Possibilities and Future Vision of Micro/nano/pico-satellites - From Japanese Experiences

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University of Tokyo
Contents

• Features of Micro/nano/pico-satellites

• Japanese History and Lessons Learned
  – CanSat to CubeSat “First CubeSat on orbit”
  – From education to practical applications
  – Important tips for development

• Visions on Various Applications of Micro/nano/pico-satellites

• University Space Engineering Consortium (UNISEC) and International Collaborations
Micro/nano/pico-satellite

“Lean Satellite”

Micro-satellite: 20-100kg
Nano-satellite: 2-20kg
Pico-satellite: 0.5-2kg

Japanese Governmental Satellites
ALOS-1: 4 ton  ASNARO: 500 kg
Kaguya: 3 ton  Hayabusa: 510 kg
Motivation of Smaller Satellites

Current Problem of Mid-large Satellites

- Enormous cost >100M$
- Development period >5-10 years
- Conservative design
- Almost governmental use
- No new users and utilization ideas
- Low speed of innovation

Trend towards larger satellites

Introduce more varied new players into space.
Innovation by Micro/nano/pico satellites (<100kg)

- **Education**
  - OPUSAT (1U: 1kg)
  - AAResST
  - MicroMAS (3U)
  - SPORESAT (3U: 5.5kg)
- **Remote sensing/Telescope**
  - AeroCube (1.5U: 2kg)
  - Dove, Flock (3U: 4kg)
  - MiRaT (3U)
  - Sunjammer
- **Weather**
  - BioSentinel計画案 (6U)
- **Bio-engineering**
  - 再突入回收 (3U)
- **Rendezvous/docking**
  - INSPIRE (3U)
- **Communication**
  - 高速通信・ISARA (3U)
  - 低速通信・AISSAT-1 (6kg)
  - RACE (3U)
  - FS-7 (3U)
- **Space Science**
  - （可視・近赤外）
  - NEMO-AM (15kg)
- **Atmosphere**
  - LWaDi (6U)
  - CAT (3U)
- **Exploration**
  - **High Resolution**
  - SCOUT (50kg)
  - Skysat (120kg)

**University/venture companies’ innovative idea and development process**

- <10M$ < 2 years < 100kg, education, constellation of many satellites
Features of Micro/nano/pico-satellites

• VERY low cost (from >100M$ to <5M$)
  – Leads to new missions, business, sciences…
  – Introduce new users (companies, countries..)
  – Can be an educational tools
  – Can be very challenging

• Short life cycle (from >5 years to <1-2 years)
  – One cycle possible during university years
  – More iterations (from “project” to “program”)
  – Early return of investment (good for business)

• Simple and transparent satellite system
  – Easy to design, operate and trouble shoot
  – Each team member can see the total system
Educational Significances of Micro/Nano/Pico-Satellite and CanSat Projects

- **Practical Training of Whole Cycle of Space Project**
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.

- **Importance for Engineering Education**
  - Synthesis (not Analysis) of an really working system
  - Feedbacks from the real world to evaluate design, test, etc.
  - Learning from failures (while project cost is small)

- **Education of Project Management**
  - Four Managements: “Time, human resource, cost and risk”
  - Team work, conflict resolution, discussion, documentation
  - International cooperation, negotiation, mutual understanding

- **The effects were found more than expected !!**
- **Also contribute to other technological areas !!**
University Satellites in Japan
37 university satellites launched in 2003-2015

From CanSat to CubeSat, Nano-Satellite
From Educational purpose to Practical application
Launchers for 37 university satellites

- **Foreign Rocket: 12**
  - ROCKOT (Russia) 2 (2003)
  - COSMOS (Russia) 1 (2005)
  - PSLV (India) 3 (2008, 2012)
  - DNEPR (Russia) 6 (2014)

- **Japanese Rocket: 25**
  - M-V 2 (2006)
  - H-IIB 17 (2009~)
  - HTV⇒ISS deploy 6 (2012)

JAXA has been helping us for our activities!!
What is the special features about space systems?

