Call for CubeSat Proposals for QB50

A network of 50 double and triple CubeSats for the exploration of the lower thermosphere, re-entry research and in-orbit science and technology demonstration

Issued on 15 February 2012

by the
von Karman Institute for Fluid Dynamics (VKI)
Brussels, Belgium

Deadline for the submission of proposals

31 March 2012

Proposals should be submitted to the QB50 Coordinating Person:
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1. Description of the flight opportunity, mission objectives

QB50 is a network 50 CubeSats in a 'string-of-pearls' configuration that will be launched together in the first half of 2015 by a single rocket, a Shtil-2.1, from Murmansk, Northern Russia into a circular orbit at 320 km altitude, inclination 79º. The 50 CubeSats will comprise about 40 atmospheric double CubeSats and about 10 double or triple CubeSats for science and technology demonstration. All 40 atmospheric double CubeSats and most of the 10 double and triple CubeSats for In-Orbit Demonstration (IOD CubeSats) will carry a set of standardized sensors for multi-point, in-situ, long-duration measurements of key parameters and constituents in the largely unexplored lower thermosphere and ionosphere. These multi-point measurements will allow the separation of spatial and temporal variations. Due to atmospheric drag, the CubeSat orbits will decay and progressively lower and lower layers of the thermosphere/ionosphere will be explored without the need for on-board propulsion. The mission lifetime of individual CubeSats is estimated to be about three months.

QB50 will also study the re-entry process by measuring a number of key parameters during re-entry, e.g. CubeSat on-board temperature and deceleration. The re-entry process will also be studied by comparing predicted (using a variety of atmospheric models, trajectory simulation software tools and CubeSat drag coefficients) and actual CubeSat trajectories and orbital lifetimes, and by comparing predicted and actual times and latitudes/longitudes of atmospheric re-entry.

A single CubeSat is simply too small to also carry sensors for significant scientific research. Hence, for the universities the main objective of developing, launching and operating a CubeSat is educational. However, when combining a large number of CubeSats with identical sensors launched at the same time into a network, in addition to the educational value, fundamental scientific questions can be addressed which are inaccessible otherwise. Networks of CubeSats have been under discussion in the CubeSat community for several years, but so far no university, institution or space agency has taken the initiative to set up and coordinate such a powerful network. CubeSat reliability is not a major concern because the network can still fully achieve its mission objectives even if a few CubeSats fail.

QB50 has been selected as the first large-scale CubeSat network in orbit because a network of CubeSats in the lower thermosphere as compared to networks in higher orbits has the following advantages

- The lifetime of a CubeSat in the envisaged low-Earth orbit will only be three months, i.e. much less than the 25 years stipulated by international requirements related to space debris (Code of Conduct),
- A low-Earth orbit allows high data rates because of the short communication distances involved,
- In their low-Earth orbits, the CubeSats will be below the Earth's radiation belts, which is advantageous because CubeSats use low-cost Commercial-Off-The-Shelf (COTS) components which are not radiation hardened,
- The orbit of the International Space Station (ISS) is maintained between 335 km (perigee) and 400 km (apogee). If a network of many CubeSats is launched into an orbit that is above that of the ISS there is a danger of collision with the ISS when the orbits of the CubeSats decay due to atmospheric drag. If the initial orbit of the CubeSats is below 330 km there is no danger of collision.

For a network of CubeSats in the lower thermosphere/ionosphere the short mission lifetime is not a deterrent as for a university the primary purpose of a CubeSat is educational and the educational objectives can be achieved even if the orbital lifetime is short.

The lower thermosphere/ionosphere (90-320 km) is the least explored layer of the atmosphere. Five Atmospheric Explorers were flown by NASA from 1963 until 1981 in highly elliptical orbits (typically: 200 km perigee, 3000 km apogee); they carried experiments for in-situ measurements but the time spent in the region of interest below 320 km was only a few tens of minutes. Nowadays, sounding rocket flights provide the only in-situ measurements. While they do explore the whole lower thermosphere, the time spent in this region is rather short (a few minutes), there are only a few flights per year and they only provide measurements along a single column. Powerful remote-sensing instruments on board Earth observation satellites in higher orbits (600–800 km) receive the backscattered signals from atmospheric constituents at various altitudes. While this is an excellent tool for exploring the lower layers of the atmosphere up to about 100 km, it is not ideally suited for exploring the lower thermosphere because there the atmosphere is so rarefied that the return signal is weak. The same holds for remote-sensing observations from the ground with lidars and radars. The multi-point, in-situ measurements of QB50 will be complementary to the remote-sensing observations by the instruments on Earth observation satellites and the remote-sensing observations from the ground with lidars and radars.

Space agencies are not pursuing a multi-spacecraft network for in-situ measurements in the lower thermosphere because the cost of a network of 50 satellites built to industrial standards would be extremely high and not justifiable in view of the limited orbital lifetime of only a few months. No atmospheric network mission for in-situ measurements has been carried out in the past or is approved for the future. A network of satellites for in-situ measurements in the lower thermosphere can only be realised by using very low-cost satellites, and CubeSats are the only realistic option.

Interest to participate in QB50 by signing a Letter of Intent (LoI) has been expressed by over 90 universities all over the world. This includes universities in 30 European countries and universities in Argentina, Australia, Brazil, Canada, Chile, China, Ethiopia, India, Israel, Peru, Puerto Rico, Russia, Singapore, South Korea, Taiwan, Turkey, Ukraine, USA and Vietnam. For many of these countries, the CubeSats that will participate in QB50 will be their first satellite in orbit and a matter of national prestige. QB50 will eventually involve well over 1000 people from all over the world: 50 CubeSat teams of 10-20 students and engineers each, numerous atmospheric scientists, instrument, orbital dynamics and ground station experts, legal experts, as well as industry and space agency representatives.

