The Future of Micro/Nano-Satellite Based Earth Observation and Communication Systems

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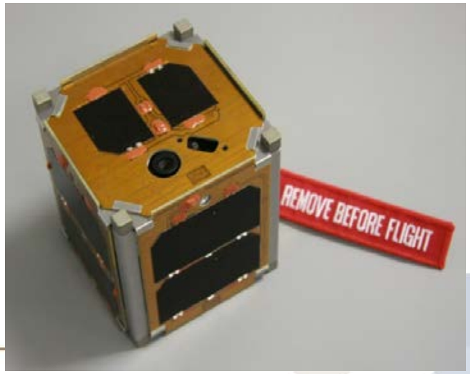
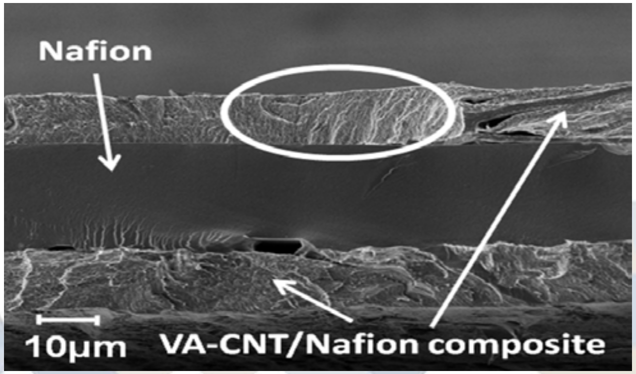
***Istanbul Technical University**
****ICAO, Permanent Mission of Turkey to ICAO**
+ Massachusetts Institute of Technology

INSTITUTIONAL BACKGROUND

Aeronautics Research Center

- Central Laboratory for Aeronautics Research (2012-)
  - +7 Faculty, 15 Research Associates, +20 Ph.D. Level Researchers
- Established to promote advanced, interdisciplinary and experimental research
- Research Focus on wide spectrum of Aeronautics Technologies
  - Design of manned and unmanned air vehicles, spacecraft and spacecraft systems
  - Flight Controls, Simulation and Avionics,
  - Nanoengineered Composites
  - Engine technologies and combustion
  - Aerodynamics, Aeroelasticity
  - Air Transportation, ATM
- Strong outreach at both university, national and international level
  - Nanotechnologies and Material Sciences
  - Electronics and Computer Science





Research Partners and Sponsors

TURKISH TECHNIC

innaxis

DEVLET HAVA MEYDANLARI İŞLETMESİ

DHMİ

MIT

SSM

1985

UNIVERSIDAD POLITECNICA MADRID

aselsan

HAVELSAN

NLR

DLR German Aerospace Center

roketsan

TURKISH AIRLINES

SAFRAN

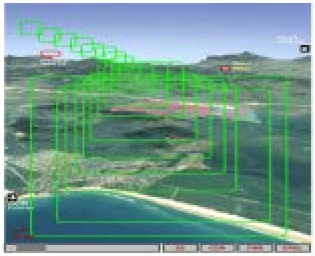
TÜBİTAK

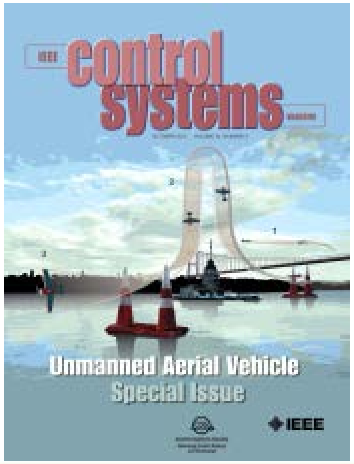
BOEING

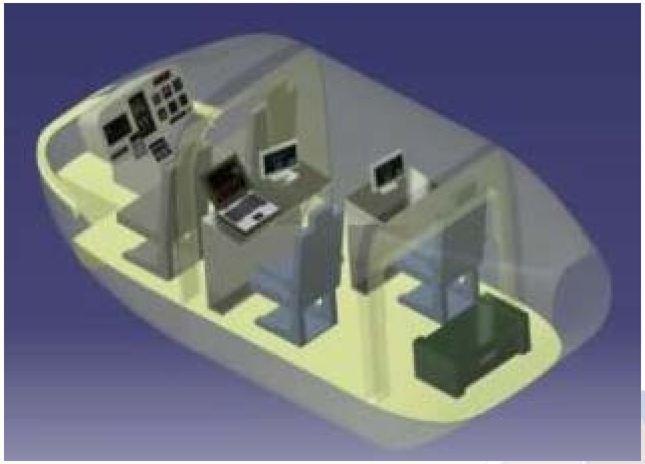
SESAR

Controls and Avionics Laboratory

- **Research Focus**
  - Advanced flight controls and avionics technologies
  - Unmanned air vehicles design and autonomy
  - Air Transport and ATM
  - Spacecraft Systems Design
  - Data Analytic Modelling, Estimation, Control and Learning
- **Notable Achievements**
  - Designed the first Turkish indigenous commercial avionics systems 2006-2009
  - Designed and built the first Turkish university-level autopilot system for UAVs. 2006-2009

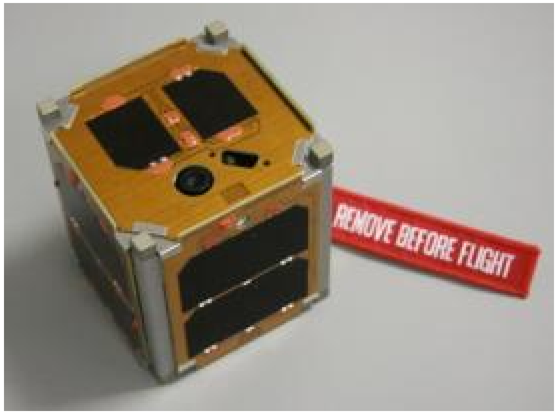


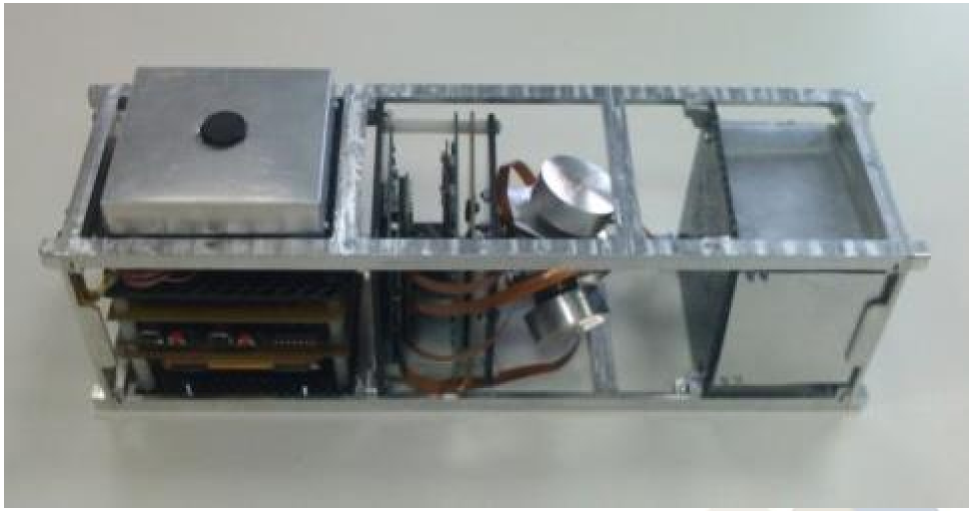




Space @ Controls and Avionics Laboratory

- Space Projects and notable achievements
  - Designed and built the first Turkish University cubesat ITUpSAT I (TUBITAK) 2006-2009
  - Designed and built indigenous bus and ADCS components for nano and micro-satellites ITUpSAT II (TUBITAK) 2009-2012
  - Winner of AIAA/AAS Cansat 2011
  - ITUpSAT I and ITUpSAT II projects were both awarded to be a part of Ministry of Science, Industry and Technology and TUBITAK «Success Stories» in 2010 and 2013





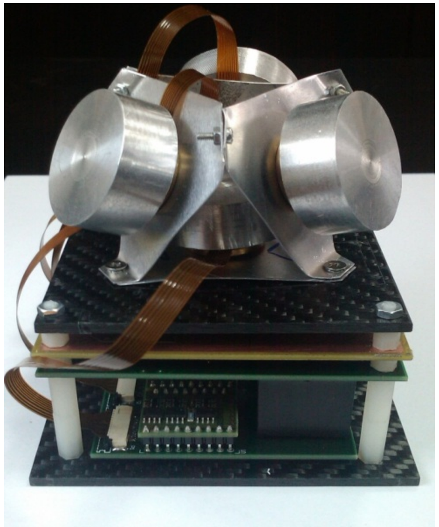
Space Focus at Controls and Avionics Laboratory

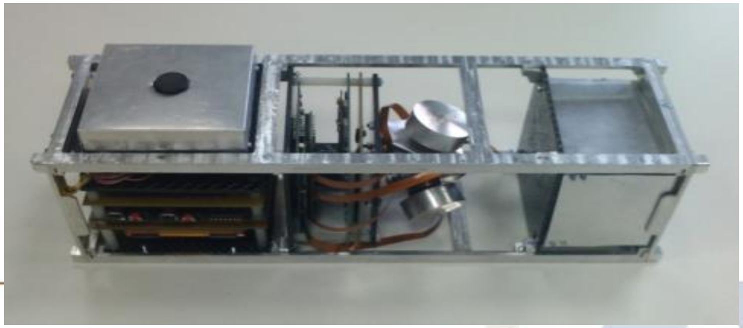
Space technology

- Earth Observation using Small Scale Satellites
  - Micro, nano, pico
- ADCS and Bus technologies
- Satellite networks
  - Swarm technologies
- Space robotics
- New Satellite and Payload technologies
  - In Space Energy Generation
  - Optical sensors
  - Radar
  - LIDAR
  - In Space propulsion

