THE QB50 MISSION FOR THE INVESTIGATION OF THE MID-LOWER THERMOSPHERE: Preliminary Results and Lessons Learned

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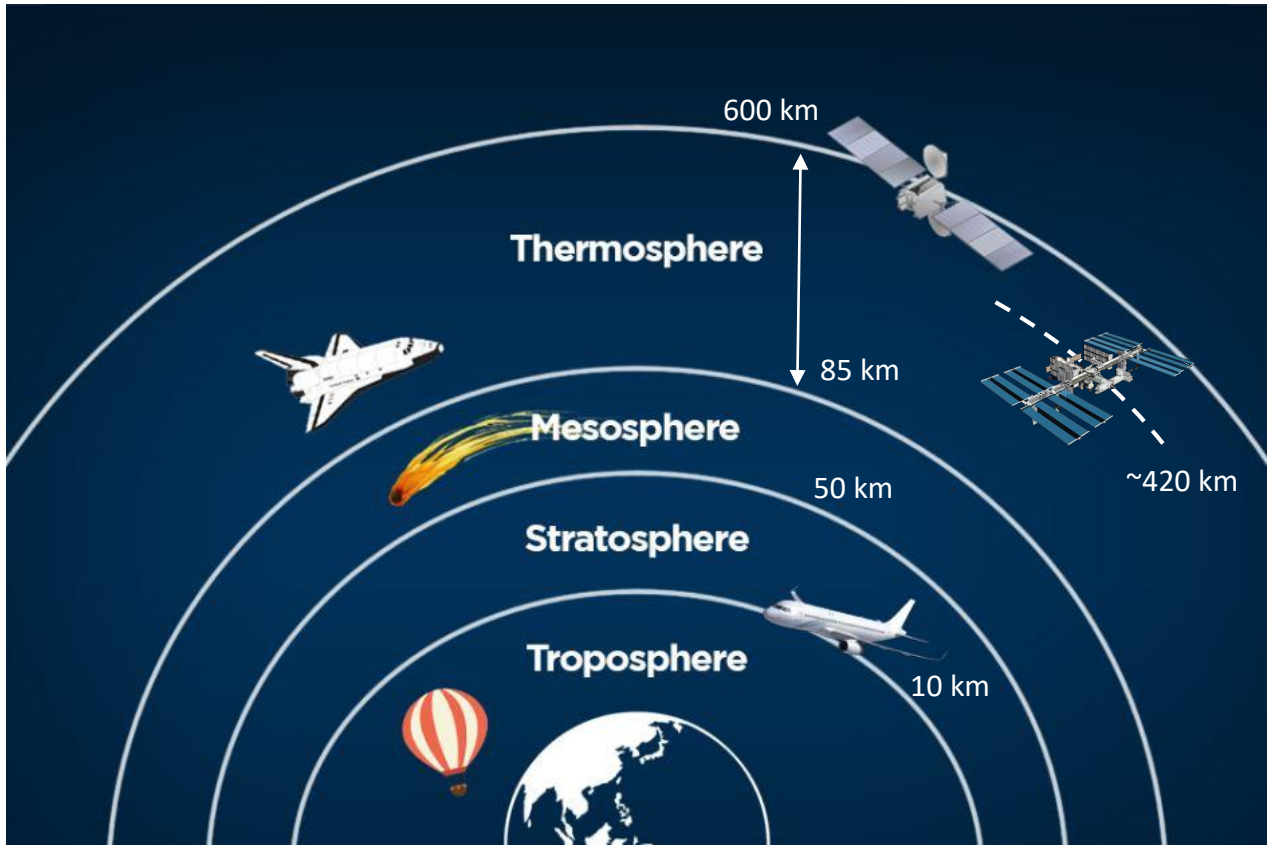
Photo Credit: NASA, NanoRacks

The Project in a Nutshell

- An international project aiming at developing a constellation of CubeSats to investigate the Earth Mid/Lower Thermosphere
- VKI is project leader and coordinates the work of 15 partners across Europe/Russia/China/USA
- 36 CubeSats (initially more than 50) from 24 countries (5 continents)
- A project funded by the European Commission under the FP7 Framework
- 4 main objectives

Why the Mid/Lower Thermosphere and Why with CubeSats?

