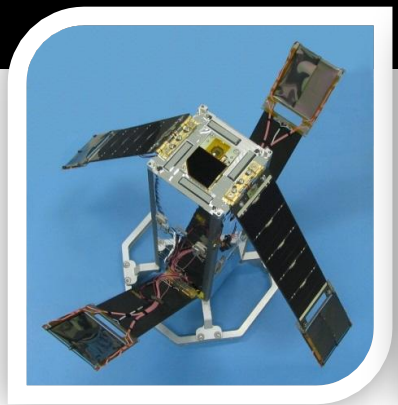
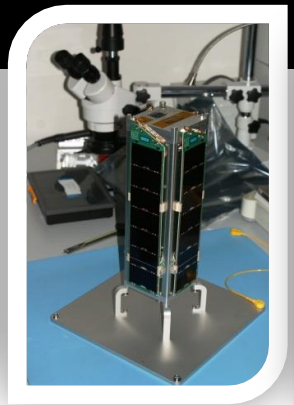
# From Single to Formation Flying CubeSats: An Update of the Delfi Programme

Jian Guo, Jasper Bouwmeester & Eberhard Gill



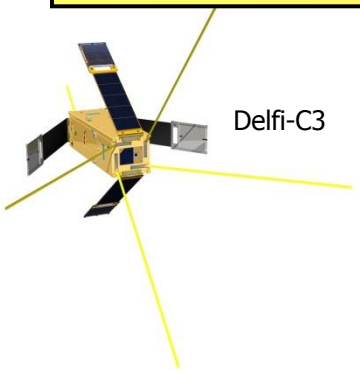


# Outline

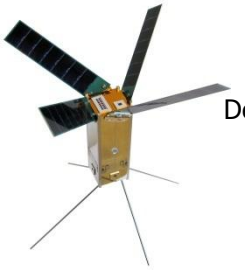
- Introduction
- Delfi-$C^3$ Mission
- Delfi-n3Xt Mission
- Lessons Learned
- DelFFi Formation Flying Mission
- Conclusions

# Introduction

Nano-Sats



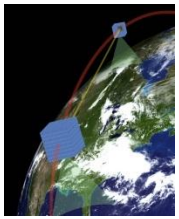
Delfi-C3



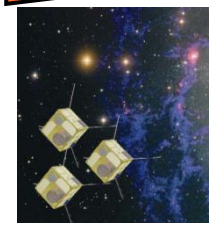
Delfi-NEXT

DelFFi
Formation Flying

Micro-Sats

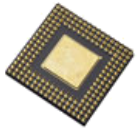


FAST
Formation
Flying

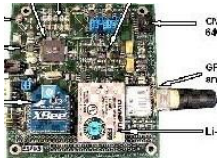


OLFAR

Miniaturized Systems



GPS on a Chip



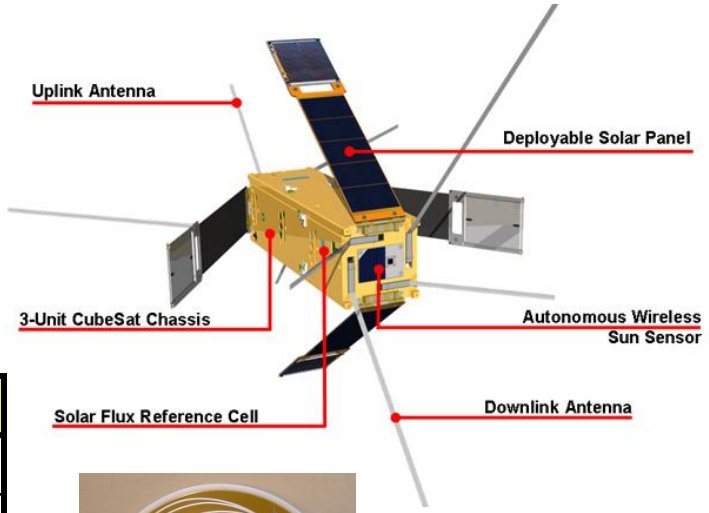
Satellite in a

package

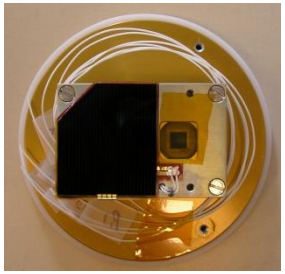
# Delfi-C$^3$ Mission

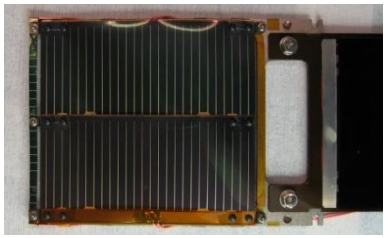
## Overview

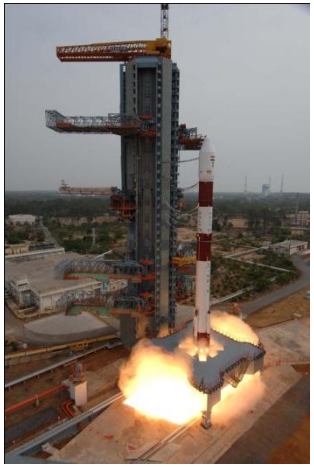
- First Dutch university satellite
- Developed by students in SSE
- Piggyback launch 28th April 2008