• A satellite cannot be contacted until the end of its mission once it is loaded on a rocket and launched – “Non-maintainable system”

• Sometimes it should survive in space for more than 5 years without any human interactions, so Carefully consider how to survive in space !!

• Imagine all possible events and anomalies which may happen on satellites and prepare countermeasures for them as many as possible

• Focus on power system and communication system: to make it survive in any circumstances

• Don’t skip required ground tests
University of Tokyo’s History
8 satellites developed (7 launched)

2003  04  05  06  07  08  09  10  11  12  13  14  15

[1] CubeSat XI-IV (ROCKOT) 2003/6
[2] Education, CIGS solar cells
[4][5][6] Remote sensing, S&F
[7] Deep space exploration
[8] Astrometry (top-science)

30m GSD Remote sensing
NANO-JASMINE (CYCLONE) 2015/12
PRISM (H-IIA) 2009/1
HODOYOSHI-1,3,4 (DNEPR) 2014/6,11

[1]-[7]:Launched and being operated in space
[8]: Waiting for launch

PROCYON (H-IIA) 2014/12

development
launch
Training step: CanSat 1999-now
CubeSat “XI-IV (Sai Four)”

**Mission:** Pico-bus technology demonstration in space, Camera experiment

**Developer:** University of Tokyo

**Launch:** ROCKOT (June 30, 2003) in Multiple Payload Piggyback Launch

**Size** 10x10x10 [cm] CubeSat

**Weight** 1 [kg]

**Attitude control** Passive stabilization with permanent magnet and damper

**OBC** PIC16F877 x 3

**Communication** VHF/UHF (max 1200bps) amateur frequency band

**Power** Si solar cells for 1.1 W

**Camera** 640 x 480 CMOS

**Expected life time** ??

Captured Earth Images are Distribution to Mobile Phones
Launch of the World First CubeSat (XI-IV, Cute-1 and others) by “ROCKOT”

2003/06/30 18:15:26 (Russia, Plesetsk time)

Project Manager of Hayabusa-2
Surviving 13+ years with 500+ pictures downlinked
XI-IV is still perfectly working after 13 years in orbit
Recently Downlinked Photos
2000  We started in situations that…

• No components on sales for CubeSat
  – Everything should be “hand-made” by ourselves
• No ground test facility in our university

- Please find out what you can do with your small money or not-so-good facility
- Please find out the persons who know how to do and who are willing to support you
  – We don’t know how to find launchers
  – We don’t know how we can get frequency
  – We don’t know how we can get export license

• But we could take much time to think & test
CubeSat “XI-V (Sai Five)”

**Mission:** CIGS solar cell demonstration, Advanced camera experiment

**Developer:** University of Tokyo

**Launch:** COSMOS (October 27, 2005) deployed from “SSETI-EXPRESS”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10x10x10[cm] CubeSat</td>
</tr>
<tr>
<td>Weight</td>
<td>1 [kg]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>Passive stabilization with permanent magnet and damper</td>
</tr>
<tr>
<td>OBC</td>
<td>PIC16F877 x 3</td>
</tr>
<tr>
<td>Communication</td>
<td>VHF/UHF (max 1200bps) amateur frequency band</td>
</tr>
<tr>
<td>Power</td>
<td>Si, GaAs, CIGS cells</td>
</tr>
<tr>
<td>Camera</td>
<td>640 x 480 CMOS</td>
</tr>
<tr>
<td>Mission life</td>
<td>&gt; 5 years</td>
</tr>
</tbody>
</table>

**T-POD deployment System**

**JAXA/NEDO CIGS Solar Cells**

**Captured Earth Images**

Deployed from SSETI-EXPRESS in space
PRISM “Hitomi”