Proposals in response to this Call can be submitted by all universities/institutes interested to participate in QB50, not only those who have submitted Letters of Intent.

2. Educational impact of QB50

For universities, the main objective of developing a CubeSat is expected to be educational next to the (pre-)qualification of new technologies. The low cost of building, launching and operating a CubeSat, as compared to larger satellites and the associated higher launch cost, has made CubeSats a viable option for universities across the world. Unlike larger projects, the short development time for Cubesats (typically two years from the start of Phase A until delivery of the fully tested satellite) is very compatible with the duration of Master and PhD theses. During the development time, 10-20 students work together in a team supervised by a professor or an experienced senior university staff member. The students learn about all aspects of space engineering and management (details in Annex 2). As educational hands-on projects CubeSats are ideal and it is, therefore, no surprise that the worldwide CubeSat community is rapidly growing. The aim is for students, through hands-on work, to develop the necessary skills and experience to succeed in the space industry.

Furthermore, through their involvement in the QB50 Project, the students will also learn about the various layers of our atmosphere and their interaction and variability, the major open scientific issues in the lower thermosphere/ionosphere and the strengths and weaknesses of the various atmospheric models and they will appreciate how QB50 will improve the situation. They will become familiar with typical payload requirements, such as mass, volume, power, field of view, pointing and attitude stability, and achievable temporal/spatial resolution as a result of data rate limitations. On QB50, the students will also become familiar with the lifecycle of space technology development and actively participate in project reviews which are typical for larger space projects. Finally, QB50 will provide an outstanding intercultural experience and will become a global network of students with the possibility of student exchange programmes.

3. Standard atmospheric double CubeSats

For QB50, double-unit CubeSats are foreseen, with one half (the ‘functional’ unit) providing the usual satellite functions and the other half (the ‘science’ unit) accommodating a set of standardised sensors for lower thermosphere/ionosphere and re-entry research. University teams are free to use any space left in the ‘functional’ unit of the double CubeSat for a technology package or a sensor of their own choice, as long as the requirements in the Interface Control Document (ICD) are met.

4. Special In-Orbit Demonstration (IOD) double or triple CubeSats

In addition to the 40 ‘atmospheric’ double CubeSats, about 10 ‘special’ double or triple CubeSats for science and technology demonstration will be selected. Examples of such special In-Orbit Demonstration (IOD) CubeSats are given below. They only serve illustration purposes and are not privileged for selection. It is quite possible that other IOD CubeSats will be proposed and selected.

- A double CubeSat accommodating a magnetoresistive 3-axis magnetometer with inboard and outboard sensors on a boom,
- A triple CubeSat (PICASSO), PICosatellite for Atmospheric and Space Science Observations,
- A triple CubeSat (GamaSat) accommodating a small re-entry capsule. This triple CubeSat will be part of the GamaSat network for testing inter-satellite communications using three or more of the standard 40 double CubeSats,
- A double CubeSat accommodating the Spherical EUV and Plasma Spectrometer (SEPS),
- A double CubeSat (GTSat) for testing the link quality between the satellite and the GENSO ground stations,

- A triple CubeSat accommodating a dual-frequency GPS receiver for high-precision satellite position determination (a few centimetres or a few tens of centimetres),
- A triple CubeSat for limb sounding of the slant total electron content using a dual-frequency GPS receiver,
- A triple CubeSat (Armada prototype) with full instrumentation, expandable solar arrays, S-band, a forerunner of a later network of 48 triple CubeSats at ~500 km altitude,
- A double CubeSat accommodating a silicon drift chamber or another charged particle detector,
- A double CubeSat, using a lightweight satellite structure composed of composite materials and for measuring surface degradation,
- A triple CubeSat demonstrating micropropulsion and active debris removal using sprayed foam,
- A double CubeSat demonstrating debris mitigation using a long electrodynamic tether,
- A triple CubeSat carrying a biological µ-gravity payload,
- A double CubeSat accommodating an atmospheric drag environment sensor.

In addition to the list above, there are four In-Orbit Demonstration (IOD) CubeSats which are already committed in the original proposal to the EC.

- 2 triple CubeSats (Delta and Phi) for formation flying from TU Delft,
- A double CubeSat (RESat) equipped with a heat shield for re-entry research from VKI,
- A triple CubeSat (Inflate-Sail) for testing a solar sail with inflatable (gas pressure) booms from Surrey Space Centre,

If less than 10 IOD CubeSats are proposed and selected, the number of selected atmospheric double CubeSats can be higher so that the total of 50 CubeSats is maintained. If less than 40 atmospheric CubeSats are proposed, the selected number of special IOD triple or double CubeSats can be higher so that again the total of 50 CubeSats is maintained.

5. Interdisciplinary science

Interdisciplinary science uses data from CubeSats participating in QB50 to carry out interesting and novel science investigations that would otherwise not be done by a CubeSat team, making use of the special expertise of the proposing team. This could involve a single QB50 CubeSat, or a large number, or all CubeSats and it could be done in real time or post flight. Examples for interdisciplinary science related to QB50 are

- ‘Ionospheric E- and F-layer tomography with the QB50 network of satellites in low-Earth orbit’, using the GPS data of all CubeSats participating in QB50 (suggested in early 2011 by the Finnish Meteorological Institute),
- ‘Lower thermosphere model validation using in-situ measurements by the QB50 network of CubeSats’ (suggested in early 2012 by the University College London),
- ‘Improving the scientific return from the multi-needle Langmuir probes on the QB50 CubeSats by making coordinated observations with the incoherent scatter radar systems of EISCAT’ (suggested in early 2012 by the Belgian Institute for Space Aeronomy).

