cells from the other sides of the cube and, finally, connected to the Li-Ion battery. Each group of cells is protected from current reversal by a schottky diode, chosen for its low forward voltage drop. This is a good compromise between the two constraints: the ability to extract the maximum power from the solar cells (which would ask for a MPPT circuit) and the high reliability required for this power supply system. Additional details are reported in annex 3.6.
From the battery we need to extract various voltages to supply the following subsystems:

Subsystem:	Voltage	Current (max value)
Silicon Detector	+/- 6V (max. ripple 1mVpp) -100V (max. ripple 3mVpp) +3.3V	20mA 20µA 40mA
Magnetometer	6-15V 15-20V	20mA 3-4A for 2µs (reset impulse)
GPS	3.3V	200mA
Rx/Tx Exciter	3.3V	100mA
LNA	5V	20mA
PA Tx	5V	2A
Antenna Switch	5V	20mA

Switching regulators are employed to obtain the desired voltages and achieve the highest conversion efficiency). When necessary (i.e. when the voltage of the cells falls below a predefined threshold), part of the instrumentation will be switched off. Eventually, the use of higher efficiency (up to 40%) Spectrolab solar cells, by now considered as an option, would reduce the frequency of shutdowns for battery recharge.
Two mechanical pins are implemented in the system for launch safety features ("Remove before Flight" and "Activation" pins), as prescribed by P-POD requirements.

7.1 Power Budget

The total power produced by the solar cells is 2.5 watts at best, using 8 cells (2 mounted on each face of the cube); this forces to power on and off some AtmoCube subsystems to save as much power as possible. The total power consumption depends upon the measurement and data-transmission schedule, that will be dynamically adapted according to the estimated available power from the battery and solar cells. The baseline by now is to perform the measurements every 300 s with a duration of 30 s. The GPS will be always powered, because the acquisition of the GPS satellite constellation at each power-up requires too much time. Also, there is the possibility to completely power off all the subsystems, except the supervisor microcontroller, to allow a complete battery recharge cycle if its remaining charge is too low. The estimated power consumption and the available power from the solar cell array are shown in Figure 7.1-1 over a period of 8 hours. This is a worst case simulation, the real situation should be better because, for example, GPS data can be used to power on the radio transmitter only when AtmoCube will be above the GS, thus extending the satellite operative life.

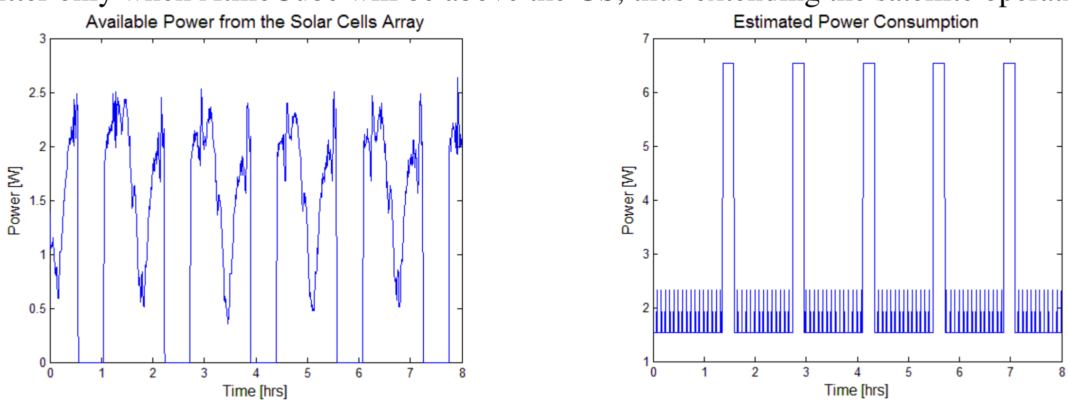


Figure 7.1-1 AtmoCube power budget: available power (left) and power consumption (right)