Space Exploration

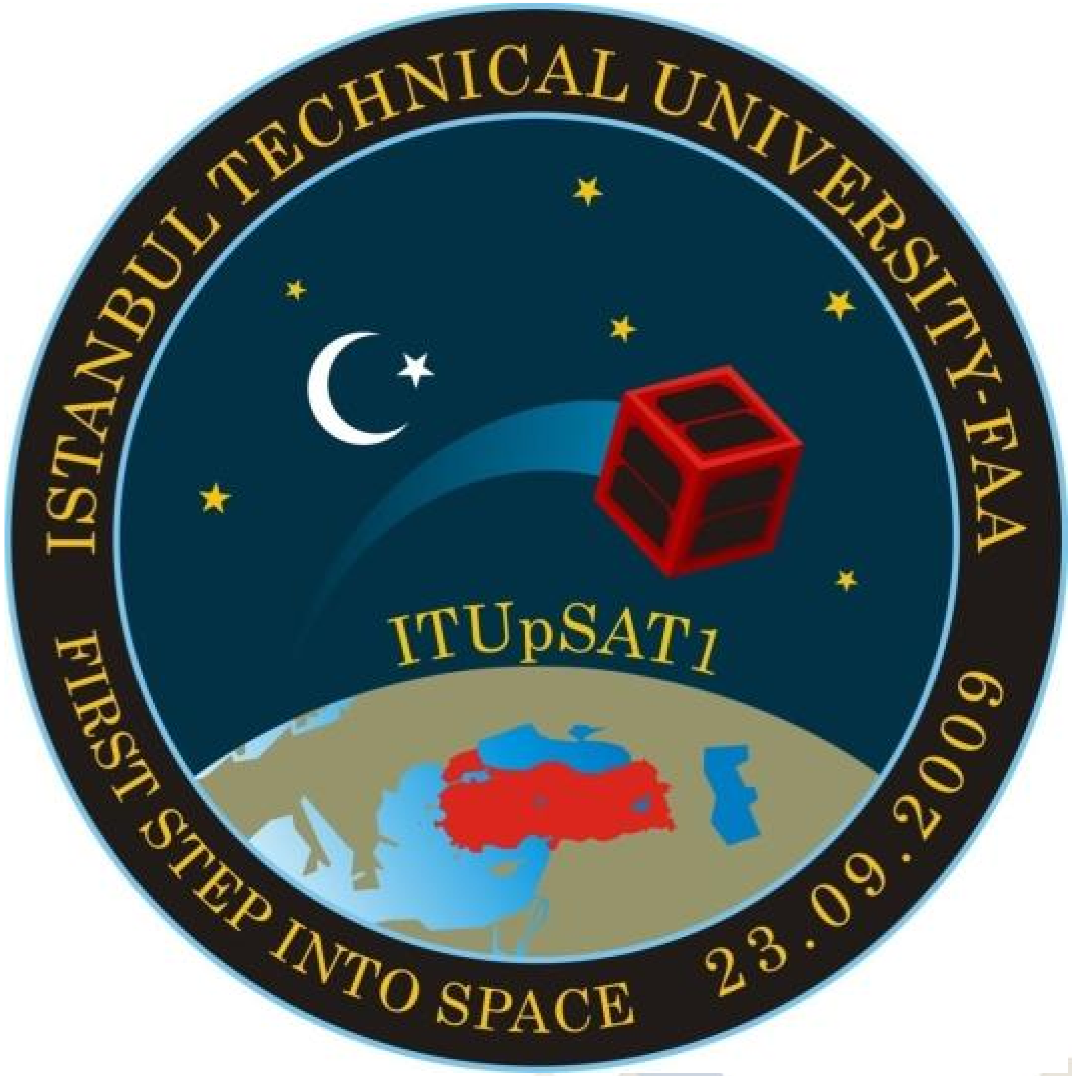
- Formation Flight
- Advanced GNC (Guidance navigation and control) also on ground

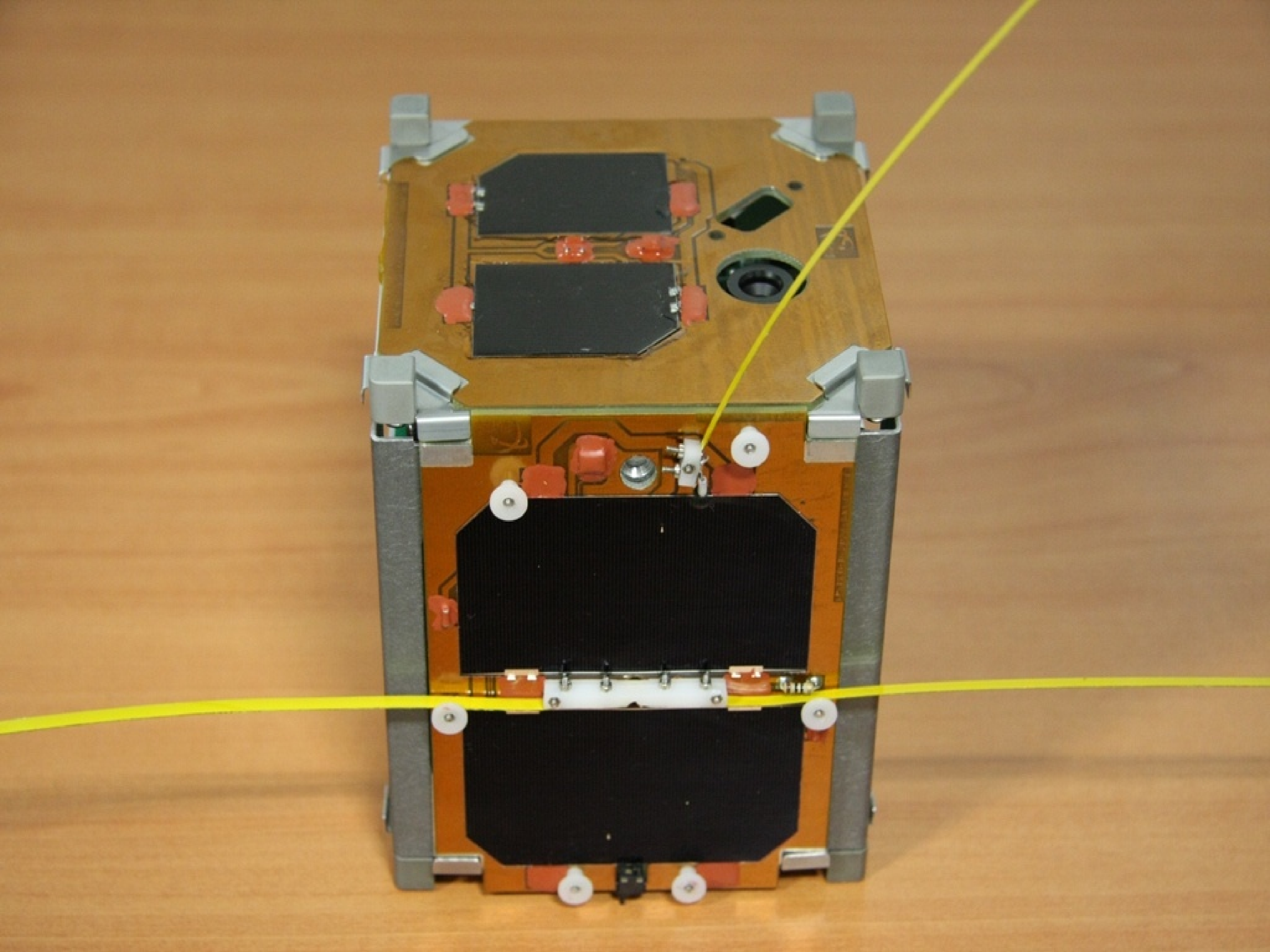


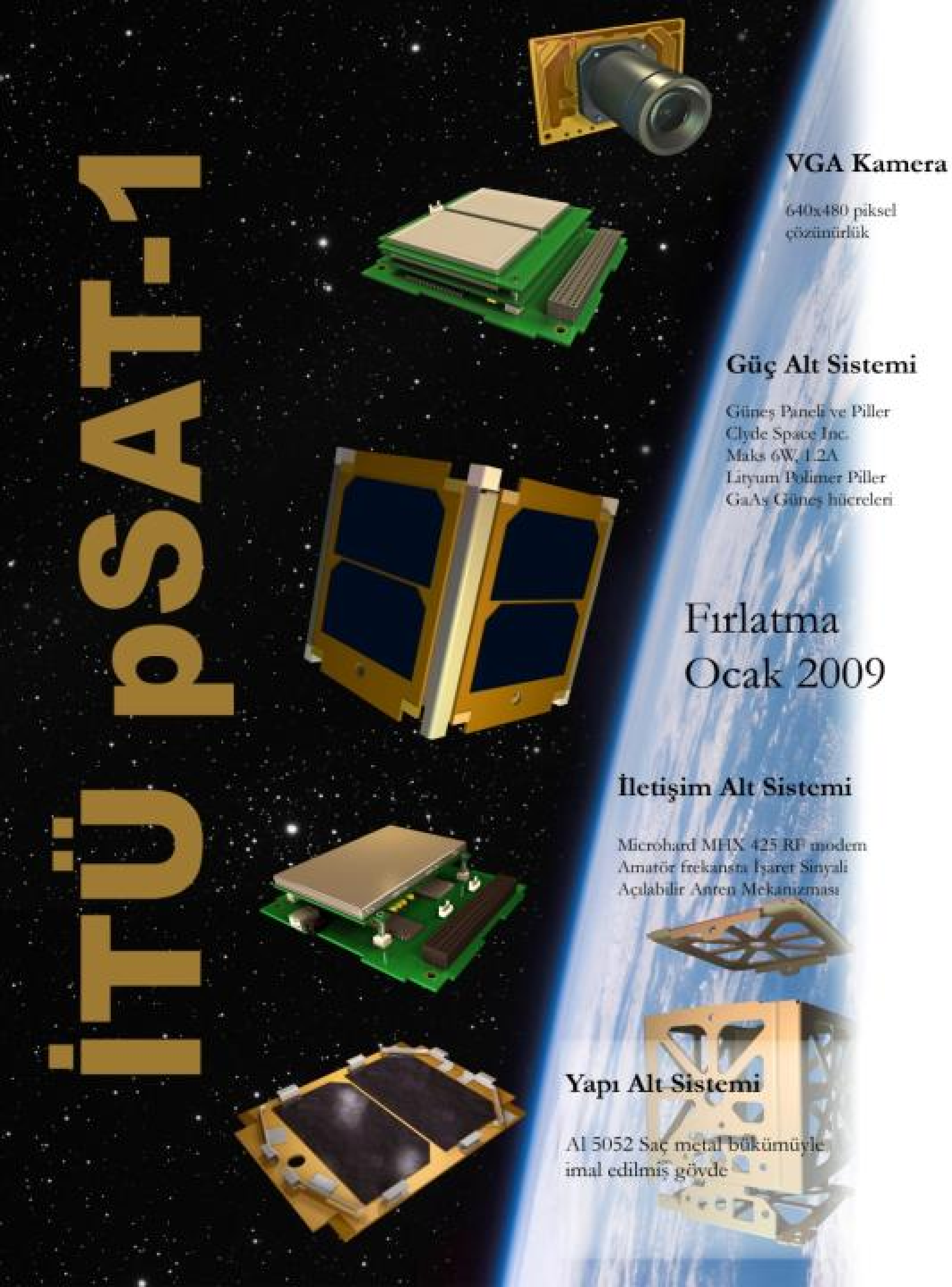


SPACECRAFT PROGRAMS

ITUpSAT I (2006-2009)