6. The Shtil-2.1 launch vehicle

The Shtil family of launch vehicles is based on the 3-stage liquid-propellant R-29RM or RSM-54 (Submarine Launched Ballistic Missile). The Shtil launch vehicles are marketed by the State Rocket Center Makeyev. The Shtil-1 (or just Shtil) is the baseline version of the launch vehicle where the payload is placed inside a special capsule in the space head next to the third stage engine nozzle. It was used to launch on 7 July 1998 from a submarine in the Barents Sea two small satellites from the Technical University of Berlin (TUBSAT-N (8 kg) and TUBSAT-N1 (3 kg)) into a 400 x 776 km orbit (i = 79º). On 26 May 2006, it launched the Russian Kompass-2 satellite (77 kg) into a 402 x 525 km orbit (i = 79º), also from a submarine in the Barents Sea. The Shtil-1 has a launch capacity of 150 kg into a circular orbit at 300 km altitude (i = 79º) and a payload volume of 0.195 m^3. However, the actual payload mass is reduced by the mass needed for the encapsulation of the payload.

The Shtil-2.1 is an improved version of the Shtil-1 where the payload is accommodated in a special section on top of the space head (max height 1.24 m, diameter in the middle (max) 1 m, diameter at the bottom 0.75 m). The payload mass that can be launched by a Shtil-2.1 into a circular orbit at 320 km altitude is 230 kg. The Shtil-2.1 is fully developed and hardware has been built and tested.

The Shtil-2.1 is launched from a submarine at sea surface. A few weeks before launch, the deployment system with the 50 CubeSats inside is mounted on top of the rocket's third stage which itself is loaded into the submarine. The submarine will sail to the launch site in the Barents Sea and will await acceptable weather conditions for the launch.

The rocket is launched from its launch site in an easterly direction. The fairing is jettisoned at the time of separation of the third stage from the second stage. After burnout, the third stage engine is jettisoned from the third stage and falls into the Pacific Ocean. The third stage itself remains in orbit. It has small thrusters for attitude and limited orbit control for 1200 s. After that time the propellant is exhausted. The third stage also carries a telemetry system and a battery which is sized to provide power for 1200 s.

In order to be accepted for flight on board the Shtil-2.1, all CubeSats shall be qualified against the QB50 Environmental Qualification Specification which will be provided to all selected teams within three months after selection.

7. Orbit

All 50 CubeSats will be launched together on a single launch vehicle, a Russian Shtil-2.1, from Murmansk in Northern Russia into a circular orbit at 320 km altitude, inclination 79°. Due to atmospheric drag, the orbits of the CubeSats will decay and progressively lower and lower layers of the thermosphere will be explored without the need for on-board propulsion, perhaps down to 90 km. The maximum achievable orbital altitude for a 230 kg payload is 320 km for a circular orbit. If mass of the final system to be launched is significantly reduced, this may result in a slight increase of the orbital altitude but not above 335 km, the lowest perigee of the ISS, extending the lifetime of the mission.

The initial total network size in orbit is determined by the deployment sequence and the separation speed and direction. The optimal CubeSat deployment scenario is currently under study, bearing in mind

- Launch vehicle and deployment system constraints,
- The need to identify each CubeSat individually as soon as possible after deployment,
- The need to establish a telecommunications link between the various CubeSats and ground stations as soon as possible after deployment,
- The need to mitigate the risk of collisions between the CubeSats and between the CubeSats and the third stage/deployment system assembly after each full orbit when the CubeSats return to the original point of release,
- The need to achieve spreading of the CubeSats all the way around the Earth as soon as possible after deployment.

The initial distance between individual Cubesats in the network will be between a few tens and a few hundred kilometres. Orbital modelling has shown that, due to air density variations along the orbit and small differences in the CubeSat ballistic (or drag) coefficients, the separation distance will change, eventually, after about a month, leading to a non-uniform distribution of CubeSats all the way around the Earth. In this way, the CubeSats will be able to explore temporal and spatial variations over a wide range of scale sizes, from a few tens of kilometres in the beginning to about 1000 km after a month.

8. Ground station network, GENSO

Typically, a university builds a CubeSat and launches it into low-Earth orbit. It also builds or already has available a ground station to track the CubeSat and enable uplink/downlink telecommunications. The period in a low-Earth orbit (about 600 km altitude) is typically about 90 minutes, but the duration of a satellite pass over the ground station is very short and varies from approximately 10 minutes in the best case to no coverage at all for most of the 16 daily orbits. When supporting only one satellite project the ground station is not in operation 97 % of the time. This is highly inefficient and often, despite on-board data storage capability, a limiting factor in mission science return.

For very low-Earth orbits (150-300 km altitude) as envisaged for QB50 the situation is a lot worse. The following table illustrates the problem (assuming a 10º cut-off elevation)

Orbital altitude	**Duration of the longest pass**	**Daily coverage by a single ground station**
600 km	10 min	3 %
300 km	5 min	0.7 %
150 km	2.5 min	0.25 %

Moreover, there are sometimes mission critical operations requiring uninterrupted coverage for longer than a single pass and, worst of all, in the case of an on-board emergency, there is no immediate access to the satellite. The situation would dramatically improve if the satellite could be in contact with numerous other ground stations along its track.

An international network, the Global Educational Network for Satellite Operations (GENSO), may well be set up in time for QB50. It would eventually comprise more than 100 ground stations in different parts of the world, providing a vastly improved uplink and downlink capability for all CubeSats. The international QB50 network in orbit would be the first major user of the international GENSO network on the ground. In case GENSO is not set up in time for QB50, CubeSat teams are encouraged to set up a subset ground station network comprising any number of ground stations.

9. 'Mission Control Centres' at VKI, Stanford and NPU

Parallel 'QB50 Mission Control Centres' will be set up at VKI, Stanford in the US and NPU in China with the following real-time functions for all 50 CubeSats

- Comparing predicted with actual trajectories, using different trajectory simulation software tools, atmospheric models and CubeSat drag coefficients,
- Monitoring the status and health of the 50 CubeSats and the deployment system,
- Displaying which ground station is in contact with which CubeSat and displaying the link quality,
- Predicting and continuously updating the approximate time and latitude/ longitude of atmospheric re-entry for the 50 CubeSats.