8 ON BOARD DATA HANDLING

The OBDH system has mainly two parts; the first contains the parameters of the satellite, the second the data collected by the sensors for the scientific measurements.
The first section contains data from HK sensors: solar cells voltage and charging current, voltage and battery drain current, sub-systems voltage power supply, internal temperature, used and free storage memory, transmission power output and received signal level. These values will be sent to ground to verify the proper working condition and to analyse the condition prior to any system malfunction.
The second section allows to sample, save and transmit data related to the scientific instruments: silicon detector, magnetometer, photodiodes and GPS.
The memory capacity is evaluated to contain the required data volume for at least 15 orbits. In this way it is possible to loose the connection with the ground station without loss of data. In case of memory overflow the OBDH will delete the old data and maintain the last measures.
All data will be handled by a microprocessor, the H8/38076R. The microcontroller unit allows to collect data from the sensors, save them into the memory, wait to establish connection with the ground station, prepare data for the transmission and send them to the transmitter.
The software is under development, some routines have been already written and tested.

8.1 Data Volume

In the table below the data budget produced by each sensor is reported.

Instrument	Data volume (bytes)
Drift Chamber	512
GPS	100
Magnetometer	15
HK	100
Photodiodes	12
Total	739
Total (with margins)	1,000

The measurements will be performed every 300 s. Considering 20 measurements per orbit and a maximum GS visibility gap of 14 orbits, the total data budget corresponds to 280 kbytes to be downlinked at the first usable link. A 9,600 baud rate corresponds to about 1 kbyte per second and thus a total time required for the downlink is of the order of 300 s, consistent with the average GS connection time.

9 THE ATMOCUBE COLLABORATION AND GROUP EXPERIENCE

The management structure of AtmoCube is based on the Principal Investigator (PI, Anna Gregorio) and the Co-Investigator (CoI, Sergio Carrato), which are supported by the AtmoCube Scientist (AS, Mauro Messerotti), and technically by the Project Manager (PM, Mario Fragiacomo) and by all the members of the AtmoCube Development Team (ADT). The Steering Committee (SC) is composed by the following people: S. Carrato, W. Bonvicini, L. Bregant, M. Fragiacomo, A. Gregorio, M. Messerotti and A. Vacchi. The full composition of ADT is detailed in the table below.

Name	Institution	Role	Title
Anna Gregorio	Dept. Physics	PI	Dr.
Mario Fragiacomo	DEEI	PM	Prof.
Sergio Carrato	DEEI	CoI	Prof.
Mauro Messerotti	INAF-OATS	AS	Prof.
Luigi Bregant	MED	Senior engineer: mechanical	Prof.
Andrea Vacchi	INFN	Science and instrumentation	Prof.
Walter Bonvicini	INFN	Science and instrumentation	Dr.
Gianluigi Zampa	INFN	Science and instrumentation	Dr.
Nicola Zampa	INFN	Science and instrumentation	Dr.
Alexander Rashevsky	INFN	Science and instrumentation	Dr.
Francesco Longo	INFN	Science and radiation environment	Dr.
Mauro Pucillo	INAF-OATS	Science and Ground Station	Dr.
Maurizio Comari	INAF-OATS	Science and Ground Station	Dr.

Piero Riosa	DEEI	Electronics	Senior technician
Elena Orlando	Dept. Physics	Science and instrumentation	PHD student
Daniele Tavagnacco	Dept. Physics	Mission analysis	Graduated student
Valentina Alberti	Dept. Physics	Science and instrumentation	MSc student
Manuela Ciani	Dept. Physics	Science and instrumentation	MSc student
Elisa Pinat	Dept. Physics	Science and instrumentation	BSc student
Veronica Baldini	DEEI	Ground Station	MSc student
Massimiliano Comisso	DEEI	Antenna	PHD student
Alessandro Cuttin	DEEI	System	MSc student
Samuele Falcomer	DEEI	Antenna	MSc student
Marco De Din	DEEI	Power	MSc student
Bruno Pendalo	DEEI	Power	MSc student
Diego Derganz	DEEI	Software	MSc student
Alessandro Corradini	MED	Mechanical	MSc student
Simone Manzato	MED	Mechanical	MSc student
Manuel Tommasini	DEEI	Radio	MSc student
Emilio Montagnana	DEEI	Microprocessor	MSc student
Mauro Popesso	DEEI	Radio	MSc student
Walter Caharija	DEEI	Power	MSc student
Matteo Sangalli	DEEI	Webmaster	MSc student
Darin Bernic	DEEI	Radio	MSc student
Igor Donadelli	DEEI	Microprocessor	MSc student