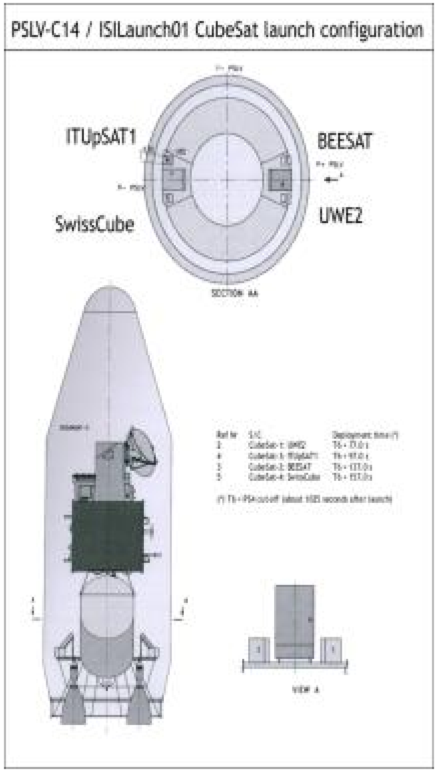


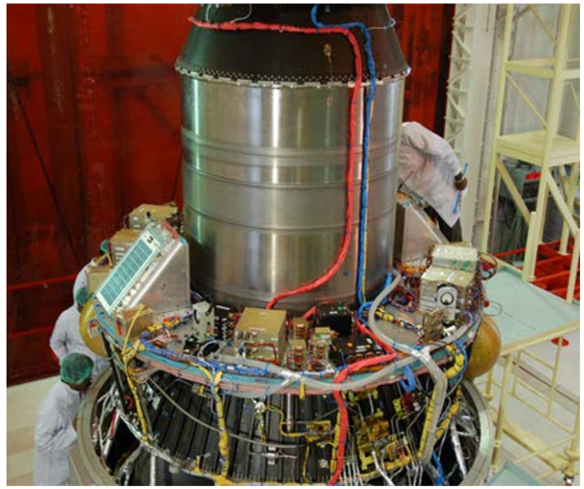



İTÜ pSAT-1
VGA Kamera
640x480 piksel
çözünürlük
Güç Alt Sistemi
Güneş Paneli ve Piller
Clyde Space Inc.
Maks 6W, 1.2A
Lityum Polimer Piller
GaAs Güneş hücreleri
Fırlatma
Ocak 2009
İletişim Alt Sistemi
Microhard MHX 425 RF modem
Amatör frekansta İşaret Sinyali
Açılabilir Anten Mekanizması
Yapı Alt Sistemi
Al 5052 Saç metal bükümüyle
imal edilmiş gövde


REMOVE BEFORE FLIGHT

PSLV C-14 : Launch 23.09.2009

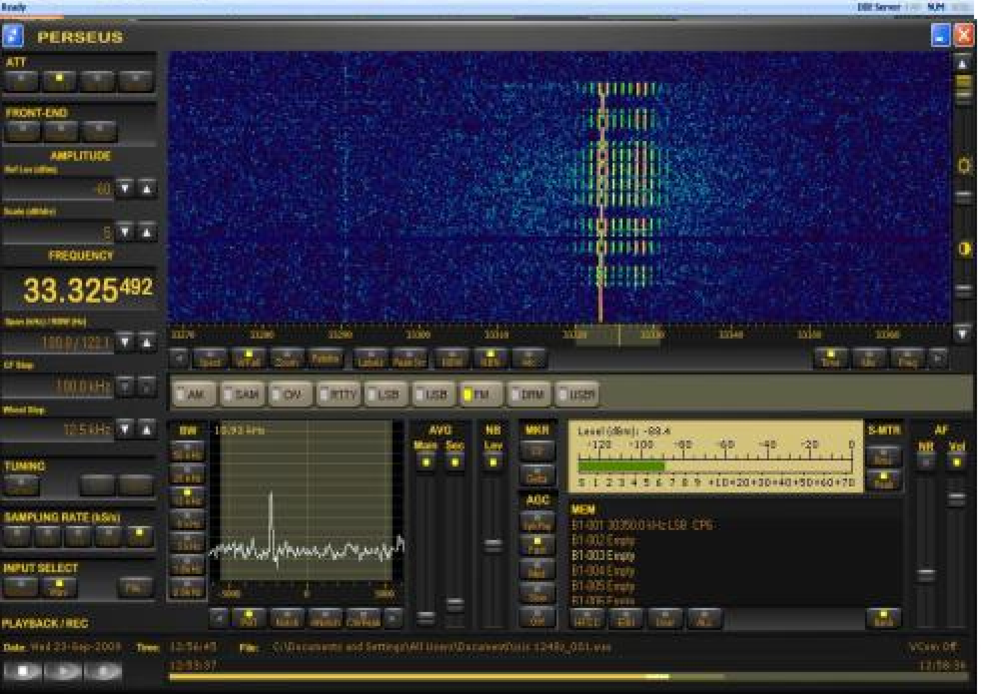




POLAR SATELLITE LAUNCH VEHICLE (PSLV)


LOS 00:13:29
437.334.502
437.325.000


ITU Ground Station
COM Settings
Telemetry
Picture
Payload
Panel Y1 Voltage -0,225 V
Panel Y1 Current 5,346 mA
Panel Y1 Temp 4,560200 Deg C
Panel X2 Voltage -0,423 V
Panel X2 Current 5,346 mA
Panel X2 Temp -55,5047 Deg C
Panel X1 Voltage -0,40499 V
Panel X1 Current 5,346 mA
Panel X1 Temp -49,6763 Deg C
Panel Z1 Voltage -0,44100 V
Panel Z1 Current 5,346 mA
Panel Z1 Temp -42,067 Deg C
Panel Y2 Voltage -0,20700 V
Panel Y2 Current 5,346 mA
Panel Y2 Temp -35,7529 Deg C
Panel Z2 Voltage -0,40499 V
Battery Bus Current 237,3772 mA
Battery 2 Temp 9,313999 Deg C
Battery 2 Voltage 7,95995 V
Cell 2 Voltage 3,93394 V
Battery 2 Discharging
Battery 2 Current 135,82 mA
Battery 1 Temp 11,107 Deg C
Battery 1 Voltage 7,97873 V
Cell 1 Voltage 3,92518 V
5V Bus Current 211,3136 mA
3.3V Bus Current 46,70685 mA
Battery 1 Discharging
Battery 1 Current 142,22 mA
Panel Z2 Temp -37,9338 Deg C
Panel Z2 Current 5,346 mA


PERSEUS
ATT
FRONT-END
AMPLITUDE
FREQUENCY
33.325492
TUNING
SAMPLING RATE (kS/s)
INPUT SELECT
PLAYBACK / REC
AM
SAM
CW
RTTY
LSB
USB
FM
DRM
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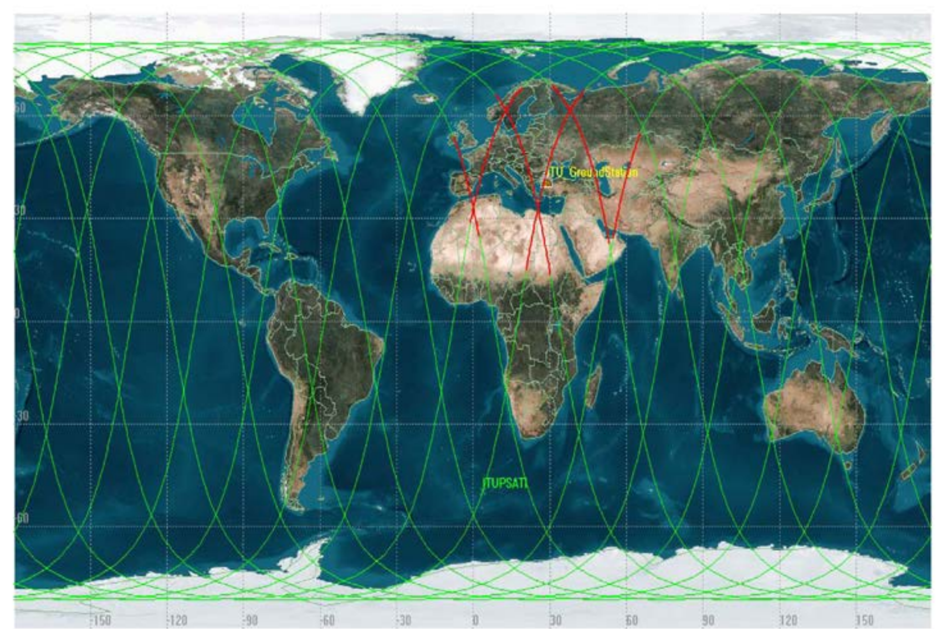
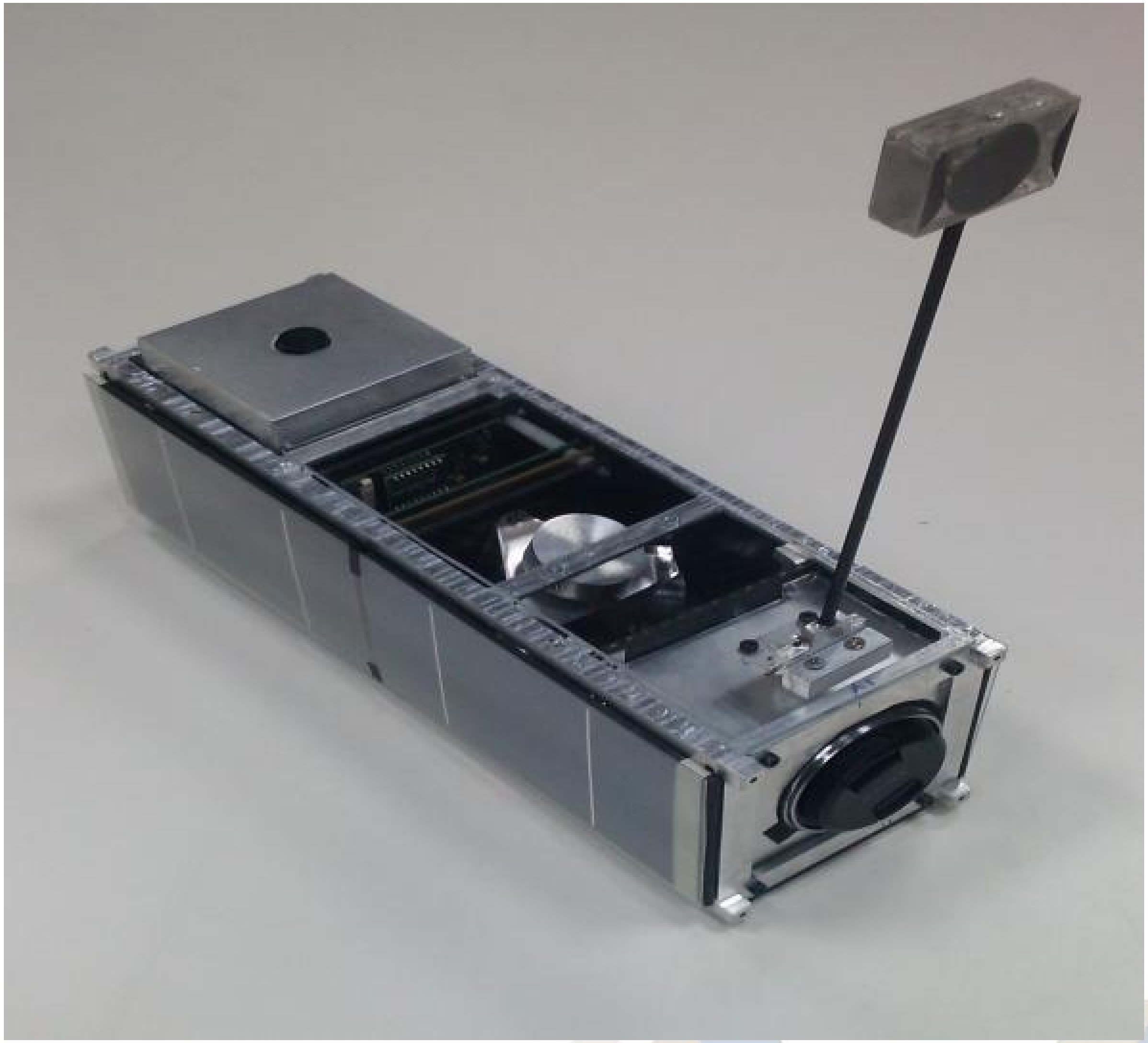
AGC
MEM
S-MTR
AF