| Key Specifications | |
|---|---|
| Dimensions | 100x100x300 mm$^3$ |
| Mass | 2.2 kg |
| ADCS | Passive magnet control |
| CDHS | I2C bus |
| EPS | Decentralized, each PCB protected by microcontroller |
| TTC | Uplink UHF @ 435 MHz, 600 bps FSK;<br>Downlink VHF @ 145 MHz, 1200 bps BPSK |
| Thermal | Passive |
| Payload | Autonomous wireless sun sensors, thin-film solar cells, transponder |



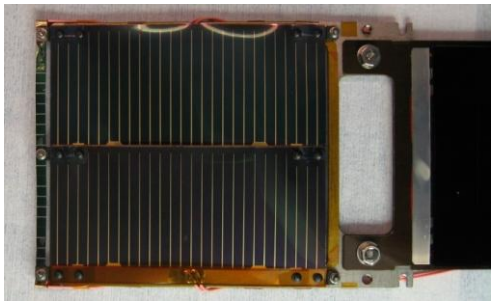




# Delfi-C$^3$ Mission

## Payloads

| AWSS | |
|---|---|
| Sensor Type | Quadrant Sun Sensor |
| Mass | 80 g |
| Dimensions | 60x40x20 mm (lxwxh) |
| Field of view | 90° x90° |
| Inaccuracy | ~ 1° |
| Data rate | 1 Hz |



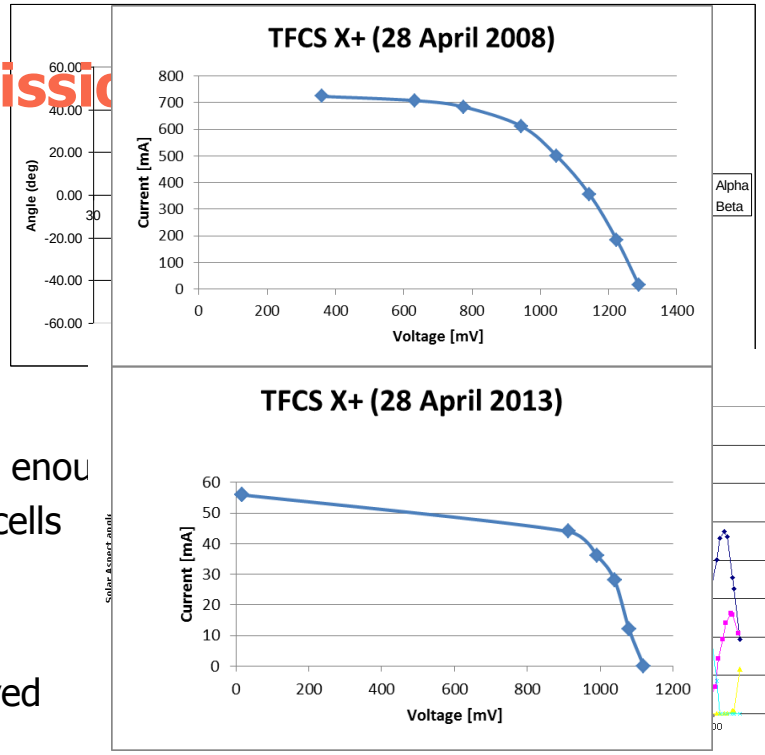
- Thin-film solar cells
  - 50% cost reduction
  - 50% increased power to mass performance

# Delfi-C$^3$ Mission

## Results

**A full missio**

- Mission
  - So far more than 5 years of operations
  - 66 students and ~ 300 radio amateurs
- Payload
  - Telemetry from all payload received
  - AWSS Z+ working, Z- little data, but still useful enou
  - More than 53,000 I-V curves of thin-film solar cells harvested
- Platform
  - All 4 solar panels and 8 Rx/Tx antennas deployed
  - All subsystems fully operational
  - Rotation rate decrease from 5.06 °/s after injection to 0 – 0.7 °/s
  - OBC/subsystems crash occasionally due to onboard difference in clock frequencies (bus issue)
  - Reboot usually completed within a few seconds (but worst case after next eclipse)
  - Downlink always comes back operational