**Mission:** Earth Remote Sensing (20 m GSD, RGB) with Deployable Boom

**Developer:** University of Tokyo

**Launch:** H-IIA (Jan 23, 2009) Piggyback with GOSAT (CO₂ monitoring sat)

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**Size**
- 20x20x40[cm] in rocket
- 20x20x80[cm] in space

**Weight**
- 8.5 [kg]

**Attitude control**
- 3-axis stabilization with
  - Sun, Magnet sensor, MEMS gyro
  - magnetic torquers

**OBC**
- SH2, H8 x 2, PIC x 2

**Communication**
- VHF/UHF (max 9600bps)

**Mission life**
- > 2.5 years

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**Captured images**
- Mexico Seashore
- US Desert
- Kita-Kyushu (Japan)
- Wide Angle Camera
Combination of “High performance but may-be-weak” processor and “Low performance but very robust and proven” processor
Photos of The Nile River

WAC (Wide Angle Camera)

NAC (Narrow Angle Camera)
Important Tips for Development

• Target level ("mission" or "bus" level)
  – Stepping up from Low/simple to High/complex
  – Transfer technology/experiences to next step
  – You can find highlight in even simple satellite

• “Kit” vs “Self-made”
  – Kit is very good to quickly get orbital results
    • But cannot understand the “inside of box”
  – “Self-made” will get deep understanding
  – Please find good combination of both strategy

• Don’t think it an easy task
  – 100,000 man-hour were required for XI-IV
Vision on Applications to Space Science and Exploration
<table>
<thead>
<tr>
<th>Size(kg)</th>
<th>Category</th>
<th>Players</th>
<th>Project Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;500</td>
<td>Mid-large</td>
<td>JAXA</td>
<td>Science: Ginga, Akari, Suzaku, Hitomi—Exploration: Hayabusa &amp; 2, Kaguya, Akatsuki—</td>
</tr>
<tr>
<td>2-20</td>
<td>Nano</td>
<td>University</td>
<td>Science: CUTE-1.7+APD II (3kg 2008) Exploration: ECUULEUS (6U EM-1 2018)</td>
</tr>
<tr>
<td>&lt;2</td>
<td>Pico</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
UT’s 4th Satellite: Nano-JASMINE

**Mission:** Astrometry (Getting precise 3D map of stars and their movements)

**Developer:** University of Tokyo, National Astronomical Observatory of Japan, Shinshu University, Kyoto University

**Launch:** Initially CYCLONE-4 was planned but changed to another launcher

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>Size</td>
<td>50 [cm-cubic]</td>
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<tr>
<td>Weight</td>
<td>38 [kg]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>3-axis stabilization with Star, Sun, Magnet sensor, FOG, RW, Magnetic torquers</td>
</tr>
<tr>
<td>OBC</td>
<td>FPGA</td>
</tr>
<tr>
<td>Communication</td>
<td>S-band 100 [kbps]</td>
</tr>
<tr>
<td>Mission life</td>
<td>2 [year]</td>
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</tbody>
</table>

**Special features:**
- Attitude Stability: 0.8 arcsec for 8.8 sec
- Thermal Stability: < 0.1K (at -50 degree)
- Map Accuracy: Compatible with “Hipparcos” Satellite (‘89)
- Telescope: two CCDs with TDI
NJ’s “Astrometry” Mission

• Mission
  – Estimate 3 Dimensional positions of stars and their movement
  – Demonstration for “JASMINE” mission

Star position determination by Annual Parallax

• Attitude stabilization
  740 m-arcsec /8.8s

• Temperature
  – 50°C, ±0.1°C stability

- Long exposure time required.
- Two telescope angular separation should be kept constant.
Japanese group is promoting series of space astrometry missions, “JASMINE program”, in international collaboration with Gaia DPAC team. JASMINE will play complementary roles of Gaia.