10. Sensors selected for the science units of the CubeSats

It is assumed that all 40 atmospheric double CubeSats and as many as possible (expected to be at least 6) out of the 10 IOD double and triple CubeSats will accommodate standard sensor package(s) selected by the QB50 Sensor Selection Working Group (SSWG). The selected sensors are:

- Ion/Neutral Mass Spectrometer (INMS)
  (350 g including electronics, 500 mW)
- Flux-Φ-Probe Experiment (FIPEX)
  (70 g, 2200-1600 mW)
- Multi-Needle Langmuir Probe (MNLP)
  (120 g including electronics, 400-1000 mW)
- Corner Cube Laser Retroreflectors (CCR)
  (12 g, 0 mW)
- Thermistors/thermocouples/RTD (TH)
  (180 g including electronics, 5 mW)

The working principles, performance and specifications (mass, power, volume, field of view, attitude requirements) of the sensors are described in detail in the SSWG Report 'Sensor Selection for QB50' (see https://www.qb50.eu/sswg_report.pdf, available from 1 March 2012).

The selected sensors will be accommodated in different sets. A possible variation of three sets is presented below. The technical requirements of the sensor sets will be detailed in the ICD. The design objective for the sensor sets is to remain within the 500 mW power budget (duty-cycled, orbit averaged), 500 g mass budget, half a CubeSat unit volume budget and 2 Mbit/day data rate budget. 20% design margin should be added on top of these budgets.

Set 1

Ion/Neutral Mass Spectrometer (INMS)
2 corner cube laser retroreflectors (CCR)
Thermistors/thermocouples/RTD (TH)

Set 2

Flux-Φ-Probe Experiment (FIPEX)
2 corner cube laser retroreflectors (CCR)
Thermistors/thermocouples/RTD (TH)

Set 3

A set of 4 Langmuir probes (MNLP)
2 corner cube laser retroreflectors (CCR)
Thermistors/thermocouples/RTD (TH)

Standard sensors for atmospheric research will be shipped from MSSL to universities/institutes in July 2013. These could either be the real sensors or a simulator, with each option having different requirements for handling, testing and liability. It is up to the universities/institutes to specify which they prefer.

11. Deployment system

Typically, CubeSats are launched from Picosatellite Orbital Deployers (PODs). These systems are stand-alone items that are integrated onto the launch vehicle one-by-one. Although this concept offers flexibility and freedom for the launch service provider on where to place the PODs, the system is relatively heavy and can be improved significantly, both with respect to interfacing effort required to the launch service provider and with respect to the achievable payload-mass to total-mass ratio. A more integrated system, which would benefit maximally from a more compact cluster of CubeSats and a much lower mass of the system compared to its stand-alone peers offers significant advantages to certain missions. The best way to ensure this is to provide a single integrated system which minimises the number of interfaces towards the launch vehicle, both physical interfaces and the associated paperwork and procedures surrounding the accommodation of payloads on board a launch vehicle. As far as the launch vehicle provider Makeyev is concerned the deployment system accommodating the 50 CubeSats can be treated as a single satellite.

Integration of 50 double and triple CubeSats is very challenging, both technically and operationally. Additional functionality such as the ability to perform checkout of the spacecraft systems and spacecraft battery charging when all satellites are integrated into the deployment system adds significant value in this project as it would circumvent the issue of having to dismount all 50 CubeSats for a battery charging procedure which is typically required for the payloads prior to launch.

It is assumed that the CubeSats are not all deployed at once, that they are deployed radially away from the upper stage rather than in the direction of flight and that the deployment speed is in the range 1–3 m/s. These assumptions will be further elaborated and specified by the QB50 Orbital Dynamics Working Group (ODWG) in the first half of 2012.

The interface between the deployment system and the upper stage of the rocket transfers the loads from the launch vehicle to the integrated payload structure. This is a crucial part for the use of the Shtil-2.1 as the launch vehicle was originally not designed for the launch of small satellites and as a result, some the launch loads, such as the maximum mechanical shock loads encountered, are not particularly well suited for satellites. The launcher interface provides the means to partly absorb these loads and not transfer the peak loads to the satellites, for instance by absorbing these using shock damping systems.

12. Requirements for CubeSats, technical specifications

The requirements for CubeSats and the technical specifications are provided in the QB50 Interface Control Document (ICD) which is an 'Applicable Document'. The ICD controls the interface to the QB50 deployment system and provides the guidelines for CubeSat development, i.e.

- Compatibility with the CubeSat Standard
- Science sensors specifications
- Science sensor accommodation, electronics
- Lifetime requirements
- Attitude Determination and Control Subsystem (ADCS)
- Electrical Power Subsystem (EPS)
- Telemetry, Tracking and Command (TT&C) subsystem
- On-Board Data Handling (OBDH)
- Thermal control
- Environmental testing
- Model philosophy
- Interface to the deployment system
- Payload environmental requirements

In the course of the Project, the ICD will be frequently updated as new technical or interface information becomes available, in particular concerning the deployment system and the launch vehicle.