# Delfi-n3Xt Mission

## Overview

### Education

> 60 students on mission

### Technology demonstration

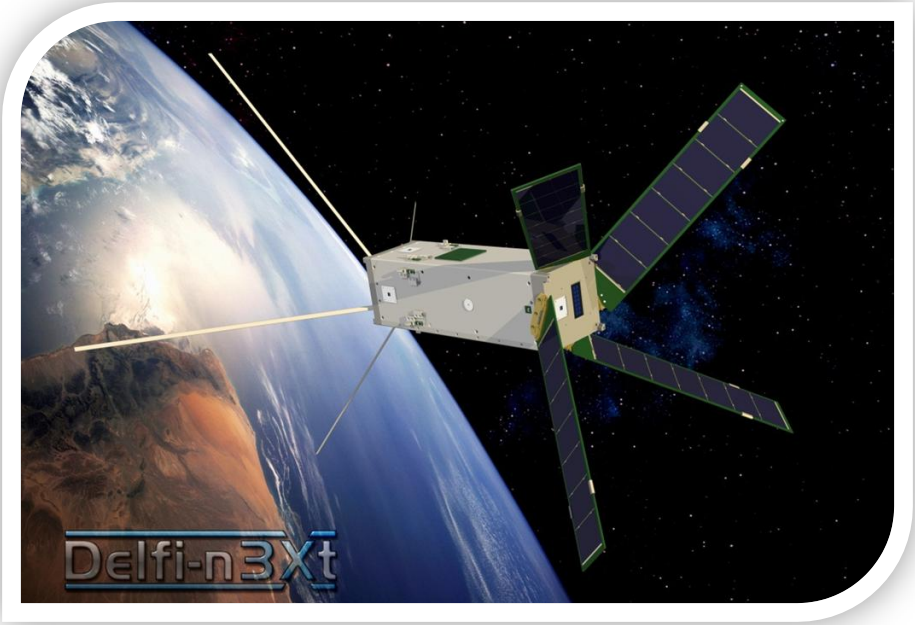
Partners from Dutch space sector

### Innovation

Improvement of bus platform

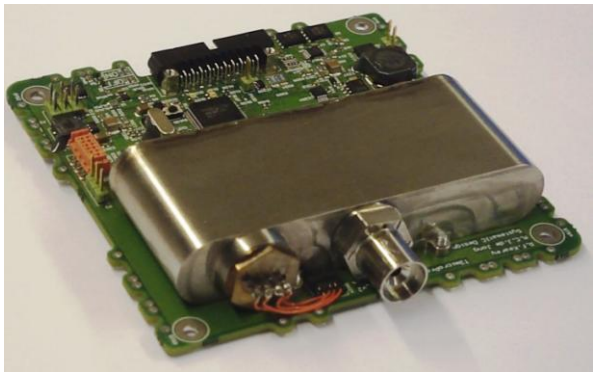
### Research

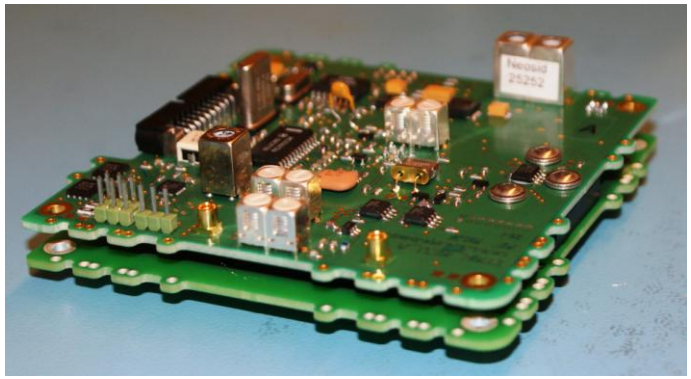
>20 scientific papers

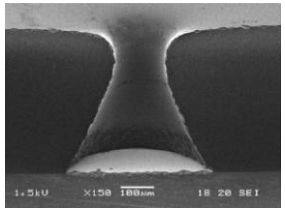


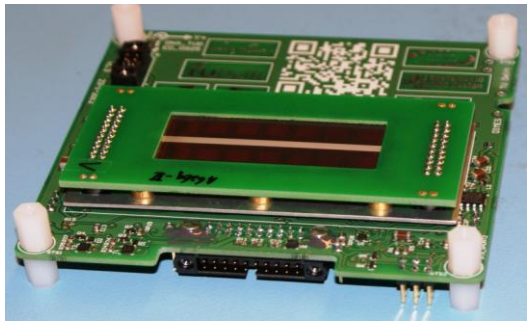