Late 2017 or early 2018
# 50kg-class deep space probe “PROCYON”

(PROCYON: **PRoximate Object Close flyby with Optical Navigation**)

<table>
<thead>
<tr>
<th>Developer:</th>
<th>Univ. of Tokyo and JAXA (Japan Aerospace Exploration Agency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch:</td>
<td>H2A rocket (together with Hayabusa-2 asteroid explorer, 2014 Dec.)</td>
</tr>
</tbody>
</table>
| Mission:   | Demo. of 50kg deep space exploration bus system (nominal mission)  
Asteroid flyby observation (advanced mission) |

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**Asteroid close flyby observation**

- **Flyby velocity**: > a few km/s
- **LOS (Line of sight) control**
- **Close flyby** (altitude: ~30km)

Launched (2014/12, together with Hayabusa-2 asteroid explorer)

Used Hodoyoshi compo.  
Developed within 1.2 years
Earth photos captured from deep space by PROCYON

Photos taken by PROCYON at close encounter of Earth in 2015/12 (one year after launch)
EQUULEUS  One of 13 EM-1 CubeSats
EQUilibrium Lunar-Earth point 6U Spacecraft

Mission to Earth Moon Lagrange Point
Intelligent Space Systems Laboratory, 2016/08/01
EQUULEUS has fundamental bus systems for deep space missions within 6U CubeSat (deep space communication, power, thermal control, attitude control, propulsion).
Logic of “order”

If you pursue the “perfect” objective from initial, you cannot get money and you cannot realize as it is very difficult to get the public approval and funding. Quickly start with “not perfect” but “good enough” science mission!
Vision on Applications to Earth Observation
Hodoyoshi-3 (left) and Hodoyoshi-4 before Shipment (April, 2014)
Sri Lanka
(LCAM 240m GSD)
Brazil
(LCAM 240m GSD)
Greek (false color) (MCAM 40m GSD)
Chiba
(6m GSD)
MicroDragon Project
(50kg Earth Remote Sensing Satellite for Vietnam Engineers)

Total 36 engineers study and join the project in 5 Japanese universities. Launch by Epsilon rocket has been decided. (mid 2018).

The University of TOKYO

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<tr>
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<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Detail Design Critical Design Review Flight Model Manufacture</td>
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<tr>
<td>System Integration &amp; Test Launch Readiness Review Ground Station Preparation &amp; Practice</td>
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</tbody>
</table>

- Oct
- May
- Dec
- Jan 2017
## HODOYOSHI-1

**Mission:** Earth Remote Sensing (6.7m GSD, 4 bands: RGB & NIR)  
**Developer:** AXELSPACE, University of Tokyo, NESTRA  
**Launch:** DNEPR launch on November 6, 2014

<table>
<thead>
<tr>
<th>Parameter</th>
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<tr>
<td>Size</td>
<td>about 50 [cm-cubic]</td>
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<tr>
<td>Weight</td>
<td>60 [kg]</td>
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<tr>
<td>OBC</td>
<td>FPGA</td>
</tr>
<tr>
<td>Communication</td>
<td>UHF, X (10-20 Mbps)</td>
</tr>
<tr>
<td>Average power</td>
<td>50 W</td>
</tr>
</tbody>
</table>

**Attitude control**  
3-axis stabilization with  
- STT, SAS, Magnetometer, Gyros, RW, Magnetic torquers  
- stability 0.1 deg/sec  
- pointing accuracy 5 arcmin  
- determination 10 arcsec

**Optical sensor:**  
15kg, 6.7m GSD (500km alt.)  
- Focal length 740mm (F# 7)  
- Swath 27.8 x max 179km (500km alt.)  
- Bands(SNR) B(57), G(74), R(80), NIR

Optical Camera (6.7m@500km) developed by Genesia Corporation
Dubai (6.7mGSD)
Future Plan of AXELSPACE

- **GRUS** (3 satellites in 2017, 50 sats in 2022)
  - Everyday coverage of the whole globe
  - 2.5m resolution images