ITU_GroundStation
ITUPSAT1

Current Status of ITU pSAT I

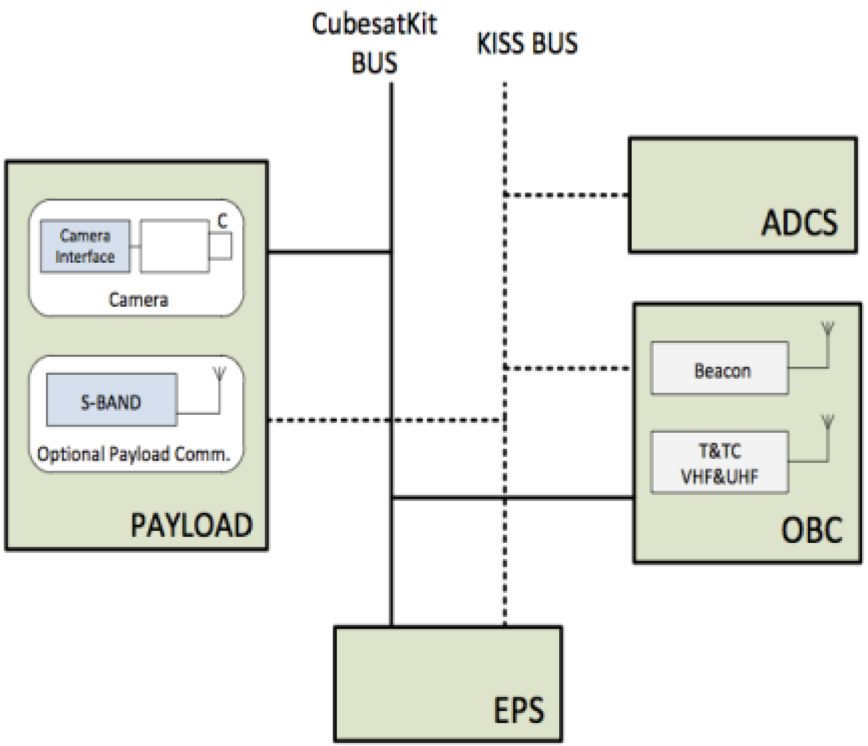
- ITU pSAT I is alive and kicking(2000+days) even though we had a major ground station problem with
  - the modem malfunctions and
  - the software resets
- Clear beacon and health status bits
- Many thanks to people all over the world who are still keeping track of ITU pSAT I
  - US, Germany, Italy, Norway, Japan, amateur radios all over Turkey.... To name a few....

ITUpSAT II (2009-2012)



ITUpSAT II : Aim and Design Philosopy

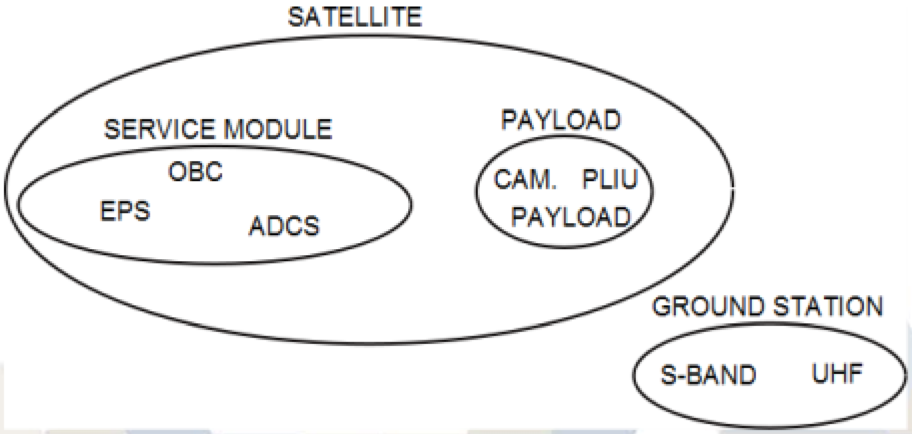
- The project aimed to design a standardized bus and a novel ADCS for pico and nano sized satellites (1-10 kg) for a wide range of applications
  - demonstrate specific challenges and solutions which require fault tolerant and reconfigurable control system
  - reliable bus design
  - medium resolution imaging (scale of 5m-50m)



ITUpSAT II Data Bus Perspective

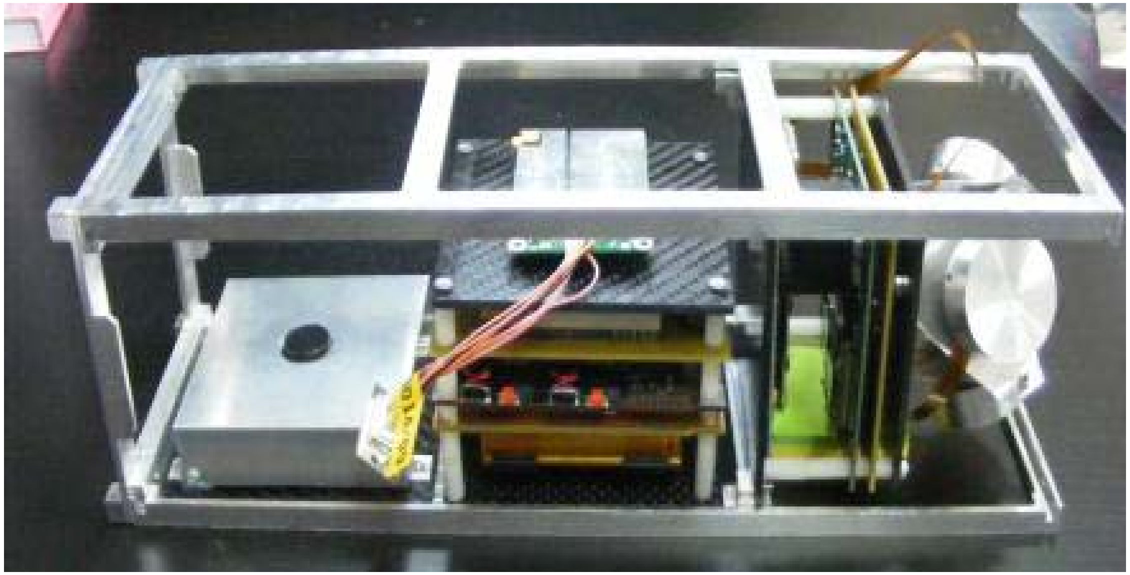
The Bus

- A unique bus based design
  - Structured around a CAN Bus and the cubesat kit bus
  - Flexible and scalable across form factors
- Bus consists of mostly in-house, in-development parts
  - OBC
  - EPS
  - ADCS
  - COM (UHF)
  - Payload Interface Unit (PLIU)



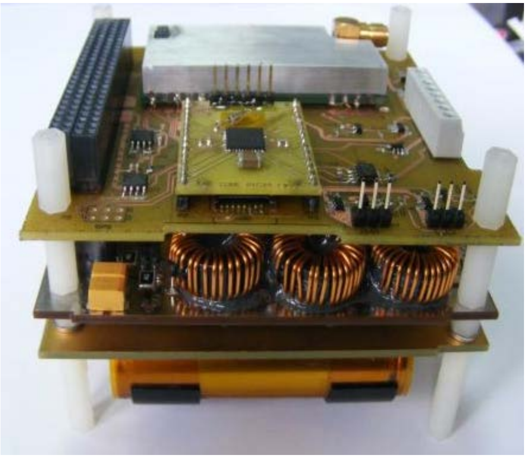
The Bus - Engineering Model

ADCS



Structure

Camera

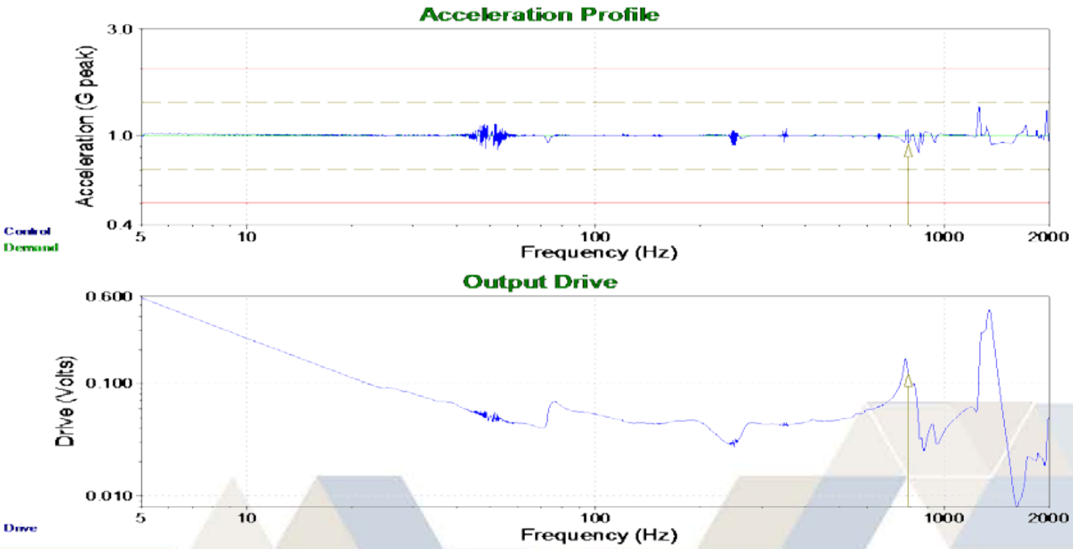


OBC & EPS

uPPT

EM Thermal/Vacuum/Vibration Testing

- Succesful Test of the EM at both qualification and acceptance level



ITUpSAT II results

- We have completed the design and development of a indigenous and reconfigurable bus architecture for nano/micro satellites
  - serve as a standard platform for a variety of space science missions
  - compliant with 3U CubeSat Standards as to enable simple access to space
  - the design mainly utilizes in-house space-modified COTS components as to reduce the manufacturing costs.
- In comparison to the existing on-market pico/nano-satellite buses, ITUpSAT II bus provides
  - higher computational power
  - higher data link capabilities
  - precise orbit determination and attitude determination and control
- The bus EM has been succesfully thermal/vacuum/vibration tested both at acceptance and quallification level.
- We look forward to new nano/micro satellite missions to utilize the bus