# Delfi-n3Xt Mission

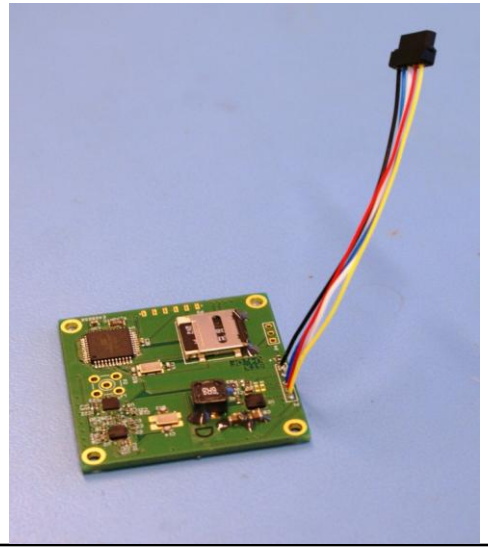
## Payloads





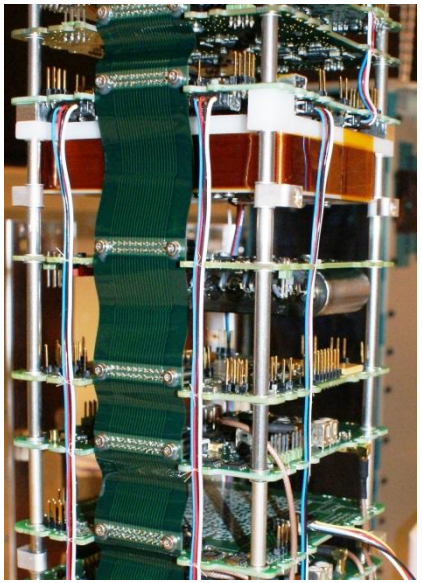


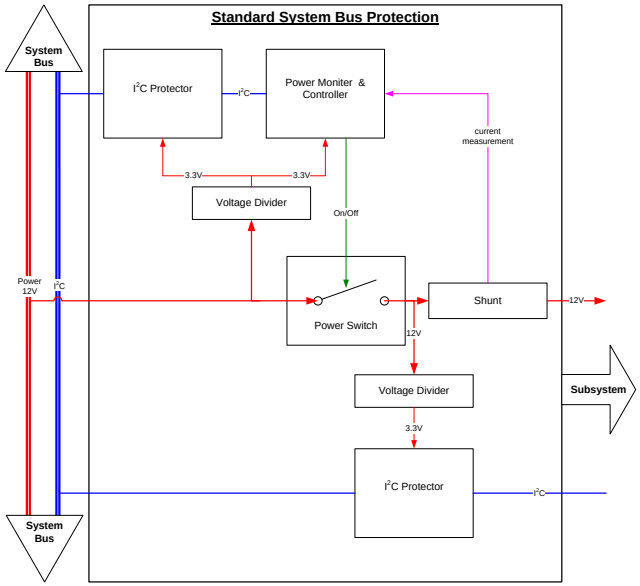


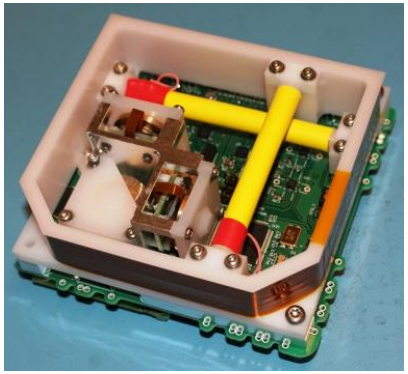


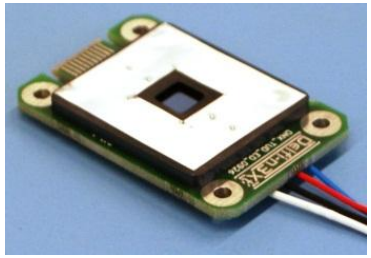
# Delfi-n3Xt Mission

## Platform







| ADCS Subsystem | |
|---|---|
| Parameter | Input |
| Mass | 330 g |
| Power | 1600 mW (max) |
| Volume | 90X90X34.6 $mm^3$ |
| Data | 1 Kbits, 2 Hz |