It is the responsibility of the ADT to develop, test and finally build the AtmoCube, to provide all tools (software, procedures and documentation) and infrastructures (database, documentation archives, networking activities) necessary to obtain the data products with the required scientific quality, to run the procedures and obtain the data products, continuously updating the tools as necessary to achieve the required data quality, and to provide infrastructures, tools and resources for developing AtmoCube scientific programs.

The University group has a good experience in the space field, being already involved in the development and operations of a number of space missions: UVSTAR, Meg-Sat1, SOHO/UVCS, AGILE and PLANCK. In addition there is a strong experience in the telecommunication and microprocessor systems design.
The INFN-Trieste group has an experience dating more than 14 years in the design, development, test and operation of SDD for position and energy measurements (and associated front-end electronics) in high-energy and nuclear physics applications. The group has also a good experience in space programs, being strongly involved in the NINA and PAMELA space missions (Wizard collaboration).
The industries are well known local industries in the electronics and telecommunication field, operating in Area Science Park, the largest Science Park in Italy.
A brief Curriculum Vitae of key persons and a description of the proposing Departments of Physics and Electronics Engineering and of the other institutions and industries participating to the AtmoCube project can be found in [AN-1].

10 EDUCATIONAL CONTENT AND OUTREACH

As already mentioned, the project has a strong educational interest, thanks to the support of the University and the other institutions with their infrastructures (laboratories, mechanical and electronics workshops), which will allow the students to improve their scientific and technical knowledge and capabilities. Due to the involvement of the Department of Physics, the DEEI and MED of the University of Trieste, of INFN (Istituto Nazionale di Fisica Nucleare) and INAF (Istituto Nazionale di AstroFisica), AtmoCube has also a strong scientific content that allows an even more interested involvement of students. Presentation of the AtmoCube activity has been well received at ESWW meetings; graduate students will have the opportunity to present new results and tools to a professional audience of scientists and industry at future ESWWs. In addition, the small industries participating to

the project (ENTEOS, ELCON, ELIMOS, SCEN, and SICOM), hosting the students for stage opportunities and giving them a technical support, allow to have a direct access to a real work environment.
The design, realization, test and launch phases of AtmoCube represent an excellent opportunity for undergraduate and graduate students to both improve their knowledge on the various related subjects and to prepare theses on specific topics which are relevant to the project, whereas the operational phase is a unique opportunity for developing expertise in data management and scientific analysis. Indeed, the educational spin-off of this project is manyfold as it involves multi-level awareness raising of space sciences. In fact:
- University students can exploit their "theoretical" knowledge and acquire fundamental expertise for their further activities also with training opportunities. The list of the 14 theses already developed within the AtmoCube collaboration is given in the [AN-2]. A program of fellowships for students under graduation (http://www.fisica.unipd.it/~direz/didattica/fisica/BandoNucl.pdf) and post-graduation (Area Science Park fellowship and http://www.ac.infn.it/index.php, n. 12628) has started. Students can gain up to 9 credits for trainings, 6 for first degree and 12 for second degree theses;
- High School students are involved at various levels, from simple lectures on project description (AtmoCube has already been presented in several High School Institutes) to direct work on data analysis via training activities (students are invited for short stages at the University), so that they can be stimulated to carry out scientific studies after the diploma. In past years, some of them concluded their diploma presenting a small study on AtmoCube. Also in this case a program of fellowships for high school students (http://www.ac.infn.it/index.php, n. 12564) has started and is being advertised. AtmoCube is also included in the "Scientific Laurea Degree" program, an Italian national project to invite high school students to University scientific degrees. We are analysing the possibility of involving in the projects also students from lower level schools. Students can gain up to 3 credits;
- The general public will be informed via popular lectures and via interviews on tv and radio as well as articles on electronic and paper journals and magazines. On top of such a education and public outreach activities there is already the availability of a dedicated web portal, www.units.it/atmocube. We are investigating the possibility of producing AtmoCube gadgets (S/C models, sweat and tee-shirts, USB memory sticks, caps, key rings, etc).