We would like to acknowledge our sponsor for space projects ;

Scientific and Technological Research Council of Turkey

TÜBİTAK

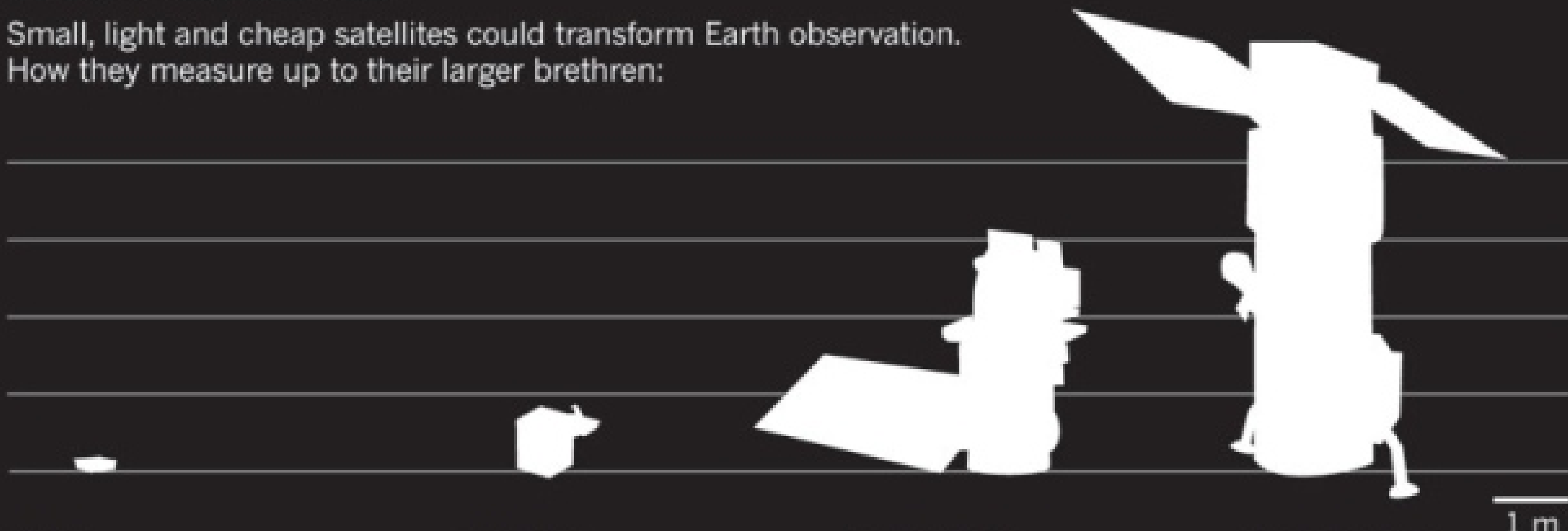
This work was funded under TUBITAK 106M082 and 108M523 Project

THE FUTURE OF MICRO/NANO-SATELLITE BASED EARTH OBSERVATION AND COMMUNICATION SYSTEMS

Small satellites are "provocative," "disruptive," and "game-changing" – Imaging Case

THE SWARM COMETH

Small, light and cheap satellites could transform Earth observation.
How they measure up to their larger brethren:



	DOVE	SKYSAT	LANDSAT 8	WORLDVIEW-3
Operator:	Planet Labs	Skybox Imaging	NASA	DigitalGlobe
Number of satellites*:	32	24	N/A	N/A
Weight:	~5 kg	~100 kg	2,071 kg†	2,800 kg
Instruments:	Optical and near-infrared spectral bands	Optical and near-infrared spectral bands	Multiple spectral bands	Multiple spectral bands
Spatial resolution:	3–5 m	~1 m	15–100 m‡	0.3–30 m‡

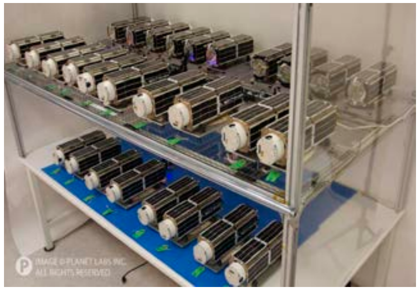
*When fully operational † Without instruments ‡ Depending on spectral frequency

Game-changers in Imaging

- Skybox Imaging
  - High spatial- and temporal-resolution Earth imaging (including high-definition video) at competitive $
  - 24-satellite constellation (2020)

Below 1m

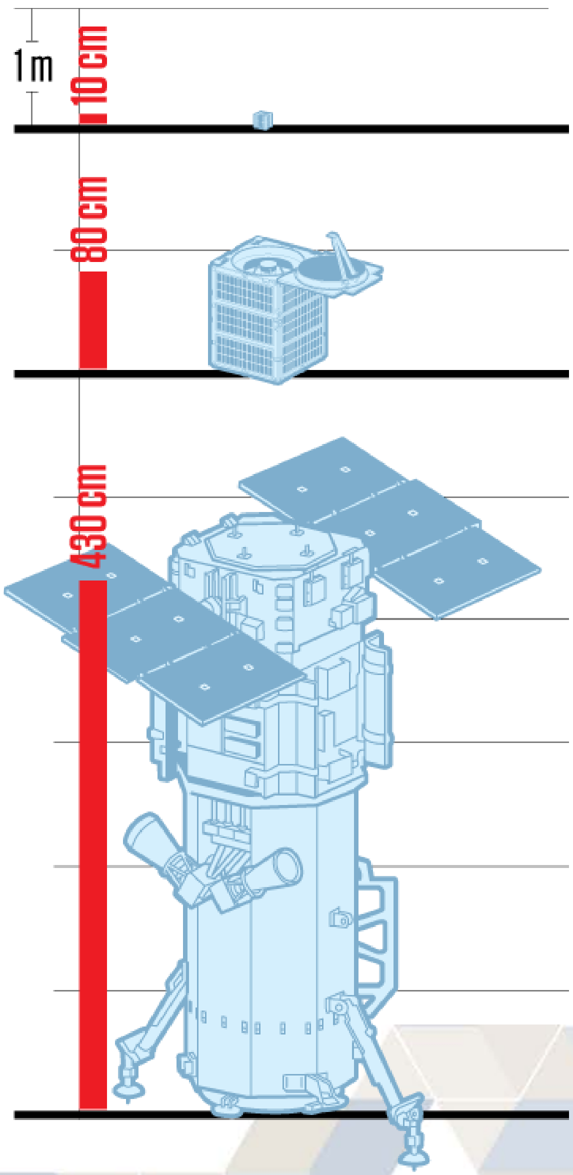
- Planet Labs
  - Medium-resolution “whole Earth” imaging with unprecedented frequency for both commercial and humanitarian ends.
  - 100-satellite constellation (2016)



3-5 meter

Business Case for Small Satellites

- Small satellites
  - Cost an order of magnitude less than traditional spacecraft,
- Launch
  - Cheaper
  - Simpler
  - More opportunities?
- From «The Need» to «The Launch»
  - Shorter Cycle
- Service Quality
  - Can be networked in large constellations capable of revisiting sites far more frequently than what's now possible
    - Serve the need for temporal knowledge
    - Possible extended spatial coverage



How is this possible?

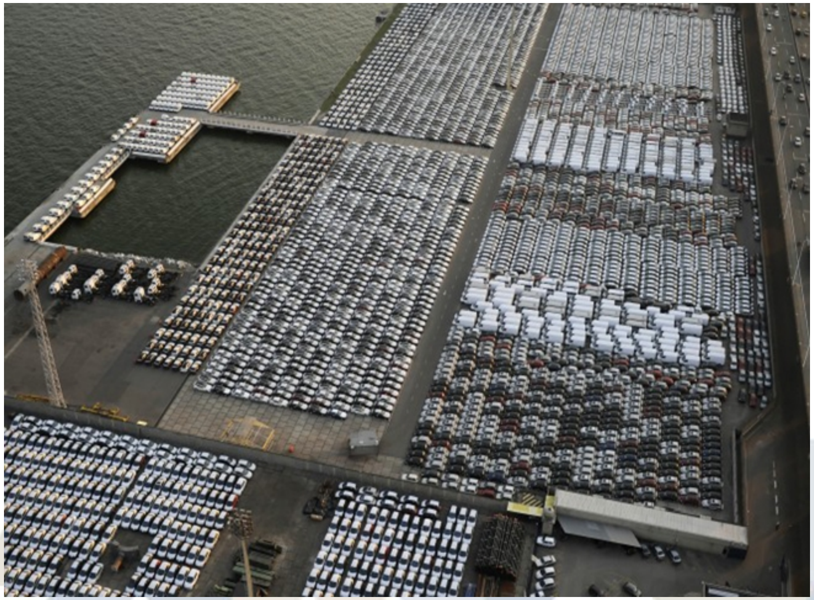
- Peter Wegner, director of advanced concepts at the Space Dynamics Laboratory:
  - *[Skybox and Planet Labs] "are using IMUs [inertial measurement units] from video games, radio components from cellphones, processors meant for automobiles and medical devices, reaction wheels meant for dental tools, cameras intended for professional photography and the movies, and open-source software available on the Internet."*

The key success factor : From Image to Information

- Skybox Imaging answering questions such as
  - Counting all the cars in every Walmart parking lot in America on Black Friday?
  - Counting the number of fuel tankers on the roads of the three fastest-growing economic zones in China?
  - What is the size of the slag heaps outside the largest gold mines in southern Africa?
  - Find the rate at which the wattage along key stretches of the Ganges River is growing brighter?
  - Could you have spotted missing Malaysia Airlines Flight 370 within hours? (if operational at that time?)