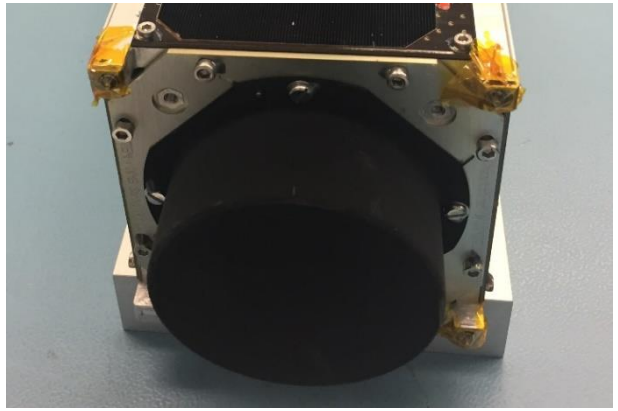


Credit: ABC News

- Less known layer of the atmosphere.
- Too low for big satellites and too high for rockets and radars.
- The constellation will fall from ~420km down to 200km in one year. Scanning the chemistry of the thermosphere.
- CubeSats are cheap and expendables.
- Validate and enhance our understanding of the phenomena in the thermosphere.
- An improved knowledge of the thermosphere density will help in mitigating/assessing the impact site of space debris re-entering the atmosphere.

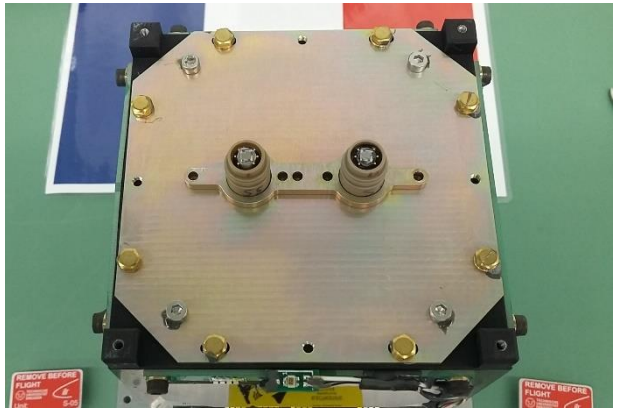
A Constellation of Instruments

10 Ion and Neutral Mass Spectrometers (INMS)



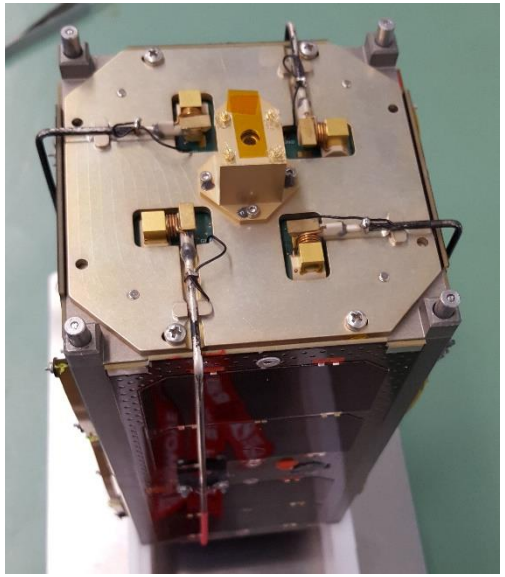
O, O_2, NO, N_2 (and ions)

14 Flux Probe Experiments (FIPEX)



O + O_2

10 multi Needle Langmuir Probes (mNLP)



e^- and T_e

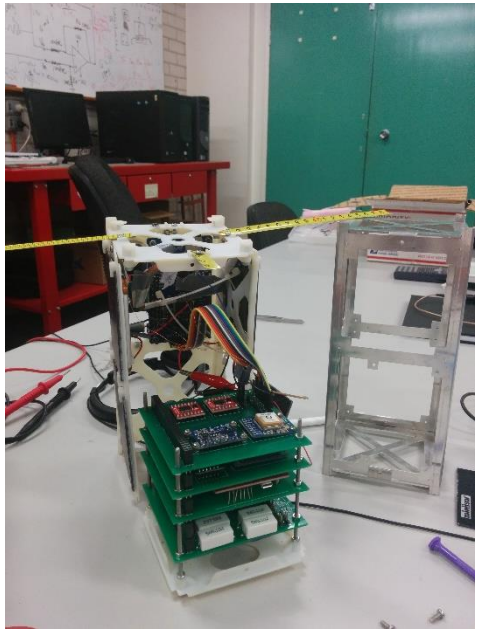
- Give detailed knowledge of the chemical/electric composition of the thermosphere
- 34 sensors distributed in a constellation of CubeSats to have a unique space-time resolution in the thermosphere