- **WNISAT-1R** (to be launched in 2016 spring)
  - Glacier Observation of arctic ocean
  - GNSS-R reflection experiment
  - Laser communication experiment
Vision on Applications to Novel Type of Missions
“Store & Forward” gets ground information

- UHF receiver onboard Hodoyohi-3 & 4 can collect data from ground Sensor Network (fixed points or mobile)

**S&F mission outline**

1. Fixed or mobile sensors on the earth get ground information and transmit them to Hodoyoshi-3&4 when they fly over the area
2. Hodoyoshi 3&4 receive and store the information, and forward (transmit) it to Ground Stations when it flies over them

*Example*

- Information A
- Information B
- Information A+B

**Application areas:** disaster prediction, water level monitoring, forest data acquisition….
### 3U CubeSat “TriCom-1”
- Store & Forward Test Satellite -

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
<th>Miscellaneous</th>
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<tbody>
<tr>
<td>Size</td>
<td>10x10x30cm</td>
<td>3U size</td>
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<tr>
<td>Weight</td>
<td>&lt; 3kg</td>
<td></td>
</tr>
<tr>
<td>OBC</td>
<td>&quot;Bocchan&quot;board</td>
<td>Internal made</td>
</tr>
<tr>
<td>Power (average)</td>
<td>4W</td>
<td>AZUR GaAs cell</td>
</tr>
<tr>
<td>Battery</td>
<td>Li-Ion 41 wh</td>
<td>LIBM</td>
</tr>
<tr>
<td>Downlink (H/K&amp;data)</td>
<td>W 1.2kbps</td>
<td>460MHz AFSK &quot;U-TRx&quot;</td>
</tr>
<tr>
<td>Uplink(H/K)</td>
<td>50W 9600bps</td>
<td>401MHz</td>
</tr>
<tr>
<td>Attitude</td>
<td>Simple 3 axis</td>
<td>B-dot law only</td>
</tr>
<tr>
<td>Sensor</td>
<td>magnetic sensor, gyro</td>
<td>&quot;GNSS&quot;</td>
</tr>
<tr>
<td></td>
<td>GPS receiver</td>
<td></td>
</tr>
<tr>
<td>Actuators</td>
<td>magnet torquer despun wheel</td>
<td>&quot;MTQ&quot; &quot;RW&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camera</td>
<td>GSD 314 m VGA @180km</td>
<td>&quot;CAM&quot;</td>
</tr>
<tr>
<td>Sub-Camera</td>
<td>GSD 67 m @600km</td>
<td>&quot;Sub-CAM&quot;</td>
</tr>
</tbody>
</table>
## Weak Signal Receiver for Data Collection Capability

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
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<tbody>
<tr>
<td>bit rate</td>
<td>100 bps, maximum 8 channels in parallel</td>
</tr>
<tr>
<td>Transmission duration</td>
<td>&lt; 300 sec</td>
</tr>
<tr>
<td>Transmission power from ground</td>
<td>20 mW</td>
</tr>
<tr>
<td>Frequency band</td>
<td>920 MHz (no license of usage is required if using 20mW power)</td>
</tr>
</tbody>
</table>
“Rental Space” in Hodoyoshi 3 & 4

- Vacant spaces of 10cm cubic size, which are sold to customers
- To provide the “orbiting laboratory” or “advertisement room” opportunity for companies, researcher, public
  - Space demonstration of new products
  - Space environment utilization (micro-gravity)
  - Space science, etc.