13. Schedule

15 February 2012	Issue by VKI of the 'Call for CubeSat Proposals for QB50' on the QB50 website
31 March 2012	Deadline for submission of CubeSat proposals to VKI
1 - 30 April 2012	Proposal clarification period/evaluation of the proposals
2 - 3 May 2012	Meeting of the Selection Committee at VKI, selection of 50 atmospheric and IOD CubeSats
7 - 11 May 2012	Individual notification of selected/non-selected CubeSat teams
11 May - 30 Sep 2012	Securing the funding for CubeSat development

1 October 2012	Submission by selected universities of the signed Contractual Agreement to VKI
Oct 2012 - Oct 2014	CubeSat development at universities
March 2013	Preliminary Design Reviews (PDRs) of all 50 CubeSats at the premises of the participating universities
March 2013	Preliminary Design Review of the deployment system at ISIS
July 2013	Shipment of the standard sensors for atmospheric research or simulators from MSSL to universities
November 2013	Critical Design Reviews (CDRs) of all 50 CubeSats at the premises of the participating universities
November 2013	Critical Design Review (CDR) of the deployment system at ISIS
Nov-Dec 2014	CubeSat flight models environmental testing
January 2015	CubeSat flight models delivery to ISIS
February 2015	Launch campaign preparation workshop at VKI
February 2015	Flight Readiness Review (FRR) at VKI
end February 2015	Shipment of all 50 CubeSat flight models integrated into the deployment system from ISIS to the launch site
1 Mar-mid Apr 2015	Launch campaign
mid Apr 2015	**Launch**
mid Apr - mid Jul 2015	QB50 flight operations
January 2016	Final QB50 Workshop at VKI

14. QB50 Consortium, Project management, communication flow

The QB50 Project is carried out by a *Consortium* of 14 institutes/industries led by the von Karman Institute for Fluid Dynamics. The QB50 Project also has an advisory structure comprising the

- Advisory Committee (chair: A. Smith)
- Sensor Selection Working Group (SSWG) (chair: A. Smith)
- Orbital Dynamics Working Group (ODWG) (chair: G. Kerschen)
- Ground station network and Frequency allocation Working Group (GFWG) (chair: G. Shirville)

The Working Groups have the task to advise the Project in certain areas where special expertise is required. Each Working Group has between 15 and 17 members. The SSWG has already had 4 meetings in the first half of 2011. The work and conclusions of the SSWG are described in a 60-page report which can be downloaded from

https://www.qb50.eu/sswg_report.pdf (available from 1 March 2012)

The report gives full details on all sensors (selected and not selected) and the rationale why certain sensors were selected and others not. It also gives the names and addresses of the experts for the various sensors who can be contacted for more information.

The ODWG had its first meeting on 3 February 2012. Among other activities it will recommend the optimal CubeSat deployment scenario in orbit bearing in mind launch vehicle and deployment system constraints. The ODWG will also calculate CubeSat trajectories and compare simulated with actual CubeSat trajectories, predicted and actual times and locations of re-entry, using different trajectory simulation software tools, atmospheric models and CubeSat ballistic coefficients. During QB50 missions operations in 2015, all this information will be displayed in the three Mission Control Centres around the world.

The GFWG has a number of tasks, such as assisting the CubeSat teams participating in QB50 with the preparation of proposals for frequency allocation to the Frequency Coordination Panel of the IARU (International Amateur Radio Union) and the subsequent notification of the frequencies to the ITU (International Telecommunication Union), supporting the operational readiness of the GENSO network of ground stations in time for the QB50 mission, and supporting the initial acquisition and identification of the CubeSats by the United States Space Surveillance Network after their deployment. The request for frequency allocation has to be done already in early 2013.

Regarding communication flow, requests for clarification should be addressed to the following persons:

Function / Area of expertise	***Name***	***Institution***	***E-mail***
Project Coordinator	Jean Muylaert	VKI	jean.muylaert@vki.ac.be
Principal Investigator	Ruedeger Reinhard	VKI	reinhard@vki.ac.be
Science Sensors	Alan Smith Dhiren Kataria	MSSL MSSL	as@mssl.ucl.ac.uk dok@mssl.ucl.ac.uk
Launch campaign, Legal Issues	Jeroen Rotteveel	ISIS	jeroen@isispace.nl
Systems Engineer	Daniel Faber	VKI	daniel.faber@vki.ac.be
ADCS and GPS	Vaios Lappas	SSC	v.lappas@surrey.ac.uk

RF Communications	Wouter Weggelaar	ISIS	w.j.weggelaar@isispace.nl
Deployment System	Cesar Bernal	ISIS	c.bernal@isispace.nl
Mission Control Software and Centre	Muriel Richard	EPFL	muriel.richard@epfl.ch
Data Processing and Archiving Centre	Didier Moreau	BIRA	didier.moreau@busoc.be

15. QB50 Workshops

The biannual QB50 Workshops are particularly important as they provide an opportunity for all participating CubeSat teams, Consortium Partners and Advisory Committee and Working Group members to disseminate and exchange information. VKI will organise two QB50 Workshops every year, the winter workshop at the end of January/early February, the summer workshop in June, both at VKI. The workshops can be attended by up to 120 participants, two representatives per CubeSat team, plus representatives of the Consortium Partners and the members of the Advisory Committee and the two still existing Working Groups. All Workshops will be preceded by parallel meetings of the Working Groups. The winter workshop will be followed by a meeting of the Advisory Committee.

As the Workshops already attract many members of the CubeSat community it makes sense to combine one of the workshops with a major CubeSat Symposium. For various reasons, the summer Workshop was chosen for this combination, starting with the 6th QB50 Workshop/5th European CubeSat Symposium in June 2013.

16. QB50 Project elements funded by the EU

The FP7 Grant by the European Union (EU) can cover the following elements

- 75 % of the launch cost,
- 75 % of the custom-designed deployment system cost
- 75 % of the cost of the standard sensors for the science units of the atmospheric CubeSats and some IOD CubeSats and appropriate documentation,
- 75 % of the cost for launch services and interfaces to the launch vehicle authorities,
- 75 % of the cost for the transport of the 50 CubeSats from the Netherlands to the launch site,
- 75 % of the cost of all CubeSat related activities during the launch campaign (e.g. functional checkout as required, integration of the CubeSats into the launch vehicle),
- Guidance and advice (if requested) during the CubeSat development.