From Design to the Assembly

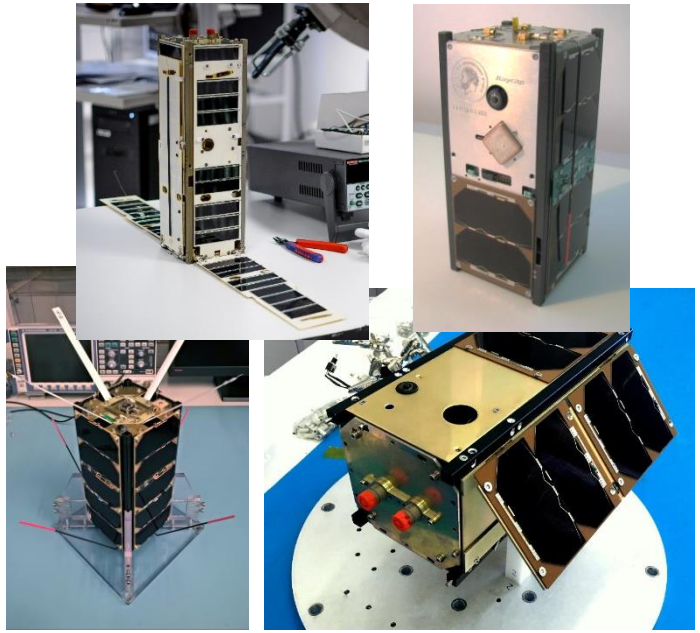
6 Years of Activities

Design

Manufacturing



Assembly



Support and guidance in every phase

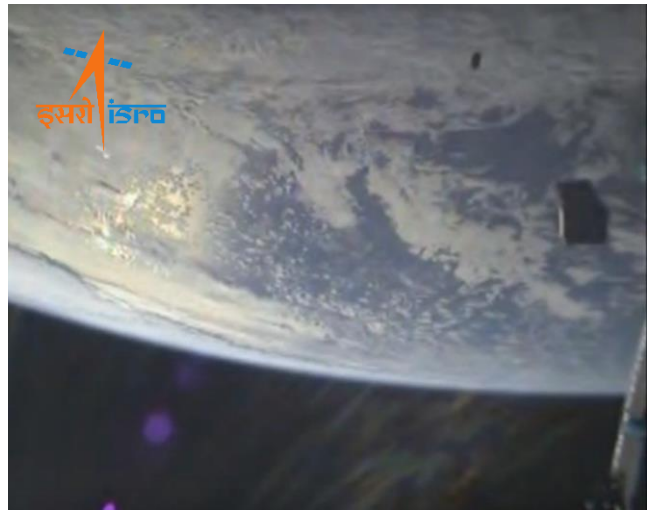
How do We Deploy a Constellation of 36 CubeSats Into Space?

28 CUBESATS FROM THE INTERNATIONAL SPACE STATION

QB50-ISS

- 28 CubeSats
- Altitude 415km
- Inclination 51.6deg
- Launched on 18th April 2017
- Atlas-V Rocket from Cape Canaveral (USA)