Typical Temporal and Spatial Use Cases

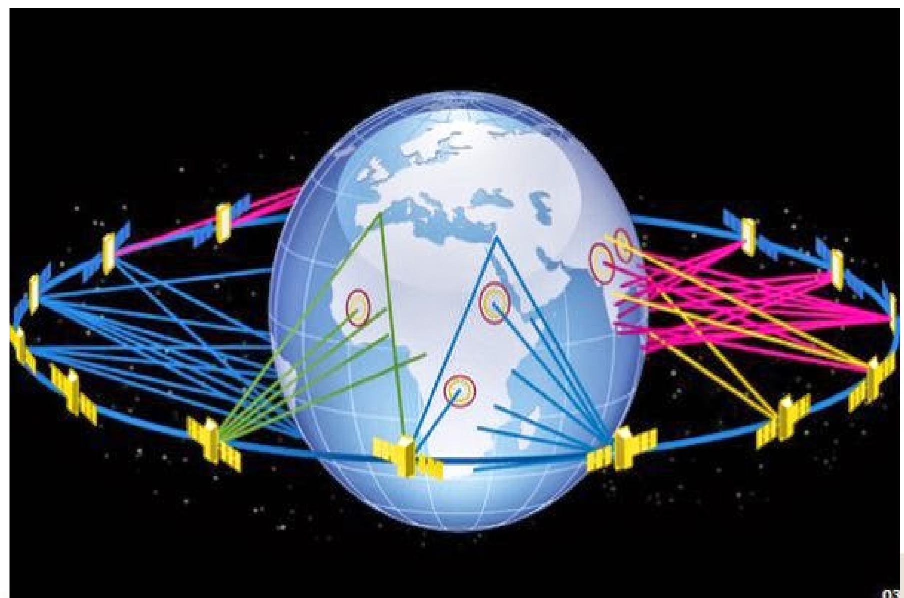
- Agriculture Health Monitoring
  - Monitoring crop health to predict seasonal yields
- Humanitarian Aid & Monitoring
  - Mapping human rights abuses like the bombing of civilian areas
- Insurance Modeling
  - Assessing storm damage to verify insurance claims
- Oil Storage Monitoring
- Natural Disaster Response
- Oil & Gas Infrastructure Monitoring
- Financial Trading Intelligence
- Mining Operations Monitoring
- Carbon Monitoring
- Maritime Monitoring



Communication Satellite Sector

Technology	Altitude (km)	Latency	Footprint
High altitude platform	15-30	Very low	Very small
Low Earth orbit satellite	160-2,000	Low	Small
Medium Earth orbit satellite	> 2,000	Medium	Medium
Geostationary satellite	36,000	High	Largest

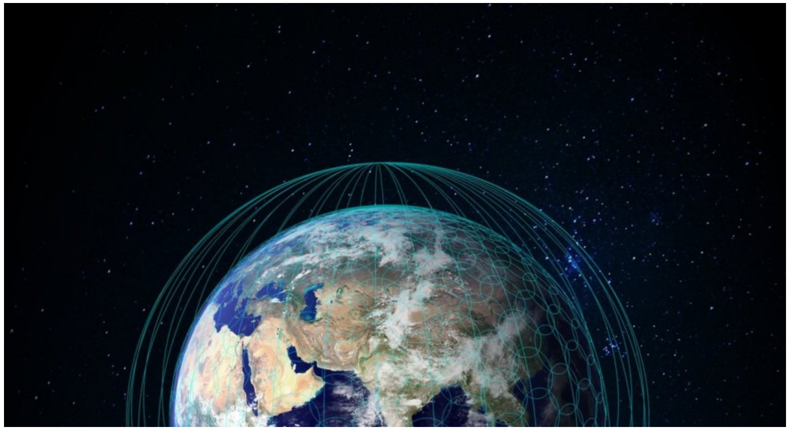
Google Project Loon



Google O3B

Potential Game-changer s in Digital Communications

- Oneweb (Formerly WorldVu)
  - 650 satellites at 1200km
  - 120kg microsatellites
  - Ku-Band
  - 50 Megabits/second internet access
  - Operational in 2019?
- Investors
  - Virgin Group
  - Qualcomm



- Ellen Musk Satellite Venture
  - 650 satellites at 1200km
  - 120kg microsatellites
  - Ku-Band
  - 50 Megabits/second internet access
  - Operational in 2020?
- Investors
  - SpaceX (backed by Google and Fidelity)

Recall Teledesic (early 1990s concept) and bankrupting of Irridium (1999) and GlobalStar (2002)

Key Factors Contributing to the Future of Micro/Nanosats

- Launch Vehicles
  - High availability
  - Rapid Deployment
  - Flexible

Virgin Galactic Launcherone

SpaceX

- Deployable Light Weight Apertures
  - Antennas
  - Panels
  - Stuctures

- Higher Efficieny Energy Generation and Storage

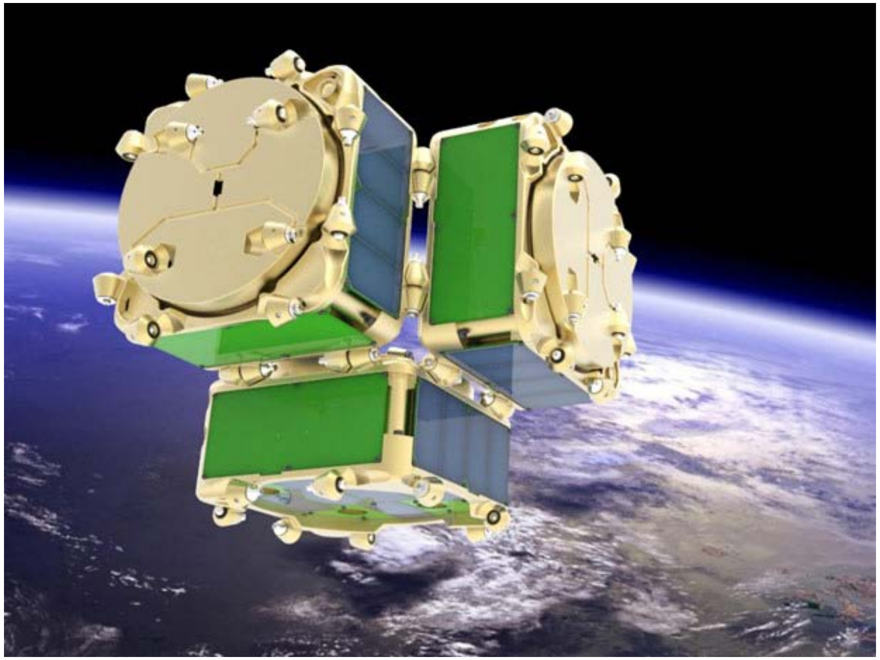
- Further miniaturization of
  - **high frequency/bandwidth transceivers**
  - **Optics and multi/hyper spectral imagers**

- Higher precision miniaturized navigation and control sensors/actuators

- Higher Processing Power

Future Concepts

- On-orbit satellite construction

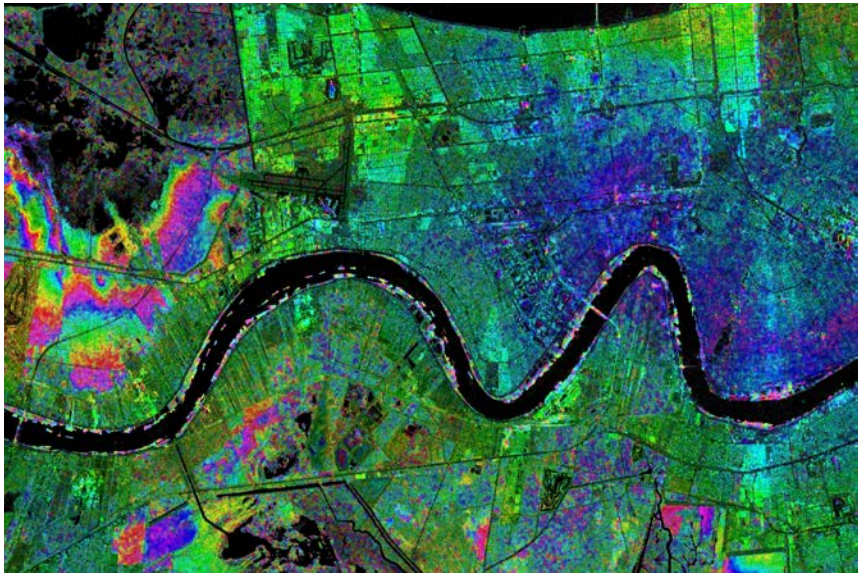


Darpa Satlet Concept is a step towards that

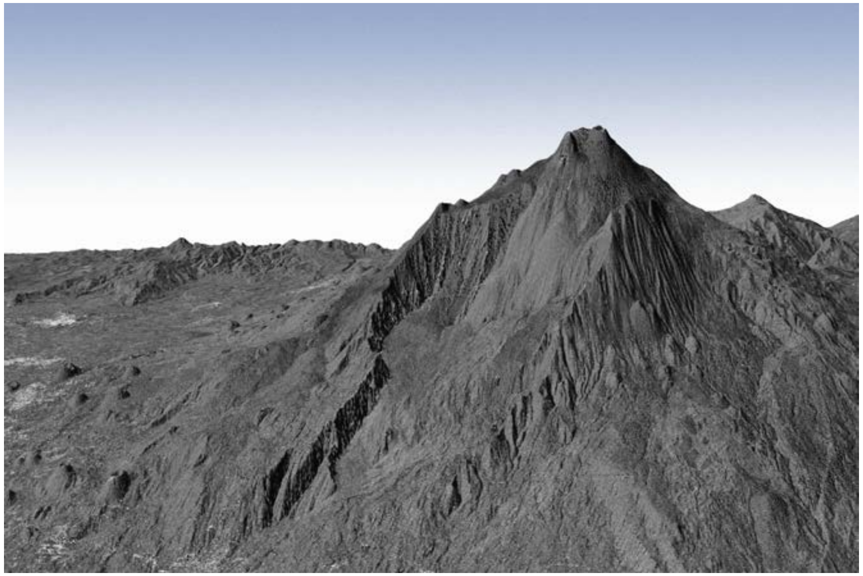
- 3D Printing of Satellites in Space

Future Concepts : Imaging Trends in Micro/Nano Satellites

- Higher Resolution, Further Spectral and Always (any time, any weather imaging)
  - Radar
  - Multispectral/Hyperspectral