With regard to the cost, there is a funding gap which has to be covered by the participating CubeSat teams. It is currently assumed that each CubeSat team will have to make a contribution to the mission cost according to the following table

CubeSat units	Carrying sensor set	Financial Commitment
2	yes	20 k€
2	no	60 k€
3	yes	40 k€
3	no	90 k€

17. Deliverables by participating CubeSat teams in the course of the Project

Selected CubeSat teams are required to

- Submit a letter to VKI from their funding source(s) and/or an industrial sponsor and/or the university guaranteeing the timely provision of funding for the development of their CubeSat,
- Submit a Contractual Agreement to VKI signed by the participating university/institute,
- Supply the required documentation in a timely manner,
- Conduct the major Project reviews (PDR, CDR, FRR),
- Operate their CubeSat in orbit (expected lifetime is about 3 months),
- Provide processed science and selected housekeeping data to the QB50 Data Processing and Archiving Centre (DPAC) within 6 months after the end of operations,
- Submit copies of all QB50 related papers and conference abstracts to VKI

18. Submission of processed science and housekeeping data to the DPAC

The CubeSat teams will be in charge of the operations of their CubeSats and are expected to submit all science data, key housekeeping data and appropriate documentation to the QB50 Data Processing and Archiving Centre (DPAC) within 6 months after the end of the mission. The Centre will be located in the Belgian User Support and Operation Centre (BUSOC) in the Belgian Institute for Space Aeronomy (BIRA) in Brussels. The QB50 DPAC has the following tasks

- Serving as the single point of contact between the QB50 Project and the CubeSat teams regarding science and housekeeping data, e.g. format specification,
- Verification (checking for completeness) and cataloguing of the data submitted to DPAC by the CubeSat teams,
- Support of the CubeSat teams in producing the necessary documentation describing their data set,
- Transfer of the data files into a uniform, user-friendly format,
- Handling of requests for data by the user community and providing clarifications to the user community if requested,
- Archiving of all data and documentation

19. Correlated scientific data analysis

A data set that has been submitted by a participating CubeSat team to the DPAC still belongs to the CubeSat team which has the Intellectual Property Rights (IPR). The data will be part of a 'data pool' which can be accessed by all teams for correlated data analysis. This is not only valuable for scientific data analysis but also for identifying and eliminating corrupted data.

Correlated evaluation of all QB50 science data will also be made by the Institute for Atmospheric Physics (IAP) in Kühlungsborn in Northern Germany, which is one of the partnering institutions in the QB50 Consortium. In the years before the launch of QB50, IAP will provide science support to the Project, and will interface with the DPAC on specifying the preferred, user-friendly formats for the science and housekeeping data. About 9 months after the end of the mission, IAP will receive all science data for scientific data analysis. Correlations of the data will be made and apparent discrepancies will be pointed out and analysed in cooperation with the CubeSat teams.

Furthermore, the QB50 science data will be correlated with remote-sensing observations from the ground by lidars and radars up to 110 km altitude and with in-situ measurements by experiments on sounding rockets up to 350 km altitude, if such data are available and are provided by the experimenter teams. IAP have their own lidar and radar sites but data from the most important lidar and radar sites located in other parts of the world will also be used. The QB50 science data will also be correlated with the relevant remote-sensing observations of the MLT region by Earth observation satellites in higher orbits (600-800 km). IAP has the intention to organise 'lower thermosphere data analysis and correlation workshops' with all interested parties.

20. Suggested outline for CubeSat proposals, page limits

Proposals for CubeSats for QB50 are solicited by CubeSat teams from either

- a single university/institute, or
- two or more universities/institutes in collaboration, or
- a university/institute and an industrial company in collaboration (in this case the university/institute must have the lead).

A university/institute can be involved in more than one proposal. Proposals in response to this Call can be submitted by all universities/institutes interested to participate in QB50, not only those who submitted Letters of Intent.

To minimise the work for the proposing teams and reviewers but at the same time contain all the important information, as a guideline, proposals for atmospheric double CubeSats and special In-Orbit Demonstration (IOD) double or triple CubeSats should be between

15 and 20 pages

These pages include the Cover Page, the Table of Contents, and all tables, figures, photos, tables, references and acronyms. Annexes are in addition. Please use Arial, font size 11 and the usual margins (no less than 2.5 cm from all edges). Experience has shown that proposals much shorter than 15 pages do not contain enough information to make a thorough evaluation of the proposal. On the other hand, there is probably no need to submit a proposal that is longer than 20 pages.

All proposals should follow the same outline. This makes it much easier for the reviewers to quickly find certain topics/facts in the proposal. The suggested outline of proposals is as follows

Cover Page, giving the

- Name of the CubeSat
- Category of the proposal (standard atmospheric double CubeSat, special In-Orbit Demonstration (IOD) double or triple CubeSat, interdisciplinary investigation)
- Name, city, country of the proposing university/institute
- Name, address, telephone number and email address of the Team Leader (Principal Investigator or Project Manager)

Table of Contents with the following chapters

1. The QB50 flight opportunity (max. 1 page)
   (this chapter is mainly required for distribution of the proposal to persons who are not familiar with QB50, e.g. national funding agencies, sponsoring industries, or colleagues inside or outside your university)
2. Satellite design
   2.1 Attitude Determination and Control Subsystem (ADCS)
   2.2 Electrical Power Subsystem (EPS)
   2.3 On-board Computer (OBC), On-Board Data Handling (OBDH)
   2.4 Telemetry, Tracking and Command (TT&C) subsystem
   2.5 Structure, thermal control
   2.6 Budgets
      2.6.1 Mass
      2.6.2 Power
      2.6.3 Link budget, data rate
3. Experiment description and required resources (if applicable)
   (this could be a small scientific or technological experiment that can be accommodated in the functional unit of your double CubeSat or it could be a longer description of your experiment if you are proposing an IOD CubeSat)
4. Ground segment (availability of or at least access to a ground station)
5. Operations (pre-launch operations including final checkout requirements, early in-orbit operations, activities and duration of commissioning, sequence of events, duration of achieving attitude stabilisation, operational modes, housekeeping parameters)
6. Availability of facilities
   (e.g. clean room, test facilities)
7. Expertise of the proposing team and/or the university/institute
   (e.g. past satellite launches)
8. Model philosophy, qualification test plan, AIT
9. Schedule
10. Progress reporting, delivery of test documentation, attendance at Project reviews
11. Expected educational impact of the university's CubeSat project and any special education and outreach activities
12. Acronyms
13. References