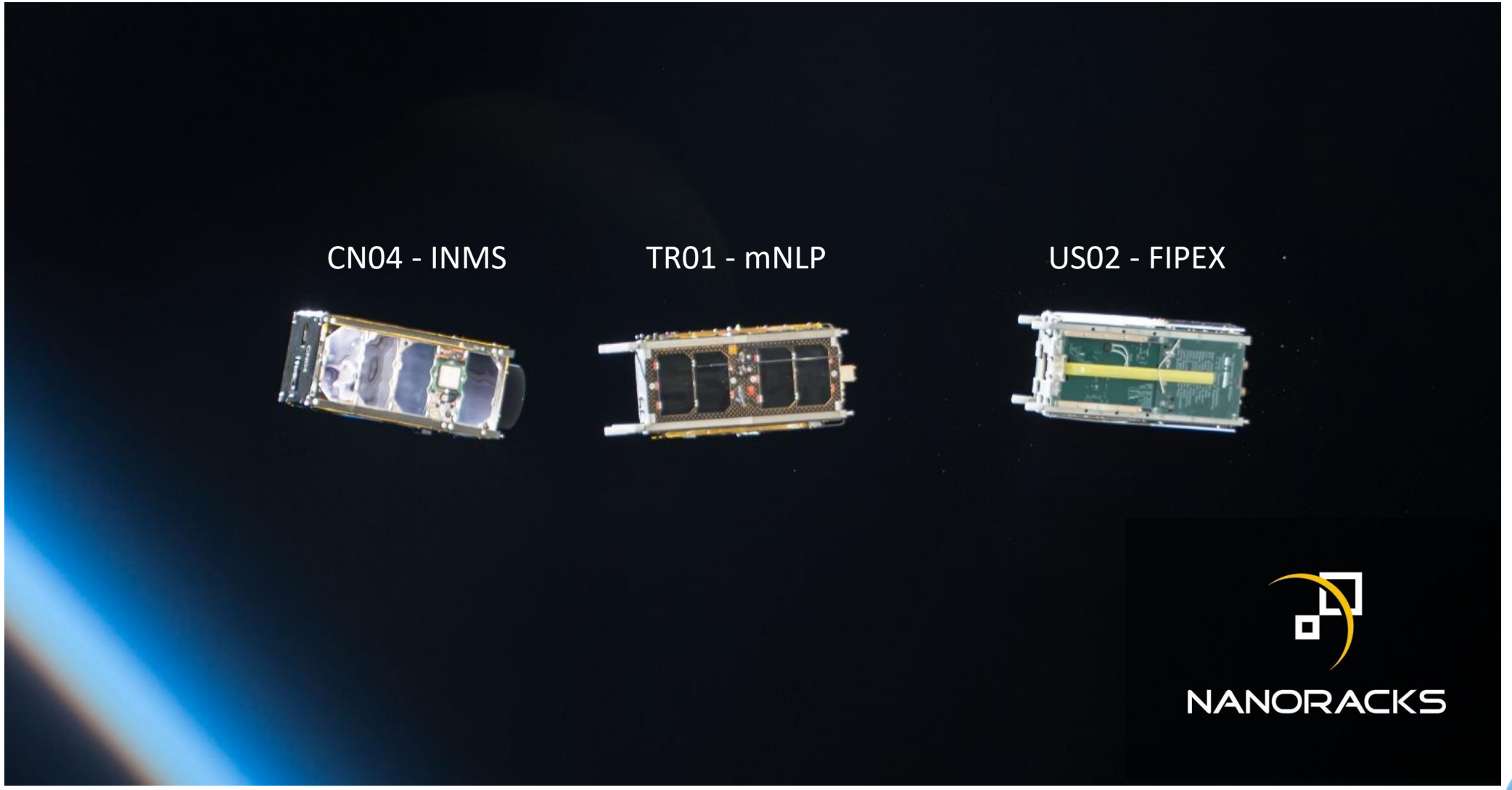
8 CUBESATS WITH THE PSLV INDIAN ROCKET



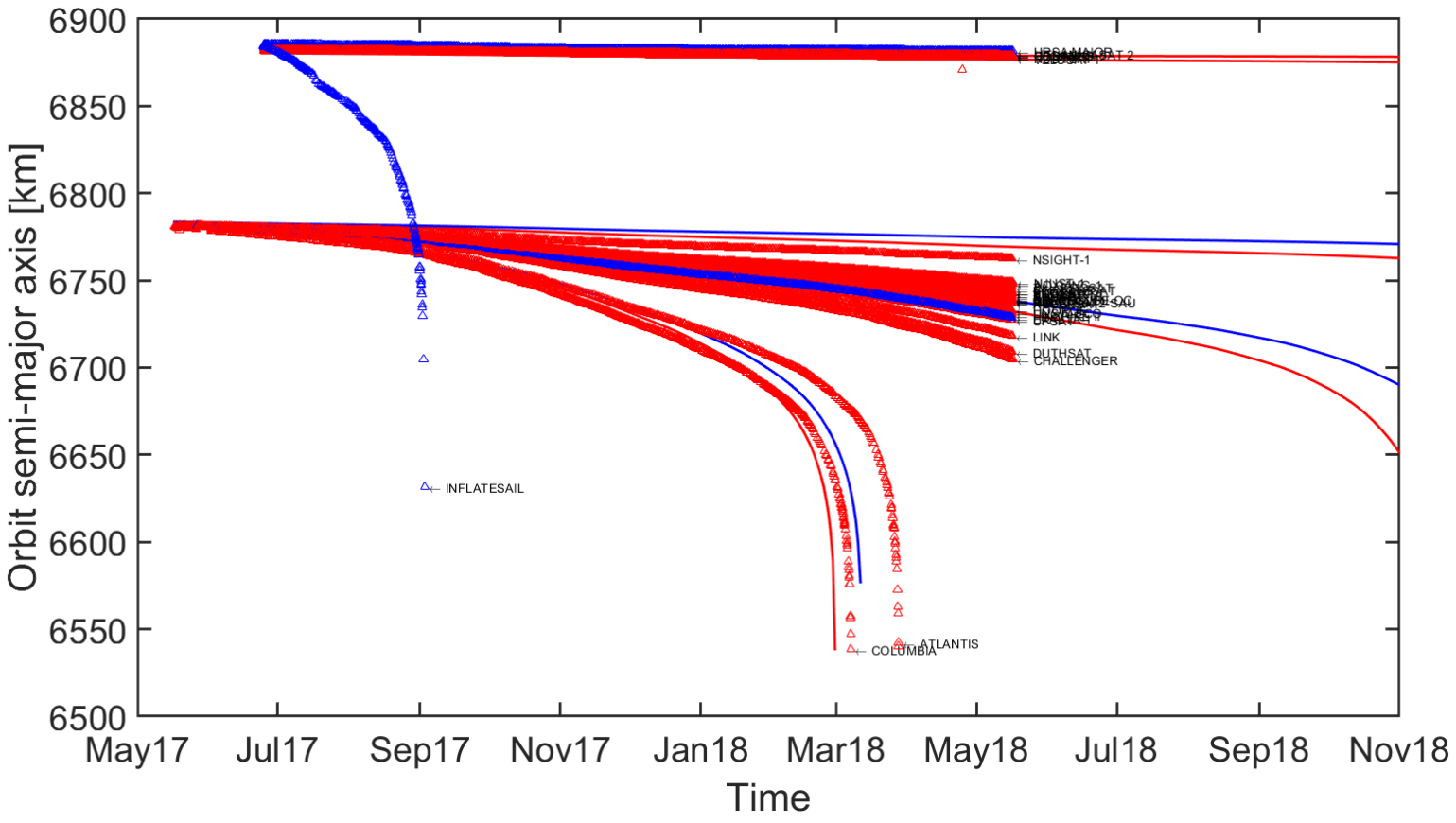
QB50-PL

- 8 CubeSats