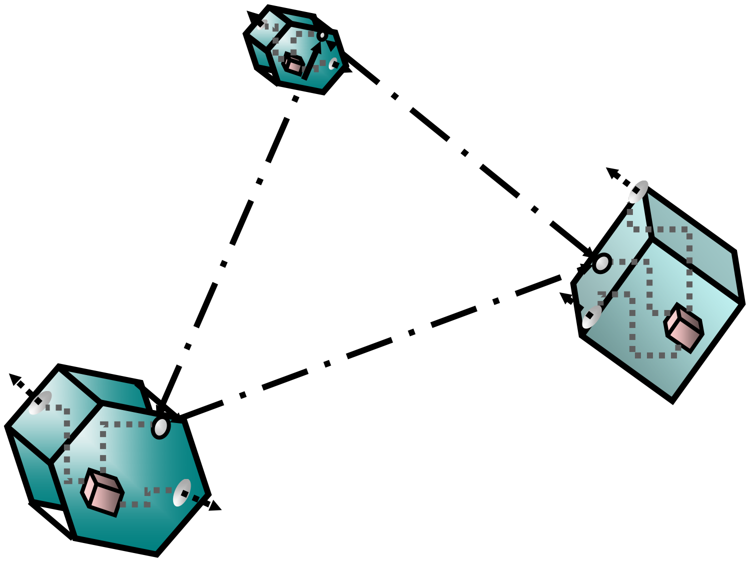


River Basin Vegetation via Hypersectral Imaging



Mt. Etna DEM via inSAR

A solution to the size problem: Formation Flying Micro-satellites

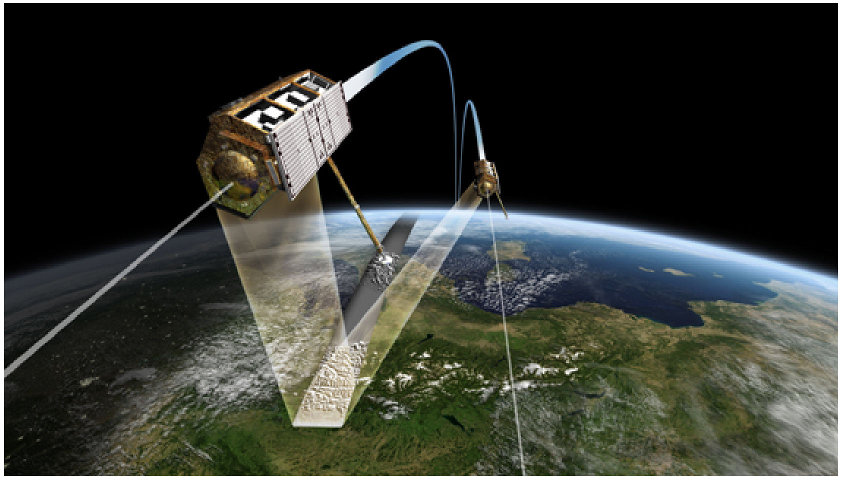


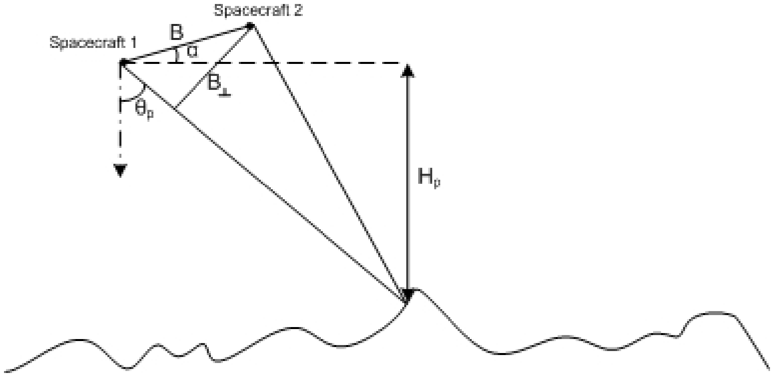
- Interferometry on simultaneous or repeat track imaging
  - Interferometric increase in height resolution : 30m => 0.5m

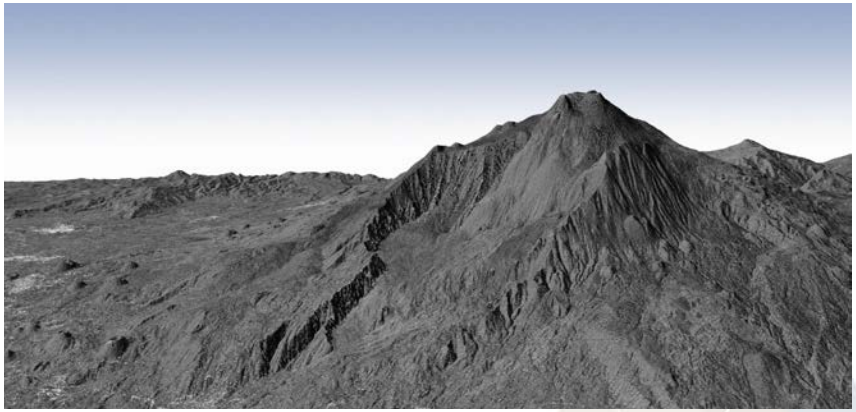
Example Requirements for High Resolution inSAR

- Meter level height resolution ➡ cm level accuracy of Baseline knowledge
- 0.01^{o} attitude control
- 2.5×10^{-12} s clock stability
- 10^{12} flops on-board

  for 1m resolution





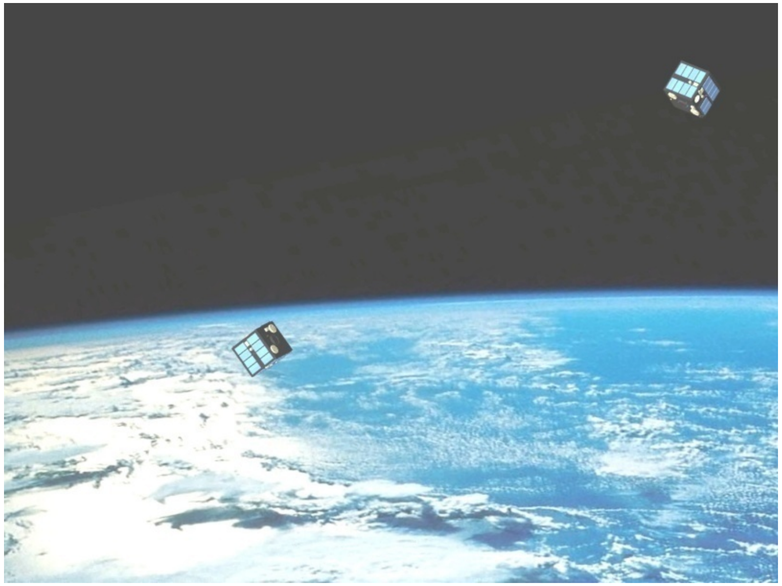


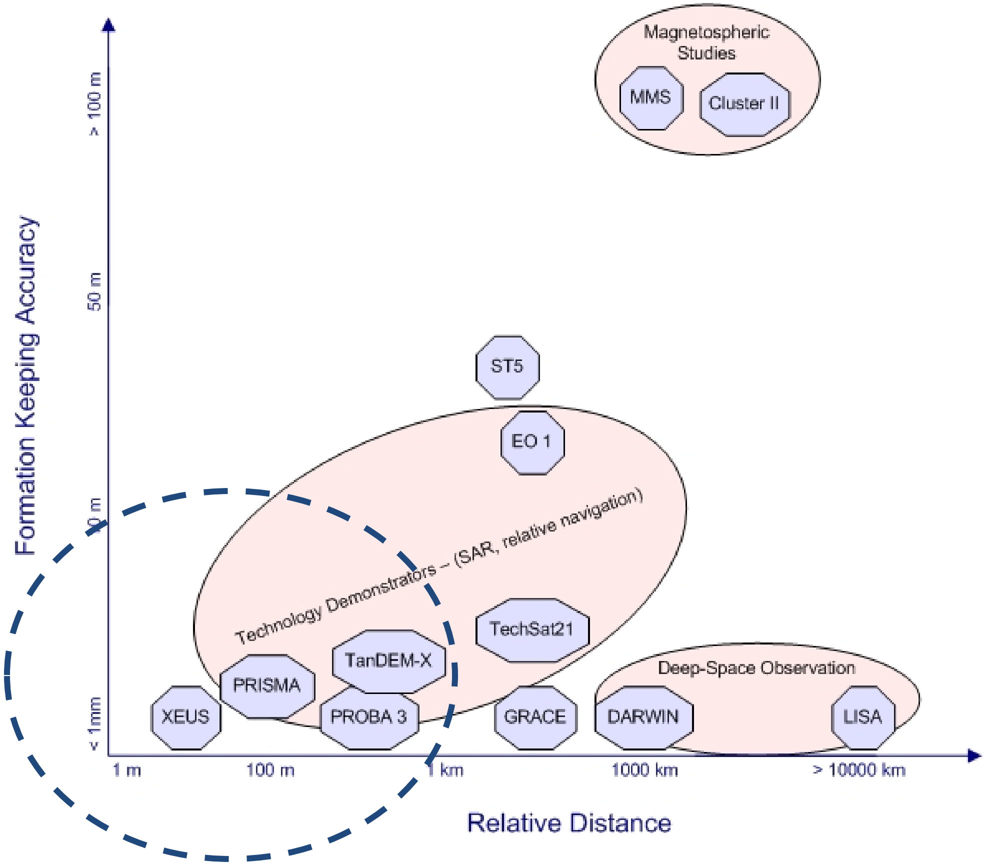
Mt. Etna InSAR Image – TerraSAR-X & TanDEM-X

Formation Flight Missions

Mission	Timeline	No of S/C	Mission	Orbit	Constellation / Formation	Constellation/Formation Size	Relative Positioning Accuracy
EO 1	2000	2 (1 is the target to be followed - already in orbit)	FF Testing by following a known s/c	Follows Landsat 7 - 700km	Formation	450km (60 seconds between s/c)	20m
Cluster	2000	4	Mapping the Magnetosphere	19000 - 119000 km	Constellation	200-18000 km	?
GRACE	2002	2	Mapping the Gravity Field of Earth	500km polar	Constellation	220km	0.01mm (GPS and mirowave ranging)
ST5	2006	3	Mapping the Magnetosphere	300x4500km Sun-Synchronous	Constellation	40-200km	5m in Leo, 100m RMS in GEO
PRISMA	2008	2	FF & Rendezvous Demo (uses GPS for FF, VBS + GPS for rendezvous, tests RF metrology)	700 km	Formation	5km -> 0m	5m(initial)/GPS
TanDEM-X	2009	2 (Will fly in formation with TerraSAR - X)	Bi-Static and ATI SAR	514 km polar	Formation	200 - 2000m	2-4 mm
MMS	2013	4	Studying the Magnetosphere	4 phases, varies between 1.2 R_E-12 R_E, 10R_E - 40 R_E	Tetrahedron Formation	Phase 1,2 - 1000 - 2000km, Phase 3,4 - on the same orbit (string of pearls) a few R_e's	100m(using GPS and xlink ranging(probably RF)) - also uses GS doppler in phase 1
DARWIN	2015	4	Deep Space Optical/Infrared Interferometry	L2	Formation	1200m	Sub millimeter(Laser metrology)
LISA	2018	3	Gravitational Wave Detection	1 AU, 20 deg phase behind Earth	Formation	Triangle, 5 000 000km	TBD
PROBA 3	TBD	2	Validate GPS + RF metrology, test coarse & fine optical metrology	600-36000km (GTO)	Formation	200-400m	cm range (0.1mm in optica metrology test)
XEUS	TBD	2	X-Ray Spectroscopy	L2	Formation	35m	0.1mm (laser metrology)
TechSat21	Cancelled	3	SAR demo	550km	Formation	500m	10cm(DGPS)(1 cm before data collection by various techniques)