11 DEVELOPMENT, TEST PLAN, COST BREAKDOWN, FUNDING SOURCES

A short description of the plan for the construction of the AtmoCube satellite, tests and upgrade of the GS is given here. More details, together with Gantt charts, are reported in annex 3.8. The plan is divided in two main branches, Satellite and Ground Station; each branch is divided in phases:
a) *Satellite*
Design Phase. The target of this phase is the design of the main aspect of the satellite: system, mechanical, hardware and software. The outputs of this phase are some specifications documents necessary for design of the Evaluation Boards (EVB).
EVB Phase. The target of the EVB Phase is a complete prototype not in the final shape. The EVB will be used for the integration of the software on the hardware and for some testing on the complete satellite system. Similarly a mechanical prototype will be used for vibration and shock test. Another dummy model will prepared with all electrical and mechanical interfaces.
Proto Phase. This is the final phase. The output is a complete satellite ready for flight.
b) *Ground Station*
Transceiver. Design of the transceiver.
Antenna. Testing and maintenance of the antenna driving system.
Server. Developing the software for housekeeping and data handling.

Activities already performed (AtmoCube Phase 2, see details in Gantts)
General project management
Analysis of Thesis & System specifications: 90%

Resources assignments: 80%
Mission analysis 70% (with reference to the elliptical orbit)

Satellite

Analysis Sat Spec: 90%
Design
Mechanical Design: 50%
Hardware Design: 60%
Software Design: 30%

Ground Station

Analysis of Thesis & System specifications: 100%
Transceiver
Power amplifier : 90%
LNA: 100%
Antenna system: 50%
Server: 30%

Milestones

	Satellite	Ground station
Start	January 2008	January 2008
End Design Phase	March 2008	
End EVB Phase	July 2008	
End Proto & End of the project	Mid October 2008	Mid October 2008

Critical path

Satellite activities that fall in the critical path:

- Design Phase. Radio design and HW design of the microprocessor.
- EVB Phase. HW & SW activity.
- Proto Phase. HW & SW activity.

The most critical parts are the development of the satellite driver software and the Silicon Detector. The schedule presented here is stringent to be consistent with VEGA launcher requirements. It is feasible with some effort but a more relaxed schedule (1-2 months) would make the situation easier.

Total costs

Details of the costs are given in annex 3.8. Commitment letters by all institutions (University depts., research institutions and industries) are attached in annex 5.

	Type	Description	Cost (€)	Source
1	Persons	Project	20,000	Area Science Park fellowship
		Steering Committee	84,200	University, institutions and industries (salaries)
2	Consumables	Electronics components et al.	2,000	SC and AG personal research funds; industries
3	Travels	Two missions of 3 days for two persons	3,000	SC and AG personal research funds
	Total		109,200	

Funding sources

Participating institutions have given their availability to support the AtmoCube project as salary of the personnel and eventually with small financial supports to acquire necessary materials. Area Science Park has confirmed the fellowship. Everything is detailed in the commitment letters and in annex 3.8.
Other funding requests have been posted to the CRUP foundation (http://www.fondazionecrup.it/) and to the Administration of "Regione Friuli Venezia Giulia". With both institutions a first contact has took place, possibly we are waiting for a final agreement.