- Altitude 500km
- Sun Synchronous Orbit 97.1deg
- Part of the Science Campaign
- Launched on 23rd June 2017
- PSLV Rocket from Satish Dhawan Space Centre

The Operations

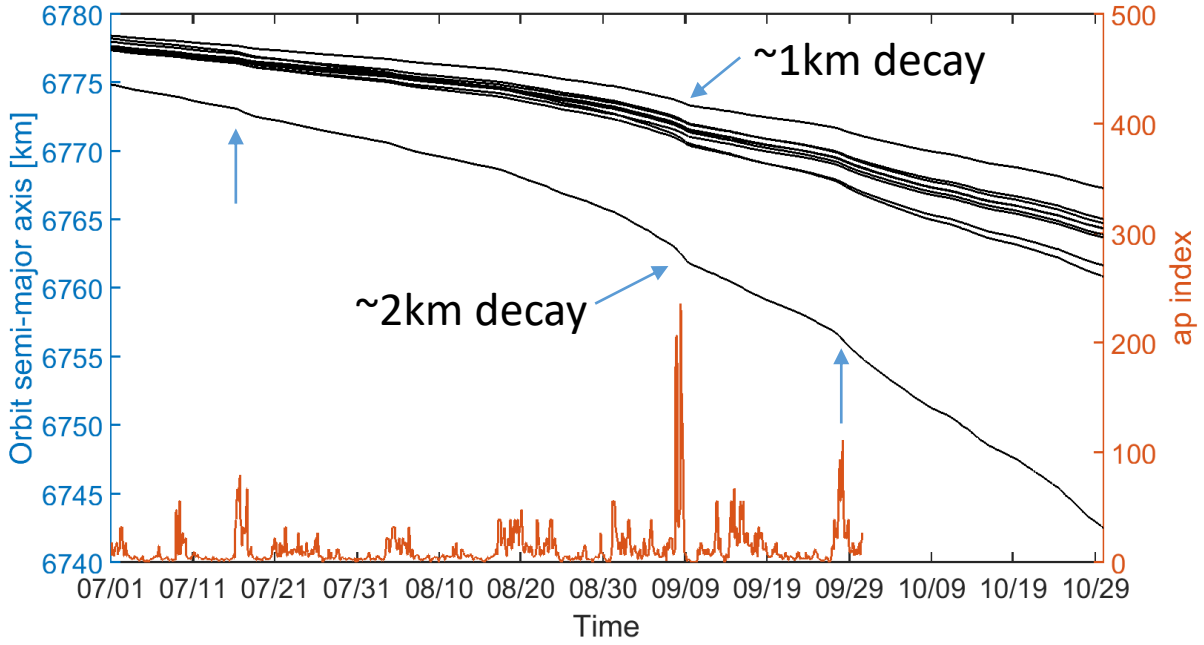


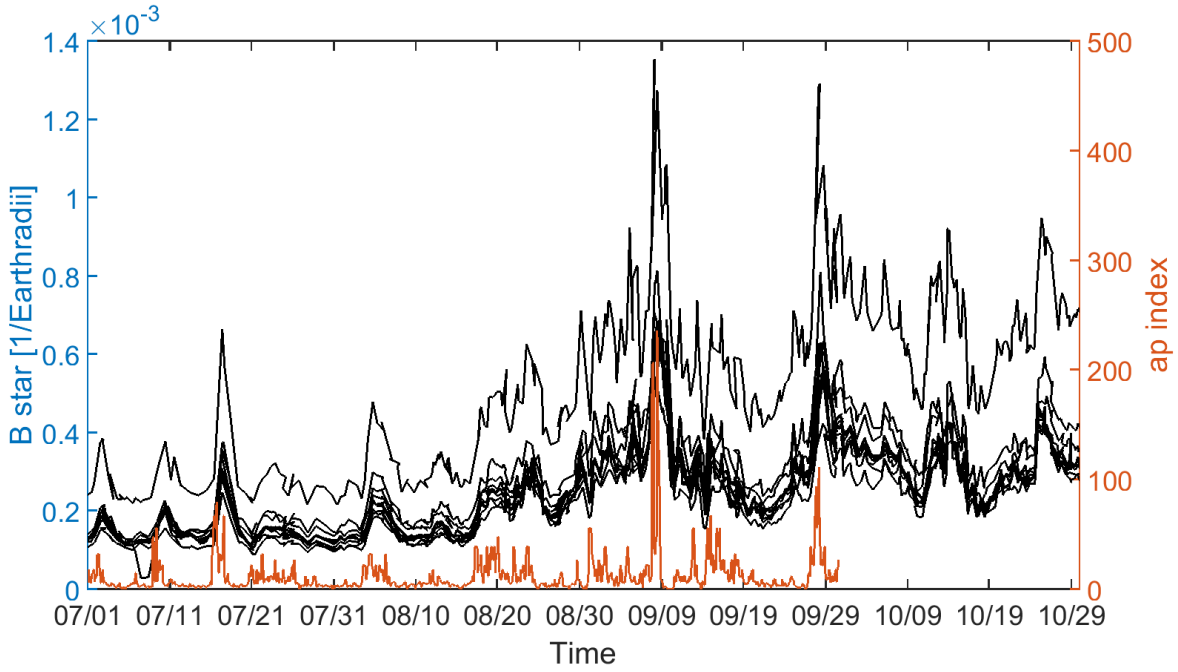
Status of the Constellation – One year later