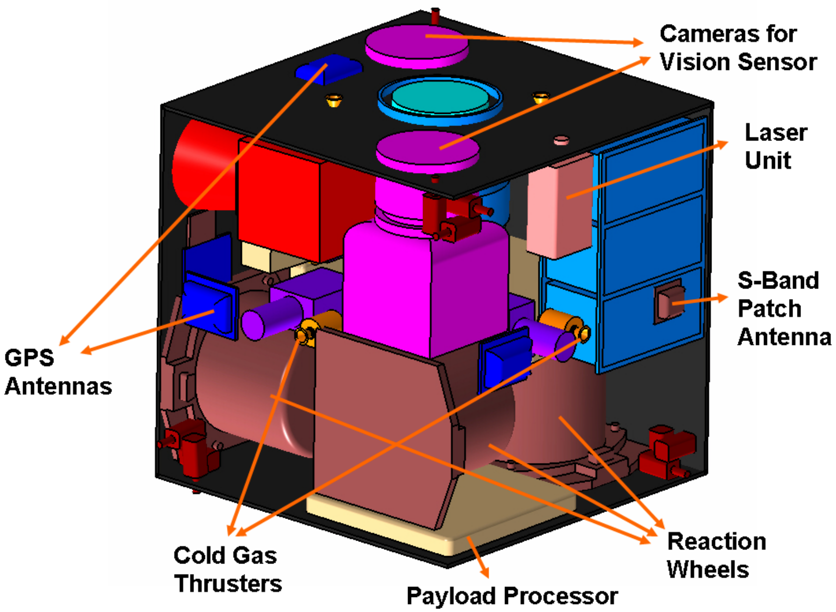
Formation Flight and Relative Distances

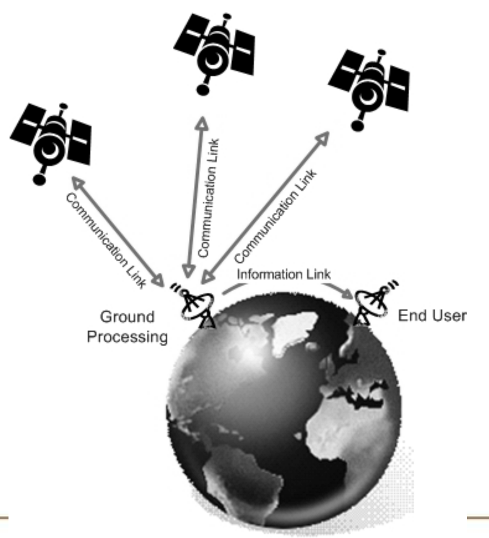


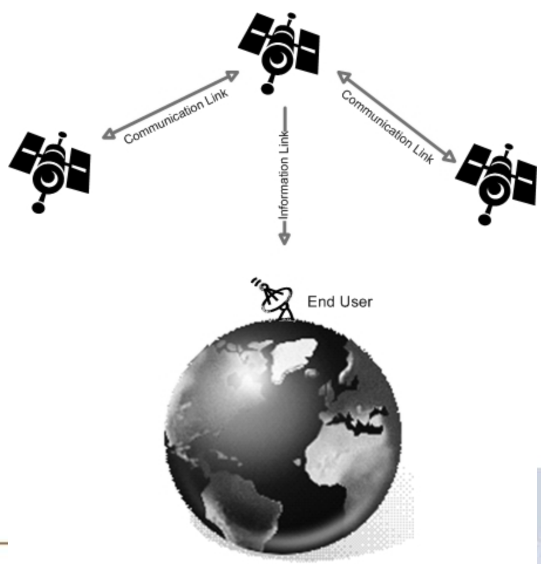


Need for on-orbit demonstration against key technologies.

Demonstrated FF Technologies



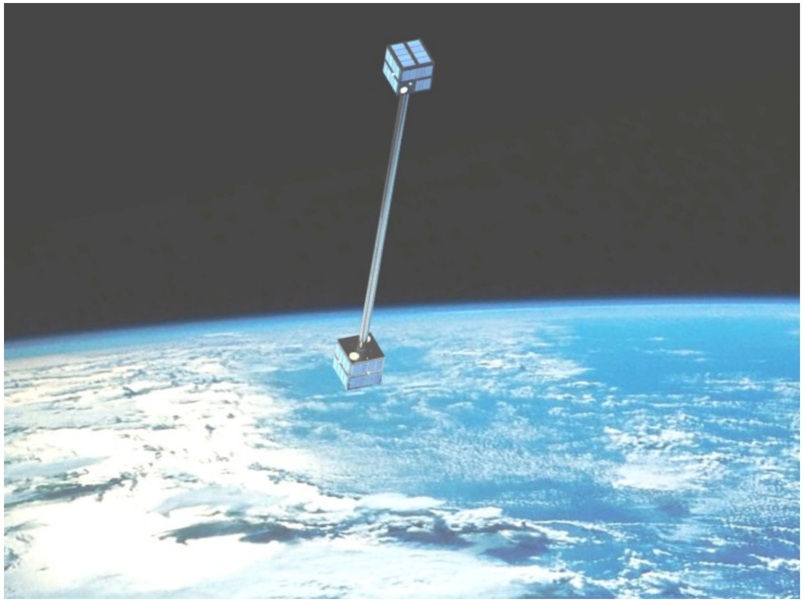


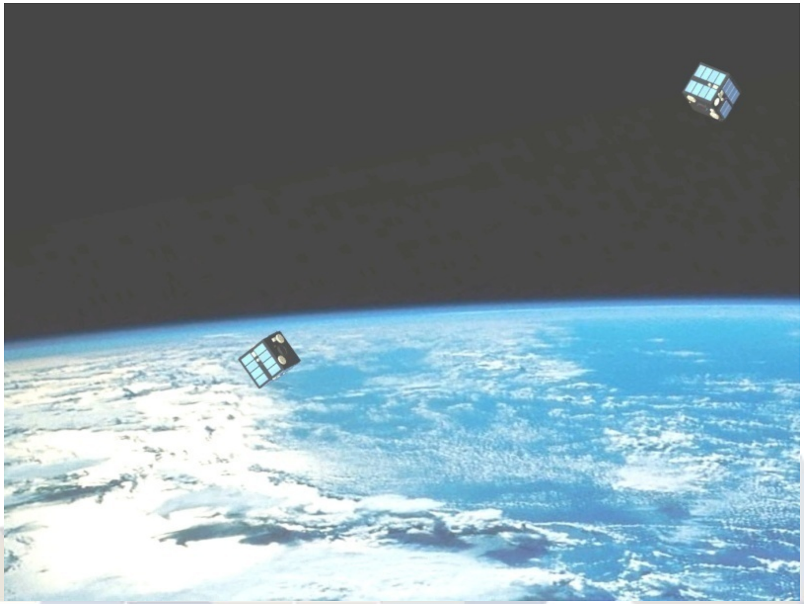


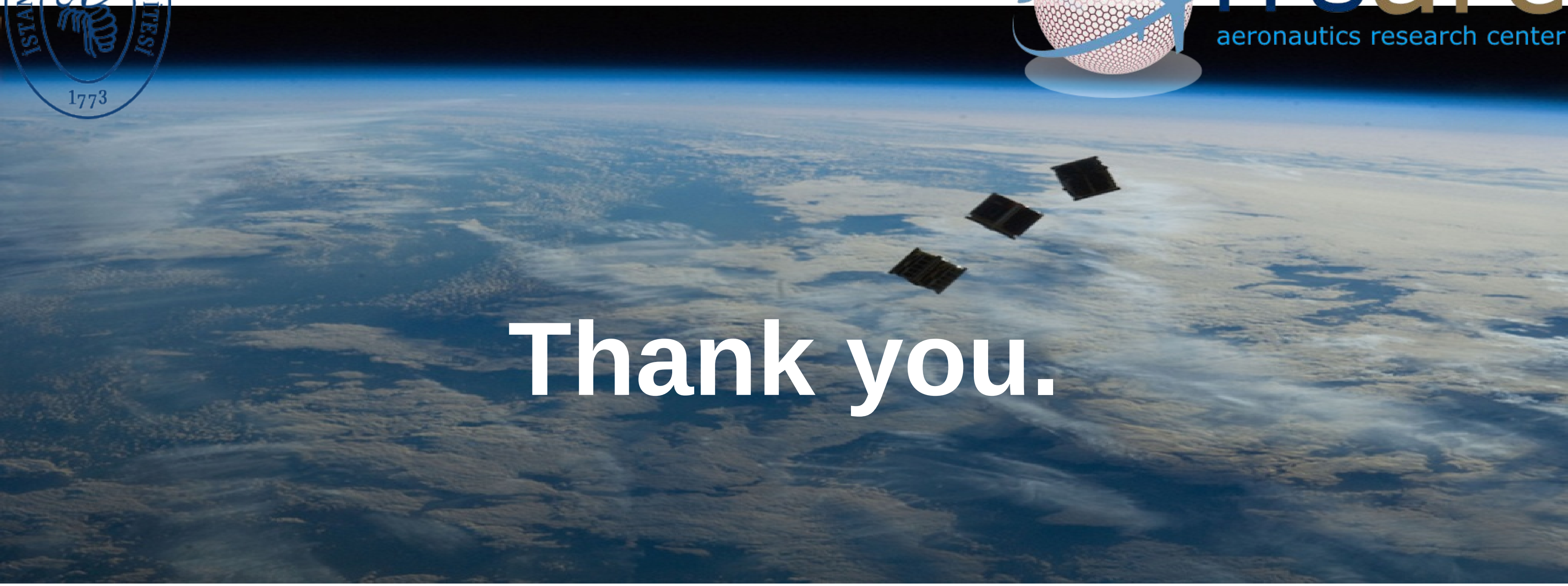
- On-board orbit control
- Autonomous simple constellation keeping
- Somewhat accurate relative motion modeling
- CDGPS
- Formation algorithms
- Basic s/c autonomy

Future Technology Drivers

- Sensors
  - Relative navigation and attitude sensing
- Communication
  - Inter-s/c comm. for interoperation and time synch
- Autonomy/Software
  - Fleet level control and coordination
  - On-board intelligence and fault-tolerance







Thank you.