# Lessons Learned

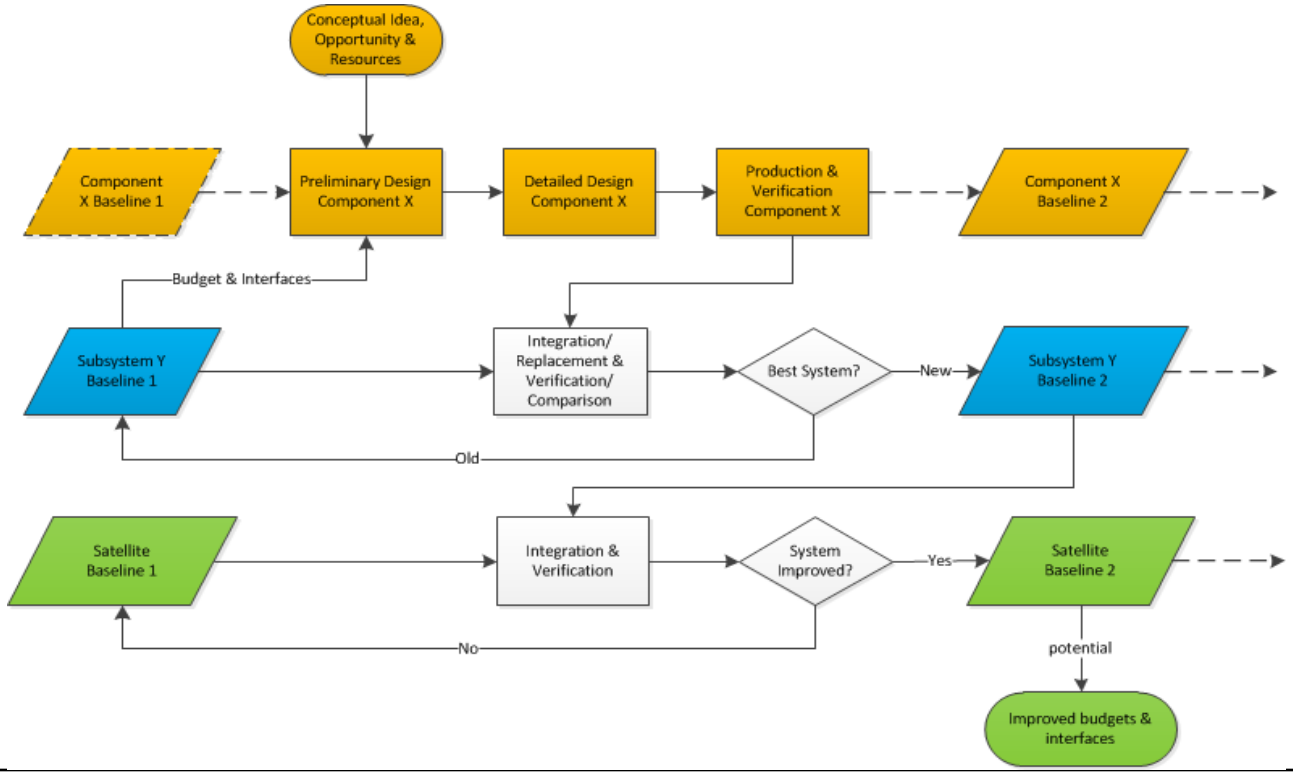
## People

- Experienced engineers are the key for innovation
- Young and dynamic engineers are most motivated for innovation, but….
- An ideal team shall include both of them
- The innovation team shall have hands-on experience on spacecraft development
- CubeSat could be a good way for the quick training of engineers
- A stable core team shall be maintained