Provided Services:
- Electric power
- Information line
- Camera
- Windows
Inside of 10cm Cubic Space

This message can be uplinked

“Moving Earth” as seen through the window

20 second video clip is downlinked and sent to Sanrio

HELLO KITTY
40TH ANNIVERSARY

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UNISEC and International Collaborations
University Educational Community **UNISEC**  
(UNIversity Space Engineering Consortium)

- Founded in 2002, became NPO in 2003
- 70 laboratories from 50 universities (2015)
- 811 students, 267 individual/company members

**UNISEC Missions:**
- Education and human resource training for space development/utilization
- Innovative space technology “seeds” development

**Activities to be Supported:**
- Joint experiment, joint development, joint education, etc.
- Workshop, symposium, technology exchange, etc.
- Consultation on legal matters (frequency, export law, etc.)
- Finding “rivals” within the community!
- “UNISEC Lecture Series”

[Website: http://www.unisec.jp]
Ground Station Network (GSN)

- If many universities’ ground stations are connected by internet, then it provides
  - Extended operation windows of their own satellite.
  - Backups of failed ground stations and rapid satellite operation

- Worldwide network is under construction
  - Germany (Wurzburg), Sweden (Lurea Univ. in Kiruna),
  - USA (Calpoly, Hawaii, Stanford, Santa Clara, etc)
CLTP History & Participants

48 participants from 25 countries

CLTP1 (Wakayama Univ. in Feb-March, 2011)
12 participants from 10 countries, namely Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey (3), Vietnam.

CLTP2 (Nihon Univ. in Nov-Dec, 2011)
10 participants from 10 countries, namely Indonesia, Malaysia, Nigeria, Vietnam, Ghana, Peru, Singapore, Mongolia, Thailand, Turkey.

CLTP3 (Tokyo Metropolitan Univ. in July-August, 2012)
10 participants from 9 countries, namely Egypt (2), Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil.

CLTP4 (Keio Univ. in July-August, 2013)
9 participants from 6 countries, namely Mexico(4), Angola, Mongolia, Philippines, Bangladesh, Japan.

CLTP5 (Hokkaido Univ. in Sept 8-19, 2014)
7 participants from 5 countries, namely Korea (2), Peru, Mongolia, Mexico (2), Egypt.

CLTP6 (Hokkaido Univ. in Aug, 2015)
Mission Idea Contest (MIC) for Micro/nano satellite utilization

- Mission and satellite design idea for less than 50kg micro/nano/pico-satellites
- Regional coordinators: 33
- History
  - MIC1 in Tokyo, March 14, 2011
  - MIC2 in Nagoya, Oct. 10, 2012
  - PreMIC3 in Tokyo, Nov. 23, 2013
  - MIC3 in Kitakyushu, Nov 19, 2014
  - PreMIC4 in Tokyo, July 3, 2015
  - **MIC4 to be held in Varna, Oct, 2016**
Global network through MIC and CLTP (MIC: 33, CLTP: 21 nations) 38 countries in total
260 attendants from 47 nations in 5th Nano-sat Sympo 2013.
7th Nano-sat Sympo will be held in October 2016 in Varna.

- MicroDragon is developed with 36 Vietnam young engineers in four years
- Collaboration with Kazakhstan, Brazil, Ukraine, etc. is under discussion
“UNISEC-Global” activities

33 regions/countries are interested to start UNISEC in their countries: South Africa, Angola, Namibia, Egypt, Ghana, Kenya, Nigeria, Tunisia, Bangladesh, Korea, Mongolia, the Philippines, Singapore, Taiwan, Thailand, Turkey, Australia, Indonesia, Saudi Arabia, Canada, USA, Guatemala, Mexico, Peru, Brazil, Bulgaria, Italy, Samara (Russia), Switzerland, Germany, Slovenia, Lithuania and Japan.

12 Local Chapters and 1 Association of Local Chapters have been acknowledged. (red part)

UNISEC-GLOBAL meeting will be held in Varna in October 2016
Summary

• The era of micro/nano/pico-satellites has come !!
• Not only “launch”, but also make it really work and perform missions in space !!
  – To make it survive in space !
• Stepping up from simple to sophisticated satellites would be a good strategy !!

• Enjoy this one week joint event and find new friends and collaborators !!