Annex 1

- Cost breakdown (hardware, manhours, travel expenses)
- Envisaged funding sources

Annex 2

- CubeSat management, functions of team members
- List of key persons, their role in the team, expertise (short, max. 20 lines CV) and availability throughout the Project duration (give a realistic percentage of the time for each key person)
- Main Point of Contact (this does not have to be the team leader) (name and full address, email, office phone number, mobile phone number). This person should be available all the time during the proposal clarification and evaluation period in April 2012.

Annex 3

Letters of support from

- A senior professor at your university/institute
- A funding agency (a letter at this stage is helpful but not mandatory)
- Industry (collaborating with a university/institute team or sponsoring a CubeSat)

Proposals for special In-Orbit Demonstration (IOD) double or triple CubeSats should follow the same outline. For IOD CubeSats, Chap. 3 will be a major chapter of the proposal, describing in detail the intended investigation.

'Interdisciplinary Proposals' are encouraged. Chapter 5 gives a definition of interdisciplinary science and a few examples of possible interdisciplinary proposals. As a guideline, proposals for interdisciplinary proposals should be between

7 and 10 pages

Interdisciplinary proposals should contain the following chapters

1. The QB50 flight opportunity (max. 1 page)
   (this chapter is mainly required for distribution of the proposal to persons who are not familiar with QB50, e.g. national funding agencies, sponsoring industries, or colleagues inside or outside your university)
2. Background of the scientific investigation
3. Data from the participating CubeSat teams that are requested to carry out the interdisciplinary science investigation and data from other sources for correlated data analysis
4. A schedule, indicating
   - when the data would be needed
   - when the investigation will be carried out
   - when the investigation will be finished
5. A description how the correlated data analysis will be carried out.

21. Selection process and criteria

Selection process

The submission of proposals to VKI will be followed by a proposal clarification and evaluation period. The selection of 50 proposals will be made by the Selection Committee at their meeting on 2-3 May 2012. As a guideline, it is intended to select 40 atmospheric double CubeSats and 10 special In-Orbit Demonstration (IOD) double or triple CubeSats. The numbers can change depending on how many CubeSat proposals of high technical quality and with guaranteed funding are received. The total number of selected CubeSats cannot exceed 50 because of payload volume and mass limitations on the launch vehicle. All proposing teams will be individually notified in the week 7-11 May of the outcome of the selection process.

The selected teams will be asked to obtain a formal letter from their funding source(s) guaranteeing the timely availability of funding for the development of their CubeSat. Such a letter should be submitted to VKI preferably within a few months after selection. Thereafter, a Contractual Agreement between the university/ institute of the CubeSat team selected for flight and VKI will be prepared and signed by both parties. The selection procedure is completed with the signing of this Contractual Agreement envisaged to be done no later than 1 October 2012.

Selection criteria
The availability of funding for developing a CubeSat will be a critical issue in the selection process. Availability of a ground station will be an advantage in the selection process but is not a necessary condition for participation in QB50. Access to a ground station is sufficient. This can either be an existing ground station at the premises of the proposing institute or it can be an existing ground station at the premises of another institute (in this case, the access to this ground station will have to be confirmed in writing at the time of proposal submission by the operator of the ground station) or it could be a planned ground station (in this case, the funding for the ground station has to be included in the cost breakdown of the proposal in Annex 1).

The following selection criteria will be applied

- Availability or likelihood of funding,
- Quality of the proposal,
- Compliance with the technical requirements
- Performance of the proposed payload and subsystems
- Expertise of the proposing team
- Availability of or at least access to a ground station
- Educational and outreach impact
- Innovative impact (for IOD CubeSats)
- Where applicable, relevance for the QB50 scientific mission (for IOD CubeSats)

If there are more than 50 proposals of good technical quality and with guaranteed funding the emphasis will be placed on selecting CubeSats from as many different countries as possible. This stresses the global character of QB50 and eases the burden on national funding agencies.

22. Contractual Agreement between the universities selected for flight and VKI

The QB50 Project, represented by VKI as the lead institute of the Consortium, is making a number of elements available to the participating CubeSat teams at a greatly reduced cost. In return, VKI expects the participating CubeSat teams to accommodate and operate the sensors selected by the SSWG for in-situ measurements in the lower thermosphere/ionosphere. If a CubeSat team that has been selected for flight on QB50 decides to drop out of the Project a place in the deployment system is lost. It will become increasingly more difficult to fill this gap the later a CubeSat team drops out.

With each CubeSat team dropping out the QB50 Project suffers as a whole. Therefore, VKI needs an assurance in the form of a Contractual Agreement that a selected CubeSat team will not drop out at a later stage. The exact wording of this Contract will be worked out in the coming months in collaboration with the selected CubeSat teams. A draft Contractual Agreement is given in Annex 1.