# Lessons Learned

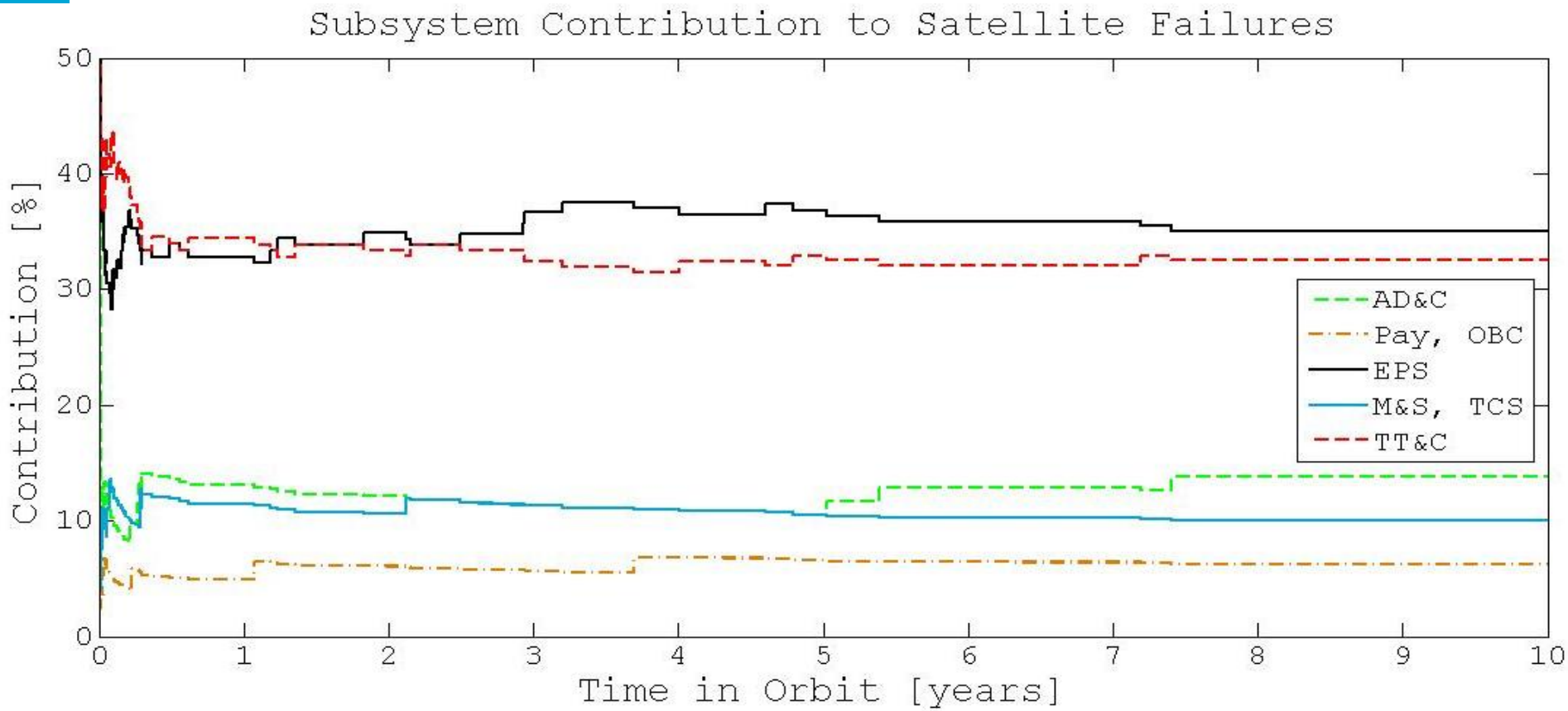
## Process

- Based on documentations or models, rather than people
- Stepwise improvement



# Lessons Learned

## Design




- Buy components at beginning, but never rely on buying

# DelFFi Formation Flying Mission

## QB50 and DelFFi

- QB50
  - An International Network of 50 double or triple-unit CubeSats in Low-Earth Orbits for Lower Thermosphere and Re-Entry Research
  - Supported by European Commission under FP7 Space
  - Launch in 2015 by single launcher
- DelFFi
  - An integrated part of QB50
  - Adjustable spatial scales for multi-point measurements of low thermosphere
  - Demonstration of autonomous formation flying using two CubeSats
  - Hands-on experience for students

# DelFFi Formation Flying Mission

## Concept of Operations

**LEOP**

- Launch, orbit insertion, detumbling, S/C checkout, payload checkout
- Collision avoidance assured by deployer

**Continued Drift Phase**

- Drift without orbit control
- Further test of platform and payload

**Formation Acquisition Phase**

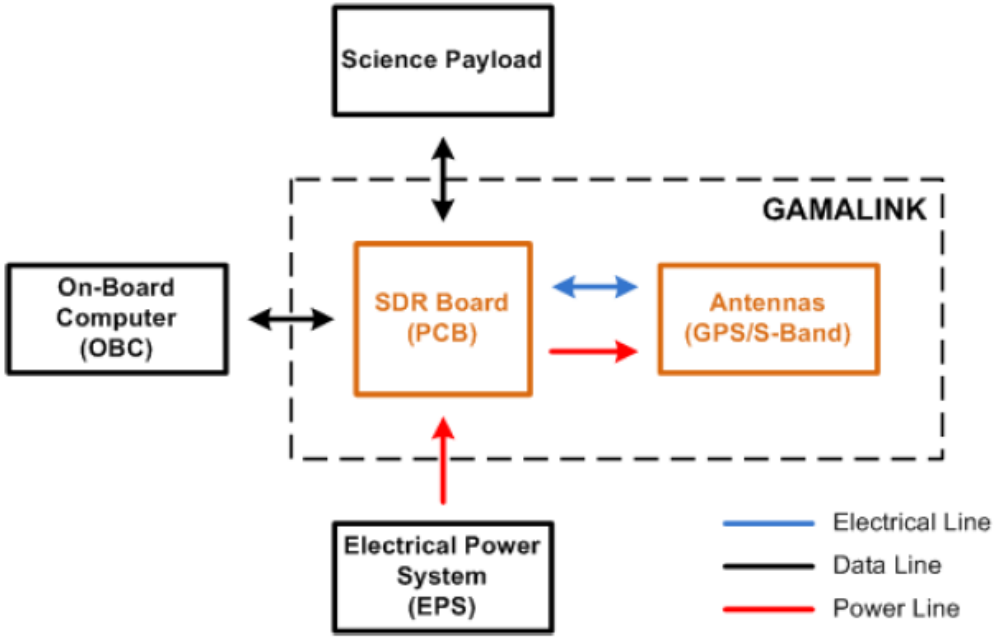
- Commence with certain along-track distance
- End with drift stop maneuvers