- Right after deployment: 9 DOA over 36 (75% active)
- 33% inactive over 36 (AU02 and AU03 resurrected, FI01 lost, KR02 alive)
- 3 already de-orbited
- Wide spectrum of achievements
- 1 INMS in commissioning phase +1 in science OPS
- 4 FIPEX in commissioning phase +1 in science OPS
- 1 mNLP in commissioning phase +2 in science OPS

Effect of September 2017 Solar Storm

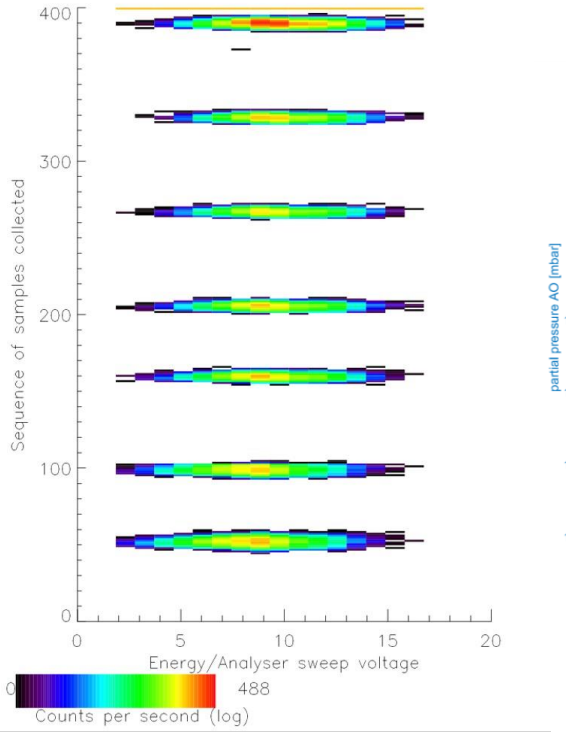


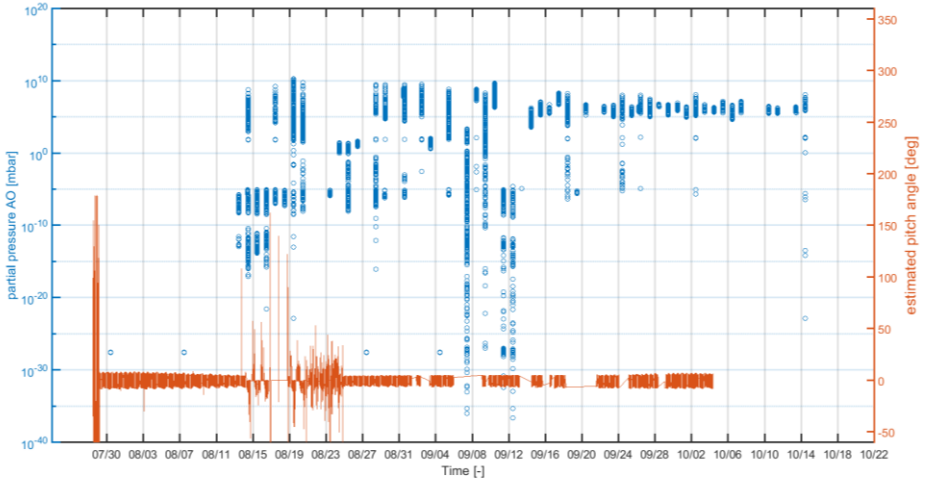


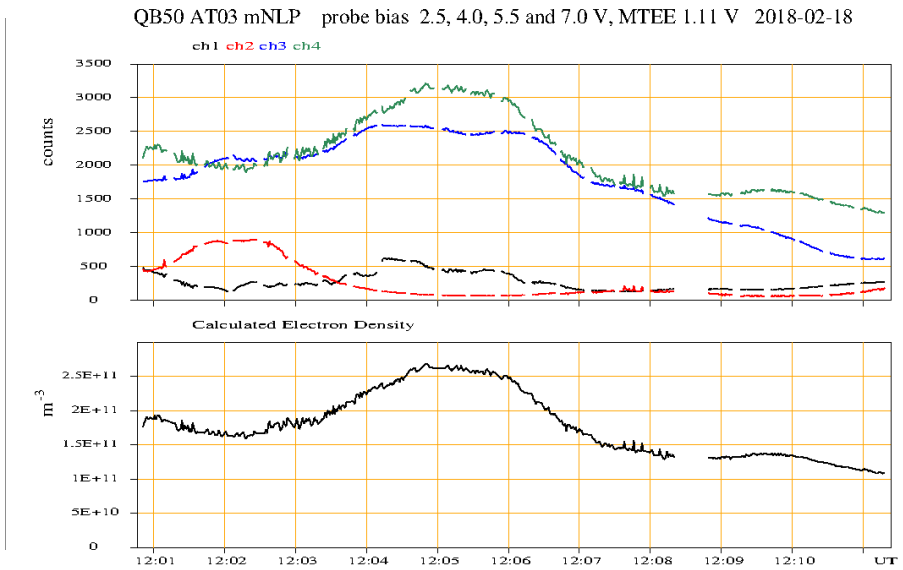
Decoupling of cross section area and atmosphere density from B* term not easy. Atmosphere density is too variable and linked to solar activity.

The Operations

Getting the Data





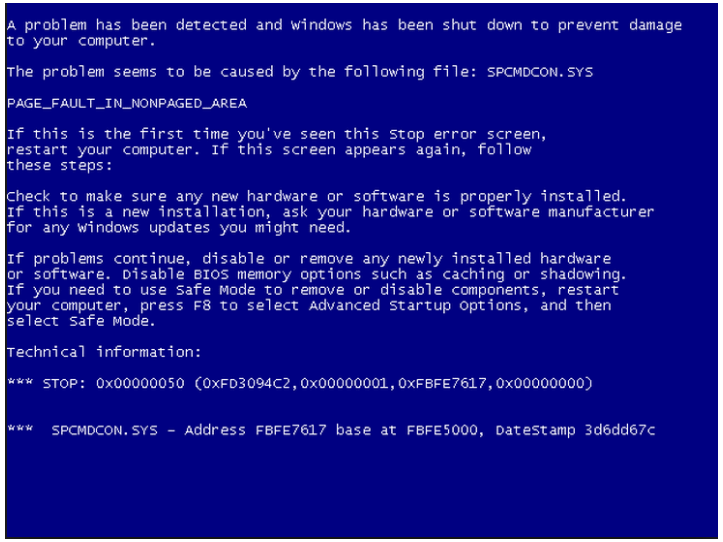


- Getting data down is only the first step
- Commissioning, post-calibration, understanding require a huge investments

Management of a Team

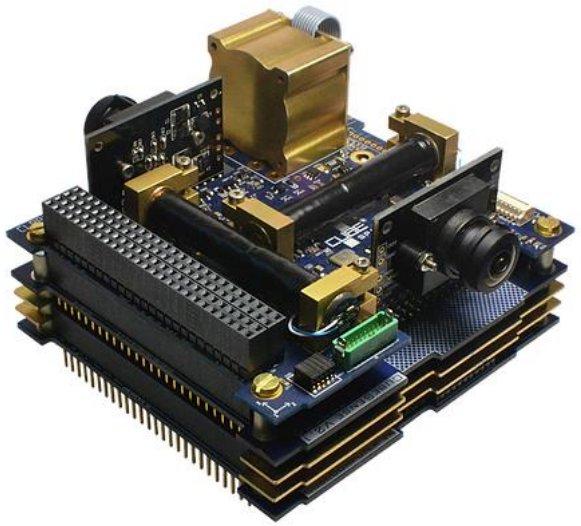
- Assign well-defined roles and responsibilities in the team.
- **Define only one reference system for the design of the complete satellite.**
- **Perform regular/weekly meetings and keep a configuration control document.**
- Start looking into export/import laws of your country from the beginning.
- **Ensure that the objectives and requirements have achievable targets and that they can provide exact values or conditions. This will help to keep track of the progresses**

OBC - Software



- Always include a bootloader in the OBC.
- **Always include an umbilical connector to the OBC that is accessible when the CubeSat is fully integrated.**
- Make sure that the processor and the memory implemented in the OBC are compatible or they provide enough resources to run the software.
- **The software shall include a software upgrade/patch capability.**
- Always implement a way to reset the counters in the CubeSat.
- **Software implementation is a perfect example of the 80/20 rule.**