23. Applicable document

- Interface Control Document (ICD) for CubeSats participating in QB50, available from 1 March 2012

24. Reference documents

- SSWG Report on QB50 candidate and selected sensors, available from 1 March 2012
- GFWG Report on communications, available from 1 March 2012
- CubeSat Design Specification Rev. 12, August 2009 http://www.cubesat.org/images/developers/cds_rev12.pdf

25. Acronyms

ADCS	Attitude Determination and Control Subsystem
AIT	Assembly, Integration and Testing
BIRA	Belgian Institute for Space Aeronomy (in Brussels)
CDR	Critical Design Review
COTS	Commercial-Off-The-Shelf (components)
CPU	Central Processing Unit
DPAC	Data Processing and Archiving Centre (in Brussels)
EM	Engineering Model
EPFL	Ecole Polytechnique Fédérale de Lausanne
EPS	Electrical Power Subsystem
EU	European Union
FIPEX	Flux-Φ-Probe Experiment
FM	Flight Model
FRR	Flight Readiness Review
GFWG	Ground station network and Frequency allocation Working Group
IAP	Institute for Atmospheric Physics (in Northern Germany)
ICD	Interface Control Document
INMS	Ion/Neutral Mass Spectrometer
IOD	In-Orbit Demonstration (CubeSats)
IPR	Intellectual Property Rights
ISIS	Innovative Solutions In Space BV
ISS	International Space Station
ITAM	Institute of Theoretical and Applied Mechanics (in Russia)
MCC	Mission Control Centre
MSSL	Mullard Space Science Laboratory (in the UK)
NPU	Northwestern Polytechnic University
NSF	National Science Foundation (in the US)
OBDH	On-Board Data Handling
ODWG	Orbital Dynamics Working Group
PDR	Preliminary Design Review
POD	Picosatellite Orbital Deployer
RTD	Resistive Thermal Devices

SSC	Surrey Space Centre
SSLLC	Space Systems Limited Liability Company (Atherton, California)
SSWG	Sensor Selection Working Group
TT&C	Telemetry, Tracking and Command subsystem
TUD	Delft University of Technology
VKI	von Karman Institute for Fluid Dynamics

Annex 1:

Draft Contractual Agreement
between the universities selected for flight and VKI
(here for the case of a double CubeSat)

The ….. (department/institute) …… of the University of ……… (city) ……. in……. country)…….. agrees to deliver a flight model CubeSat to VKI in January 2015, in time for a launch in April 2015. The CubeSat will be a double CubeSat, with one unit providing the usual satellite functions (attitude determination and control, uplink and downlink telecommunications, power subsystem including a battery and body-mounted solar cells, on-board data handling and storage by a CPU) and the other unit accommodating the standard sensors for lower thermosphere/ionosphere and re-entry research as selected by the Sensor Selection Working Group (SSWG). Our CubeSat team is free to use any space left in the functional unit of the double CubeSat for a technology package or a sensor of our own choice. We will supply the required documentation in a timely manner, participate in the major Project reviews, carry out the required environmental tests including providing appropriate documentation, operate our CubeSat in orbit and provide our processed science data and key housekeeping data to the QB50 Data Processing and Archiving Centre (DPAC) within 6 months after the end of the mission. VKI will not take out an insurance for the launch vehicle or the participating CubeSats.

All 50 CubeSats will be launched simultaneously on a single launch vehicle (a Russian Shtil-2.1) into a circular orbit at about 320 km altitude, inclination 79º. Due to atmospheric drag, the orbits will decay and the CubeSats will be able to explore all layers of the lower thermosphere/ionosphere down to perhaps 90 km without the need for on-board propulsion. By choosing an optimal deployment scenario, while bearing in mind launch vehicle and deployment system constraints, it is expected that the network will spread out all the way around the Earth after about a month. The lifetime of the CubeSats from deployment until atmosphere re-entry will be about three months.

Our university/institute will make a contribution of 20 k€ to the launch cost. A data set that has been submitted by a participating CubeSat team to the DPAC still belongs to the CubeSat team which has the Intellectual Property Rights (IPR). The data will be part of a 'data pool' which can be accessed by all teams for correlated data analysis.

Deliverables by participating CubeSat teams in the course of the Project

- Submission of a letter to VKI from their national funding agency and/or an industrial sponsor and/or the university guaranteeing the timely provision of funding for the development of their CubeSat,
- Submission of a Contractual Agreement to VKI signed by the participating university/institute,
- Provision of the required documentation in a timely manner,
- Participation in the major Project reviews (PDR, CDR, FRR),
- Operation of their CubeSat in orbit (expected lifetime is about 3 months),
- Provision of calibrated science and selected housekeeping data to the QB50 Data Processing and Archiving Centre (DPAC) within 6 months after the end of operations,
- Submission of copies of all QB50 related papers and conference abstracts to VKI

Papers in refereed journals shall include at the end a proper *Acknowledgement*, referring to the QB50 Project.

Annex 2:

Suggested functions in a CubeSat team

As a suggestion, a typical CubeSat team would have the following functions

- Project management, team leader, cost and schedule control, preparation and submission of a proposal to a funding agency, requesting co-funding from an industrial sponsor,
- Attitude Determination and Control Subsystem (ADCS),
- Telemetry, Tracking and Command subsystem (TT&C),
- Electrical Power subsystem (EPS),
- On-Board Data Handling (OBDH) subsystem, CPU,
- Structure and Harness,
- Thermal subsystem,
- Assembly, Integration and Testing (AIT), CubeSat ground support equipment,
- Launch vehicle and deployment system interfaces, environmental test requirements,
- Identification and selection of environmental test facilities, carrying out the environmental tests,
- Mission analysis,
- Request for frequency allocation (needs to be done 2 years before launch),
- Ground segment (ground station antenna, radio control room, participation in GENSO),
- Software development for OBDH, spacecraft operations and data processing,
- Performance specification and requirements of a particular science or technology payload in the functional unit,
- Accommodation of the standard sensors in the science unit,
- production of progress reports and review documentation,
- CubeSat legislation and regulations,
- Data evaluation, provision of processed science data and key housekeeping data to the DPAC,
- Publication of papers in scientific or technological journals,
- Educational impact and outreach activities, public relations, news releases, establishment and maintenance of a website, maintenance of an archive of all QB50 related publications and documents.

Of course, a single student could carry out several of these functions.