**Formation Keeping Phase**

- Using 8 GNC scenarios
- Last for 20-30 days

# DelFFi Formation Flying Mission

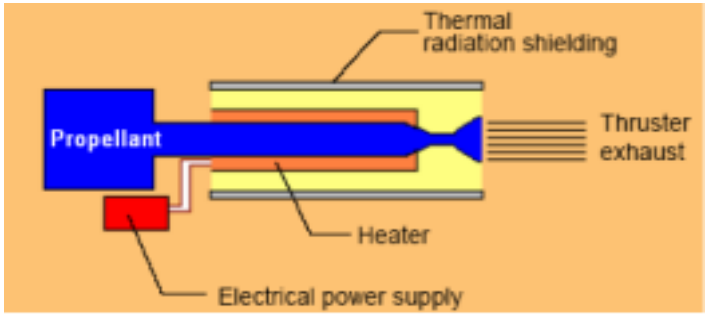
## GAMALINK

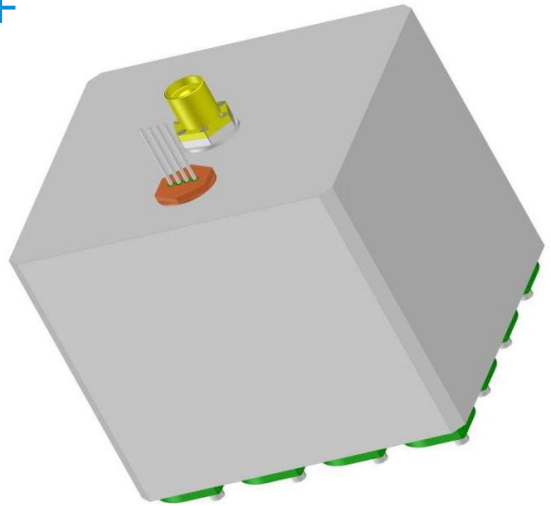


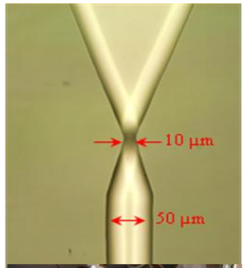

| Parameter | Value |
|---|---|
| Frequency | 2.45 GHz (S-band) |
| Bandwidth | 40 MHz |
| Positioning precision | 5 m |
| PCB size | 80×80×10 $mm^3$ |
| PCB mass | < 100 g |
| Number of antennas | 4 (3 S-band + 1 GPS) |
| Antenna size | ~ 15×15 $mm^2$ (S-band)<br>~ 20×20 $mm^2$ (GPS) |
| Data interface | $I^2C$, UART |
| Supply voltage | 3.3 V |
| Power consumption | < 1.5 W (transmitting)<br>< 200 mW (S-band receiving)<br>< 50 mW (GPS receiving) |