Attitude Determination Control Subsystem



Credit: CubeSpace

- Verify that the GPS board has the proper firmware to work in space. Usually the GPS hardware is delivered with a ground enabled firmware.
- Magnetorquers are enough if used in orbits higher that 400km altitude. Lower that 400km altitude a combination of magnetorquers and reaction wheels is preferred.
- Residual magnetic dipoles in the CubeSat can generate unwanted magnetic moments in space.
- **Long wires on the solar panels can generate current loops and consequently high dynamic magnetic moments.**
- **The magnetometers are temperature dependent.**

Manufacturing, Integration and Testing

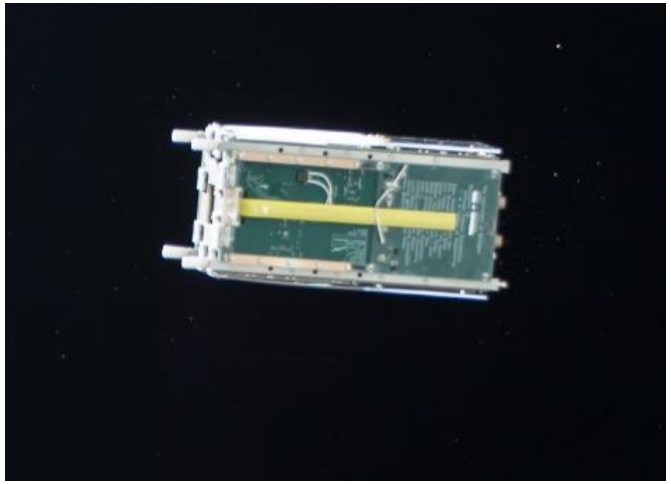
Credit: NASA

- **When receiving a component/subsystem, test it! When assembling a component, test it! When assembling a CubeSat, test it! And then re-test everything again!**
- Never trust the datasheets.
- **60% of the failures during the integration in the deployer is caused by a CubeSat with dimensions out of specs.**
- The reverberation on the TVAC chamber and the impedance mismatch, due to modified environment for example, could lead to damages to the COMM system amplifiers is used.
- **Never use the transceiver with the antenna stowed.**
- The execution of End-To-End Hardware-In-the-Loop tests shall be a priority

Ground Segment

- **The ground station shall come before the CubeSat.**
- Validate the ground station with real transponders in space (e.g. FunCube transponder, ISS APRS) well in advance.
- Have spare parts (e.g. replacement RF cables) available.
- **Experience comes with practice (and frustration).**
- In case of emergency (e.g. the satellite becomes deaf, the link budget is not correct), having access to a more powerful ground station can save the mission.
- Engage the local radio ham community. They have the answer!

Operations



Credit: US02 Team

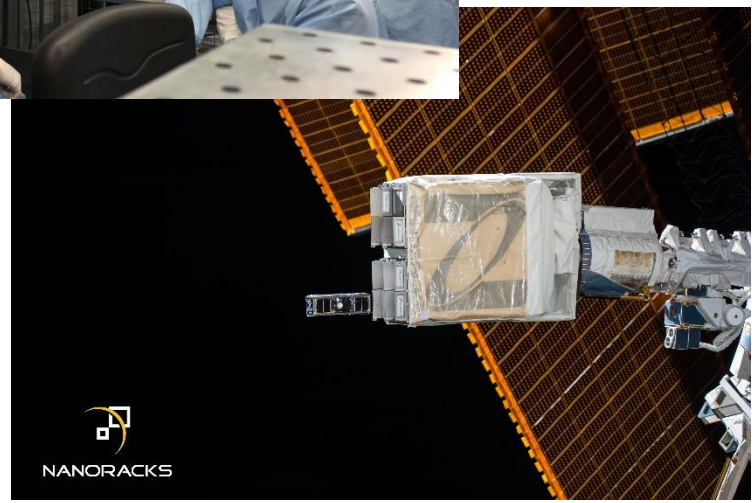
- **The verification of a successful deployment (e.g. an antenna or a boom) can be very uncertain in space.**
- Test your commands on ground eventually.
- **The on-board clock in space can be affected by very high time drifts (e.g. 154 sec in 4 weeks).**
- Include a watchdog to power cycle the entire CubeSat if no ground command is received within 3 days.
- **Most of the failures preventing the CubeSats to reach their objectives are originated by poor testing on ground, unreliable link budgets and poor ADCS design.**
- **You will always have surprises from space.**

Concluding with Some Perspectives

- Science is education, but education is not science
- One single science payload across the constellation (KISS)
- Few and more guided
- Targeting 6U constellation
- ‘Testing’ should be your new religion
- Operations/exploitation need to be funded

- Interested to make QB-NEXT happen, come and talk to me!

The QB50 Project



Thanks to all the Consortium and Teams