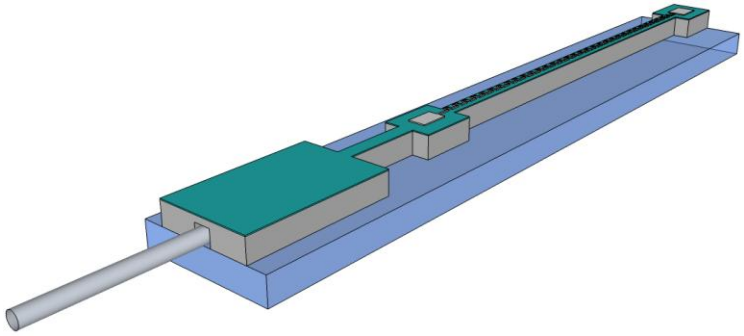
# DelFFi Formation Flying Mission

## Micro-Propulsion System - µPS+



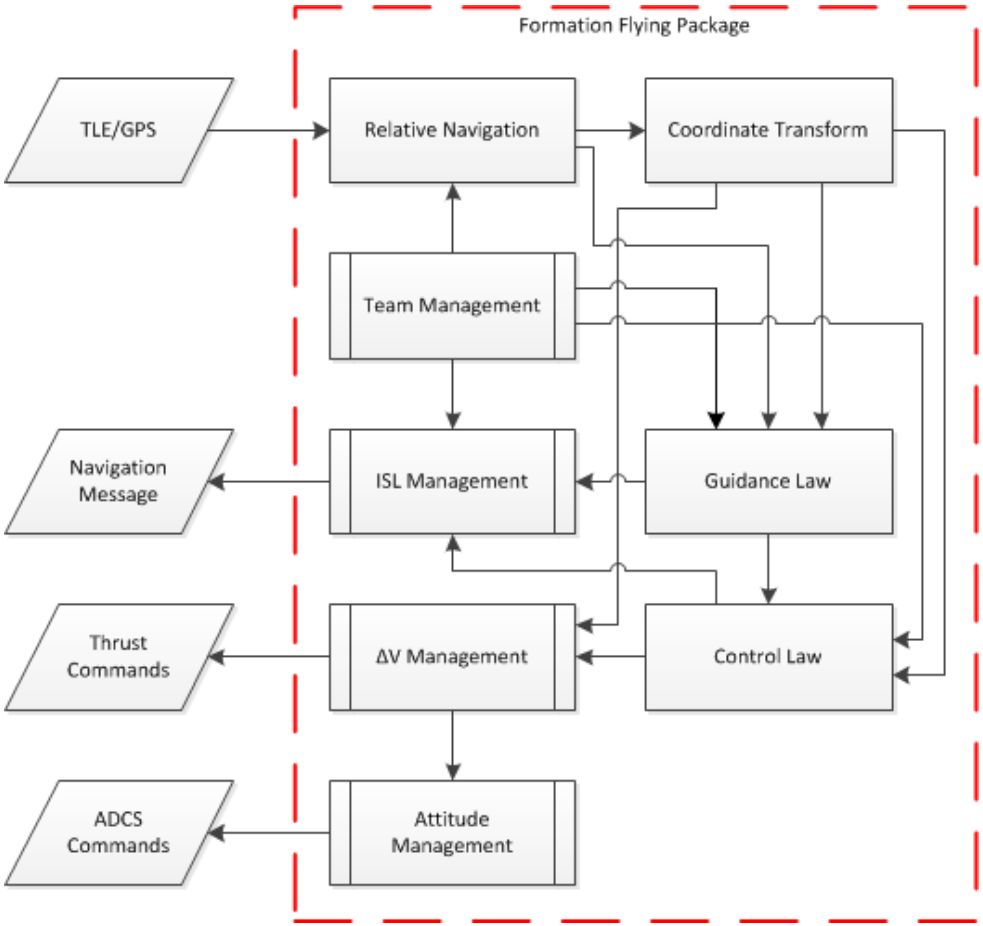


| Parameter | Value |
|---|---|
| Specific Impulse | 100 s |
| System Mass | 459 g |
| Propellant mass | 60 g |
| Number of CGG | 16 |
| Chamber Pressure | 7.6 bar |
| Max thrust | 9.5 mN |
| Gas temperature | 573 K |
| Dimension | 90×90×80 $cm^3$ |

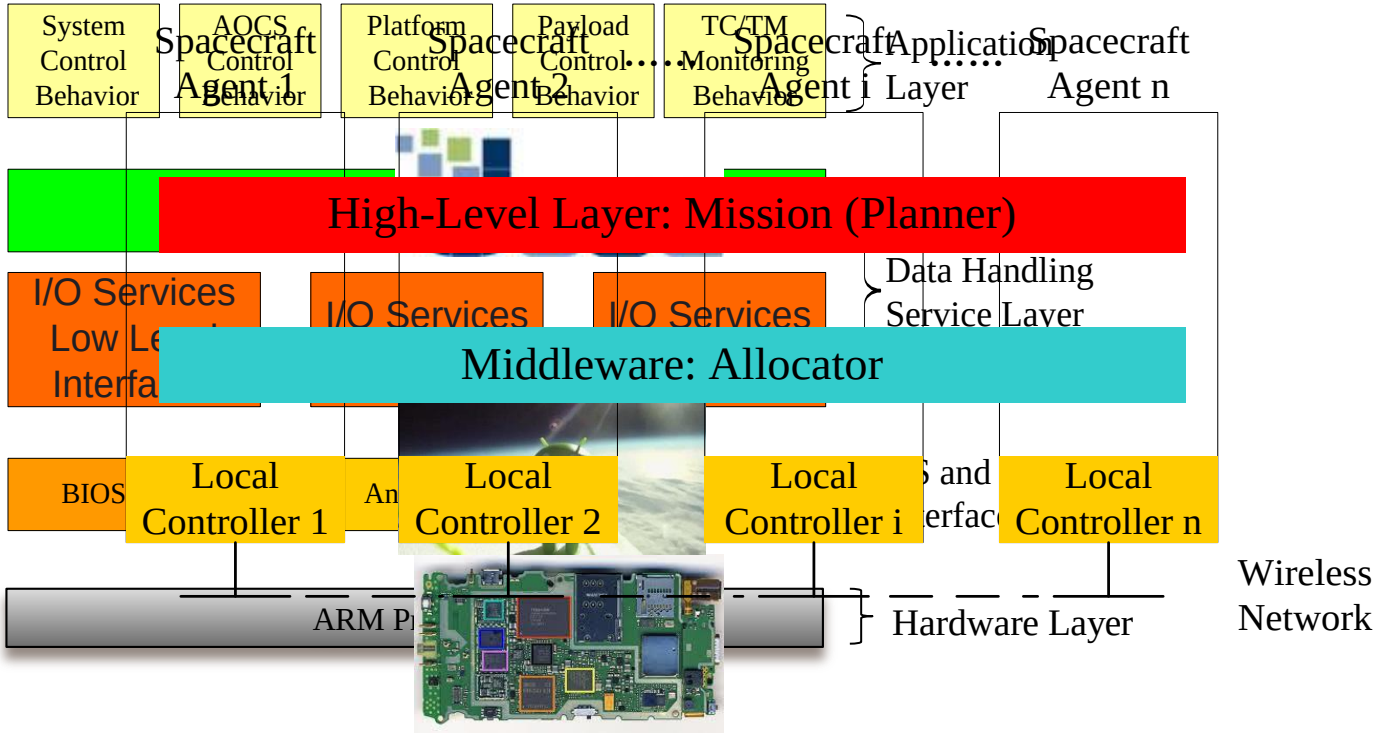
# DelFFi Formation Flying Mission

## Formation Flying Package



# DelFFi Formation Flying Mission

## Multi-Agent based FF Controller Experiment



# Conclusions

- Delfi-C$^3$ is a full success beyond all expectations!
- Delfi-n3Xt satellite and ground station are ready for countdown.
- DelFFi will demonstrate formation flying with CubeSats and is a significant step towards networks of small satellites.
- The lessons show that the reliability of critical subsystems shall be guaranteed using e.g. SPFF design.
- (Soft/Hard)Redundancy and a reliable databus are essential for a success CubeSat mission